S.LI.DES
Smart strategies for sustainable tourism in LIvely cultural DEStinations

2014 - 2020 Interreg V-A
Italy - Croatia CBC Programme
Priority Axis: Environment and cultural heritage
Specific objective: 3.1 - Make natural and cultural heritage a leverage for sustainable and more balanced territorial development

Deliverable 3.2.5.
Simulation report

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Activity:	**2 - Developing the visitors' mobility models: now-casting, forecasting and simulations**
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Partners involved:	**LP – University of Cà Foscari (IT)** **PP1 - CISET (IT)** **PP2 - Ecipa (IT)** **PP3 - SIPRO Ferrara (IT)** **PP4 - City of Bari (IT)** **PP5 - City of Venice (IT)** **PP6 –CAST-University of Bologna (IT)** **PP7 – Institute for Tourism** **PP8- Craft College- Institution for adult education Subsidiary Rijeka** **PP9- Development Agency of the City of Dubrovnik-Dura** **PP10-Sibenik Tourist board**

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INTRODUCTION

The aim of the models is to simulate the tourist mobility on the road network of an historical centre where traffic restriction rules are applies. The models are conceived to take into account:

1) The existence of attractive points of interest (POI) in the considered areas that determine the tourist mobility demand and the duration of the visit;
2) The interaction between the tourist flows and the mobility of local city users (resident and daily commuters) are present in the same area;
3) The availability of statistical data collected in the data hub on the expected tourist presences during the different periods of the year and new data collected by the experimental campaigns that have been realized by each city using distributed sensors and that also allow real time data collection.

The models have been focused on the simulation of pedestrian and public means mobility considering that the historical centres of the cities involved in the project are areas with strong traffic restrictions and the tourists perform manly a pedestrian mobility. The model outputs provide dynamical information on the evolution of the pedestrian flows on the road network (Dynamics mobility maps) and the distribution of presences in the considered area or on specific POI during a specific day or a 'representative' day for a chosen period (heat maps and plot of the presence evolution). The models can be used in two modalities: the now-casting mode and the forecasting mode. In the first case the model simulation reproduces the evolution of the mobility flows during a specific day integrating the data collected by the sensors and the statistical mobility data performing a now-casting procedure that extends the information recorded at specific point to the whole considered area. On the other hand, when the real time data collection is available, the simulations allow to forecast the evolution of the mobility flows from the present moment to next future during the same day. The now casting models are useful to cope with the problems to understand how the tourists move in the city in different periods, to evaluate the effects of the new initiatives, to correlate the observed tourist flows with the information from other data sets (i.e., social media) or to verify the effects of policies. The forecasting models are useful to consider situations during events that could be generate crowding problems. In this report we illustrate some examples of simulations performed in the all the cities involved in the project to understand the main features of the models themselves: (a short documentation of the models is provided in the WP 3.2.2 and WP 3.2.4). The simulations are performed realizing fives fundamental steps:

1) Using the population distribution divided in the three main categories Tourists, Commuters and Residents, the model associates a mobility demands to each categories according to the distribution of the attraction points, the activities present in the area: the tourist mobility demand depends on the visit time budget are the distance of the attraction points, the commuters mobility is mainly an origin-destination to the work place with a random mobility components near the work place, the resident mobility is a diffusive mobility in the area;
2) The city users are introduced in the simulation using specific entry points (sources) for the tourist and the commuters according to the data recorded by the flow sensors of the experimental campaigns, whereas the residents move in the area according to the circadian rhythms (in presence of Hotels in the area a percentage of tourists are supposed to be stay in the area).
3) Each virtual city user realizes its mobility demand moving on a georeferenced road network (the road networks are derived from Open Street Map) according to dynamical rules that simulates the pedestrian dynamics on the road with a typical average velocity of 1 m/sec (the tourist velocity is also reduced due to the frequent expected stops) and the crowding effects that slow down the velocity (we assume the existence of a Fundamental Diagram for pedestrian dynamics);
4) At each crossing point the individuals may choose different directions according to the best paths towards the local destination, the accessibility of the road network (i.e., for the tourists we assume a partial knowledge of the road network so that their mobility is mainly concentrated on a subnetwork related to the most attractive roads due to the presence of shops or to the historical interest) and random effects that simulate the individual free will;
5) The model estimates the required time to visit the main tourist attractions in the area and consider delay effects due to the queues and consider the typical daily mobility path length for a pedestrian that is distribution according to an exponential with an average between 3-4 km, so that the individual mobility agenda could be modified is the elapsed time is much longer than expected visit time or the realized mobility paths exceed the expected length.

The output of the simulations is represented by dynamics flow maps or heatmaps that can be visualized in the dashboard of the SLIDES project.

In the report we discuss the simulation results for each city involved in the project. The tuning of the models is still going on as the experimental campaigns will collect new data on the tourist flows after the pandemic COVID-19. The simulation results will be also useful for the development of the pilot actions of WP4. In the following sections we illustrate the experimental campaigns and the model simulations for all the cities participating to the SLIDES project.

1. Experimental Campaign and Model Simulations for the city of Ferrara

The data collection is performed by means of 6 Wi-Fi/Bluetooth scanners that record the presence of a mobile device in the chosen area when the connection Wi-Fi or Bluetooth is switched on and associate an anonymous ID to each device. The location of the sensors in the Ferrara historical centre is shown in the Fig. 1.1 The Wi-Fi/Bluetooth scanners consider only a sample of the population in an area whose dimension depends on the antenna sensitivity; they do not distinguish the flows in different direction but since the ID associated to the device is unique that are able to detect the same device in different location and to reconstruct the mobility demand. We have decided to integrate the Wi-Fi presence data in the dynamics model since a preliminary analysis has shown a better quality of the Wi-Fi data with respect to the Bluetooth. The data are collected in the datahub and make available to the models. The sensor location has been chosen to consider the problem of detecting the mobility flows from the station and the parking areas near the historical centre and the presence the main POI of the Ferrara centre. The Figure 1.2 shows an example of the data recorded by the sensor located near the train station: the red curve refers to the presences recorded from 7/1/2021 and 10/01/2021, whereas the blue curve refers to the average presences in the 2 successive weeks at a time scale of 15 minutes. The Figure 1.2 highlights clearly the circadian rhythms of the use of the station area and difference among the days of the week. A fluctuation analysis points out the peculiarities of the presences of the considered day with respect to the expected average so that it would be possible to analyse the changes due to the realization of the pilot actions of the project comparing the measures collected during different periods. One of the results of the experimental campaign is to characterize the average use of the considered area during the different periods of the year to distinguish the presences of the visitors from the presence of residence and commuters and to study the changes in concomitance with specific tourist events or after the realization of new tourist initiative. The penetration of the mobile device sampling recorded by the sensors with respect to the total population present in the area will be estimate during the experimental campaigns (a rough estimate is ~1/3 of the total population).

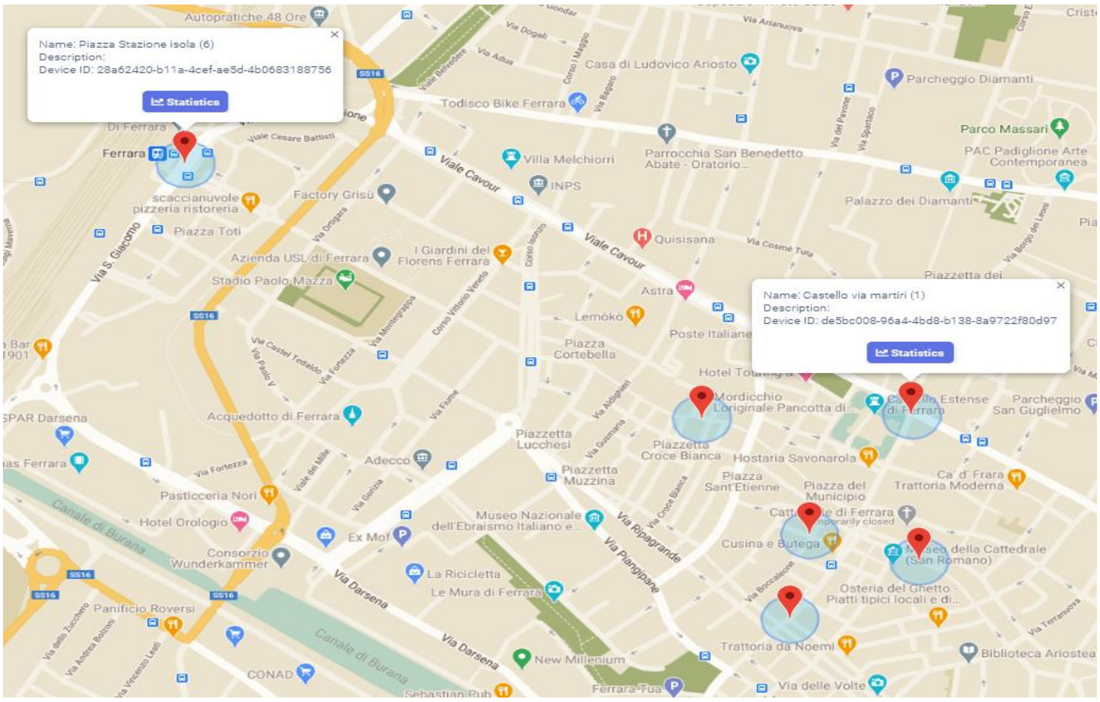

Figure 1.1: The dots show the location of the Wi-Fi scanner installed in the Ferrara historical centre to perform the experimental campaign

In the Figure 1.3 we show the average presences measured in the Castello square of Ferrara in January 2021 for each day of the week.

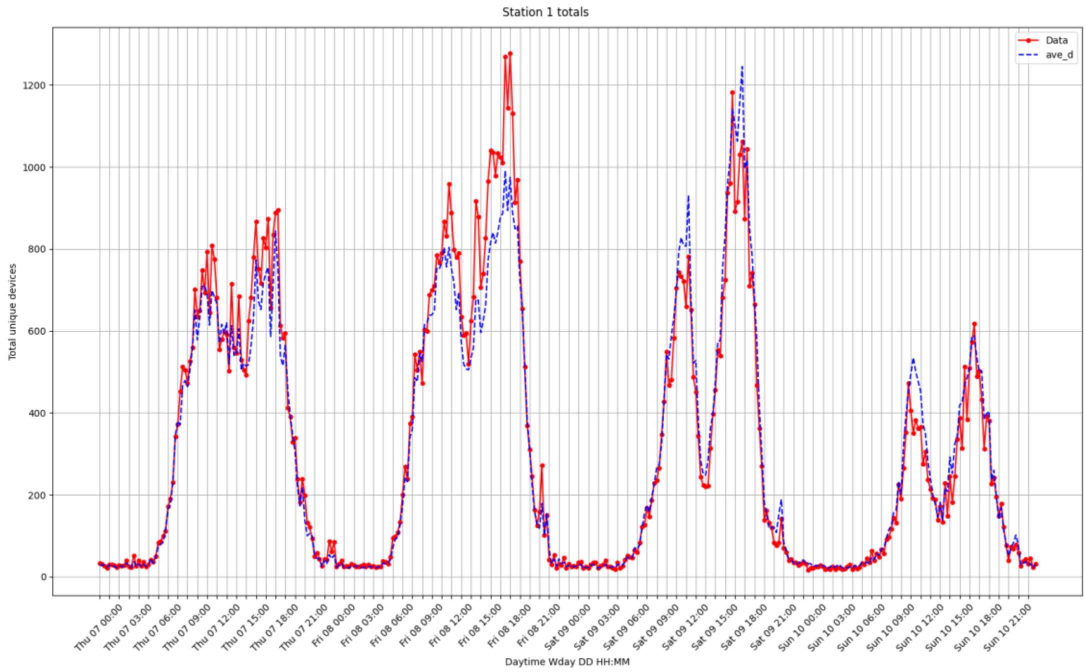

Figure 1.2: Example of presences recorded by the Wi-Fi sensor installed near the Ferrara train station at a time scale of 15 minutes.

The red curve on Figure 1.2 shows the presences detected from 07/01/2021 to 10/01/2021 whereas the blue curve is the average presences during the two successive weeks.

The visitors' mobility model in Ferrara has been built to reproduce the mobility flows in the historical centre integrating the collected data recorded by the sensors. In Figure 1.4 we show the road network of the considered area that has been derived from the Open Street Map (OMS) internet site road network that is a public cartography. Each road is considered by the model with associated an attractivity degree according to the historical interest, the accessibility or the presence of tourist activities. The tourists will realize a mobility entering the historical centre from sources points and organizing their daily agenda to visit the main attractions present in the area. The mobility agenda consider the constraint of a finite time budget for the visit (related to entry time) and a 'mobility energy' that limits the path length of the visit according to an exponential empirical distribution derived from previous observations on pedestrian mobility (Chiara Mizzi et al. *Unraveling* *pedestrian mobility on a road network using ICTs data during great tourist events* EPJ Data Science volume 7, Article number: 44 (2018)).

When an individual has accomplished the mobility agenda, he reaches the same initial entry point to leave the area: in this way we simulate the fact that individuals arriving by train or by cars have to go again to the train station or to the parking areas.

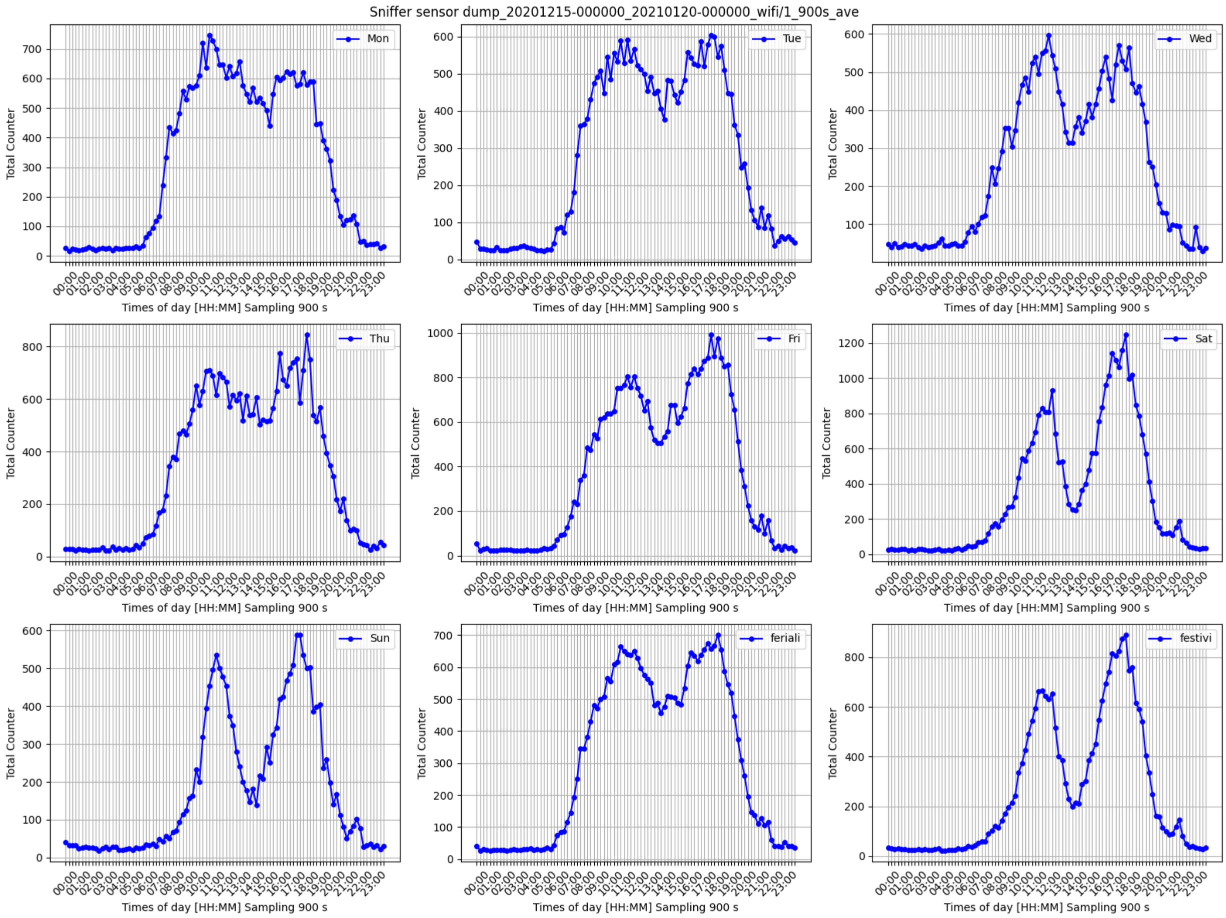

Figure 1.3: average number of presences recorded by the Wi-Fi sensor installed in Castello Square in the Ferrara centre; the last two plots highlight the difference between the working days (feriali) and the holidays (festivi).

In the Figure 1.5 we show the location of the source points used in the simulations for Ferrara: we remark as the location of the sensors has been chosen (when it was possible) to detect the incoming mobility flows at the entry points and to measure the presences near the main attraction POI (ex. Piazza Castello, see Fig. 1.1). The definition of the main attraction points has been discussed with the Ferrara municipality (Table 1) and the model realized the tourist mobility demand defining the mobility paths by a best path algorithm on the weighted road network. In the realization of the pilot actions, we will consider the possibility of adding new attraction points according to the policies to improve the tourist offer. Moreover, we have weighed the single rads in the network according to their accessibility from the sources to the attractions and their historical and tourist interest.

Figure 1.4: The road network of the Ferrara historical centre as provided by the Open Street Maps (https://www.openstreetmap.org) (left picture) and as implemented in the visitors' dynamical models (right picture).

The commuters enter in the simulations mainly from the train station and they perform a random mobility since the economic activity are diffused in the area. The resident mobility is also considered assuming the presence of a diffusive mobility in the area with random origin-destination point. The nowcasting model consider the evolution of the incoming flows at the entry points from the measures of the installed sensors or inferring their evolution from the available information using the sensors installed nearby or statistical data.

Figure 1.5: The location of the source points considered in the simulations of visitor mobility in the Ferrara historical centre: the blue dots denote the sources where Wi-Fi sensors are located, whereas the red dots are the sources inferred by the model. The red circles are the location of the other Wi-Fi sensors that are used to calibrate the model parameter and performing validation procedures.

Castello	Castello Estense
Cattedrale	Ferrara Cathedral
Diamanti	Diamanti Palace
Museum 1	MEIS Museum

Museum 2	Schifanoia Museum

Table 1: Main attraction points in the Ferrara historical centre

The Figure 1.6 show an example of incoming flows used by the model to reconstruct the mobility flow during a given day assuming the arrival of ~10000 tourist (the incoming flow are artificially amplified with respect to the actual measures due the persistence of the COVID-19 epidemic in this period that drastically reduced the people mobility and the social activity in Europe). To each tourist incoming in the area the model attributes a mobility agenda considering the expected time of visit (that depends on the arrival time) and the mobility 'energy' (path lengths) that is attributed from an exponential distribution. The mobility agenda are built in a probabilistic way considering the possibility of visiting different attractions and taking into account the required visiting time.

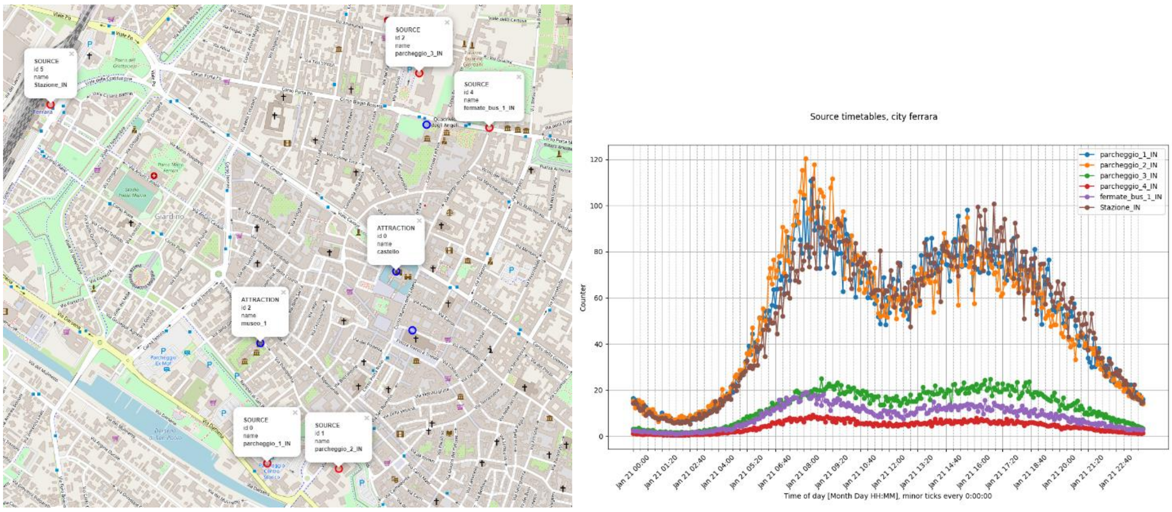

Figure 1.6: (Left) Locations of source entry points (red circle) and attractions (blue circle) in the Ferrara historical centre. (Right) Incoming visitor flows from the sources (number of individuals per 5 minutes) used in the simulations: the data are artificially amplified with respect the actual measures due to the presence of the COVID-19 epidemic that drastically reduced the people mobility.

In Figure 1.7 we plot the path lengths distribution for the visitors and the residents computed by the simulation and the expected visit time durations. We observe as the local mobility is characterized by short paths (peaked at ~1.5 km) with an average duration of 30 minutes (remark: the model is not simulating the daily mobility of residents but only their single trips), whereas the tourists have a mobility paths of average length 4.5 km (exponentially decaying for longer distances) and an expected visit time between 2 and 4 hours. We associate a best path length to each individual, that can be interpreted as mobility energy associated to the mobility in the historical centre, whose distribution is shown in Fig. 1.8 (left) together with the number of attractions inserted in the tourist mobility agenda (right). The model is able to simulate the mobility in real time on the road network considering the slow-down due to crowding effect according to the existence pedestrian fundamental diagram. At a crossing point each individual chooses the next direction in a probabilistic way considering both the best path towards the local destination, the accessibility of the roads and random effect that simulates the unavoidable perturbations to the dynamics due to the individual freewill: then the realized paths are longer than the best paths computed using origin destination mobility. When a visitor has performed the mobility agenda or he has spent the expected visit time budget, he comes back to the same entry point at which started the visit, and he exits the simulation. A snapshot of the graphic interface of the visitor mobility model is shown in Figure 1.9 (left) where the points give the position of a single individual along a road. The simulation results provide a dynamic flow map for the reconstructed mobility flows in the area that is elaborated in the project dashboard according to a colour scale (see Figure 1.9).

To study the existence of crowding effects the model allow to plot a heatmap of the people distribution in the historical centre: an example is show in Figure 1.10. Both the dynamics flowa maps and the heat map can be computed for shorter time intervals so that is is possible to get a dynamc evolution of the mobility in the road network during the considered day. The simulation also gives the evolution of the expected presences at the main attraction points as it is shown in Figure 1.11.

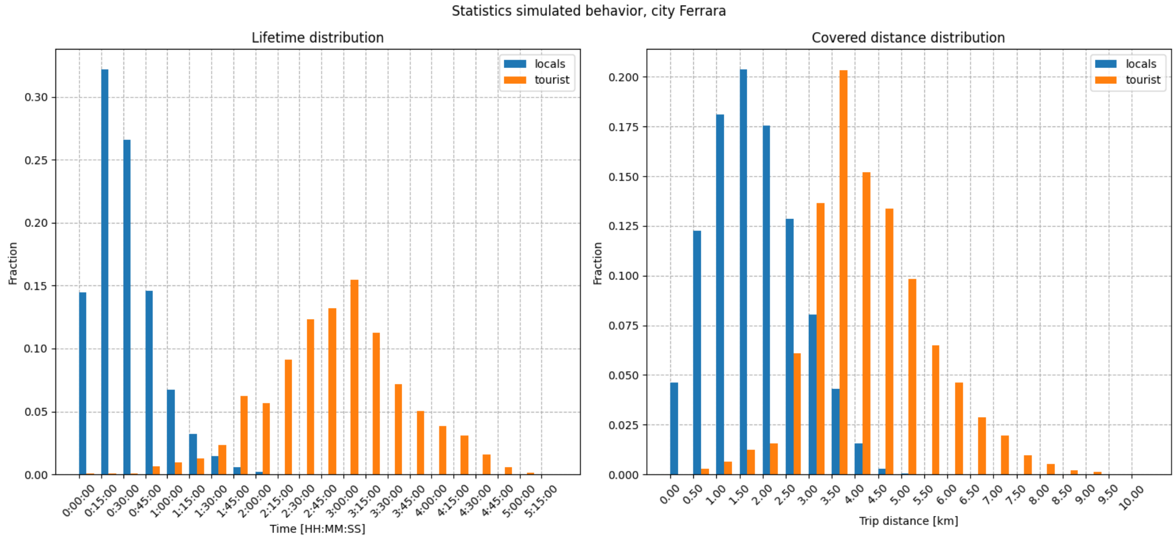

Figure 1.7: (Left) distribution of the time duration of resident paths(blue) and the visit duration of the tourists (orange). The curves are normalized to corresponding population. (Right) Path length distribution simulated in Ferrara historical centre for the resident paths (blue) and the tourist paths (orange).

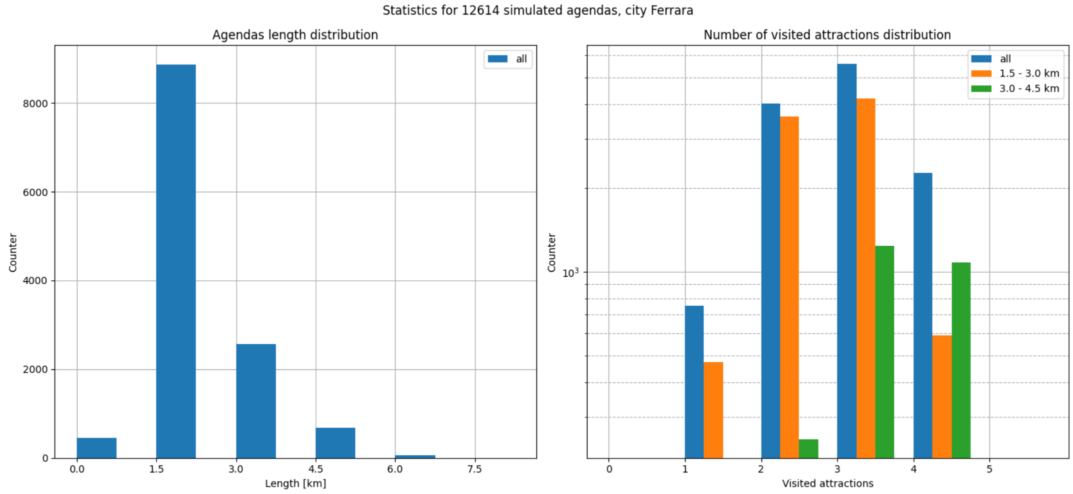

Figure 1.8: (Left) expected best path length associated to the mobility demand in the Ferrara historical centre and the number of attraction points inserted by the model in the tourist mobility agenda disaggregated on the expected path lengths (right); i.e. the longer paths are associated to a greater number of visited attractions.

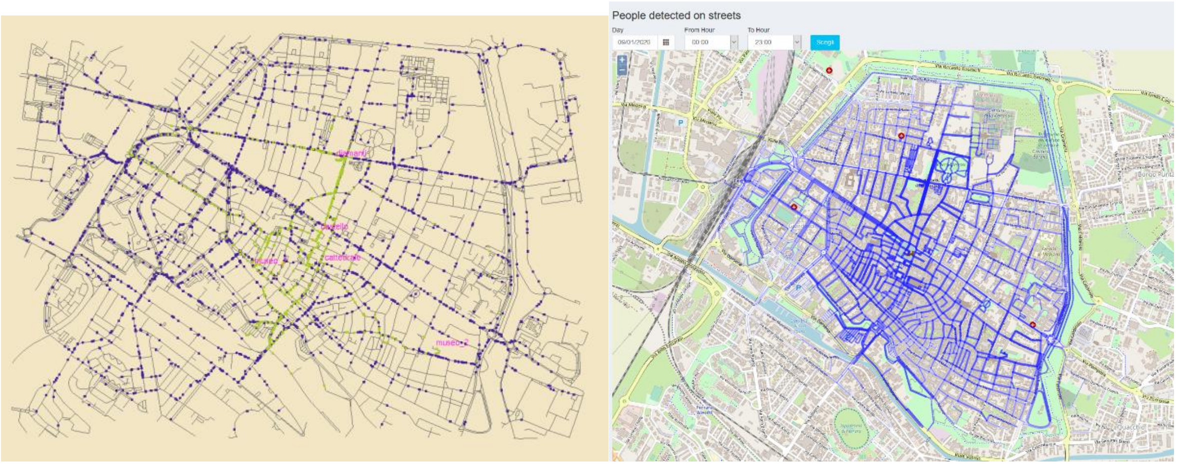

Figure 1.9: (Left) snapshot of the graphic interface of the visitor mobility model that simulates the invidual mobilily (dots) in the raod network realizing a dynamical model based on the existence of a foundamental diagram for pedestrian mobility. (Right) Dynamic flow map for the daily mobility in the Ferrara historical centre reconstructed by the visitor mobility model: the road thrickness is proportional to the integrated mobility flows simulated by the model during the considered day.

Figure 1.10: heatmap of the daily presences simulated by the visitors mobility model in the Ferrara historical centre. The people distribution is mainly concentrated in the city areas nearby the main attraction points.

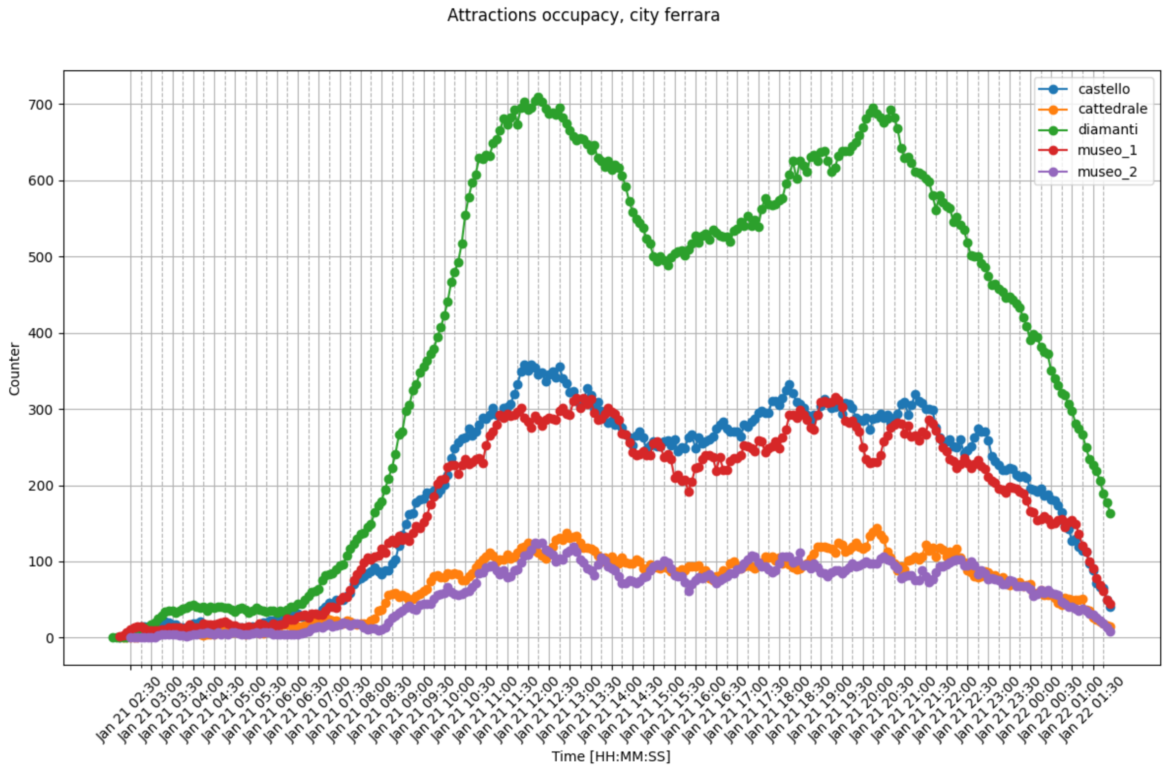

Figure 1.11: Daily evolution of the presences (occupancy) at the main attractions in the Ferrara historical centre as simulated by the Visitor mobility models.

The simulated presences reflect both the circadian rhythms and the required visit time associated to the attraction, so that the occupancy increase when the visit time increases. The model considers the possibility of inserting different attractions in the individual mobility agenda according to the expected visit time and path length.

The models also allow to perform a short-term forecasting of the mobility using the real time data collected by the sensors. This procedure aims to point out the possible change in the mobility state with respect an average situation, that could be interesting to perform safety policies. The forecasting procedure is performed in two steps. Using an average behaviour computed using the data collected in the datahub in the previous month we perform comparing of the real time signals to highlight the difference that are statistically relevant: i.e., they are unlikely when compare with the expected signal fluctuations derived from the historical data. We show an example of this procedure in Figure 1.12 for the signals recorded by the Station sensors installed in Ferrara. The system recognized some periods (defined by different colours) during which the flows recorded at the train station were remarkably greater or lower with respect the expected values. These situations are typically observed in concomitance of events that could attracts more visitors or to the effects of weather conditions.

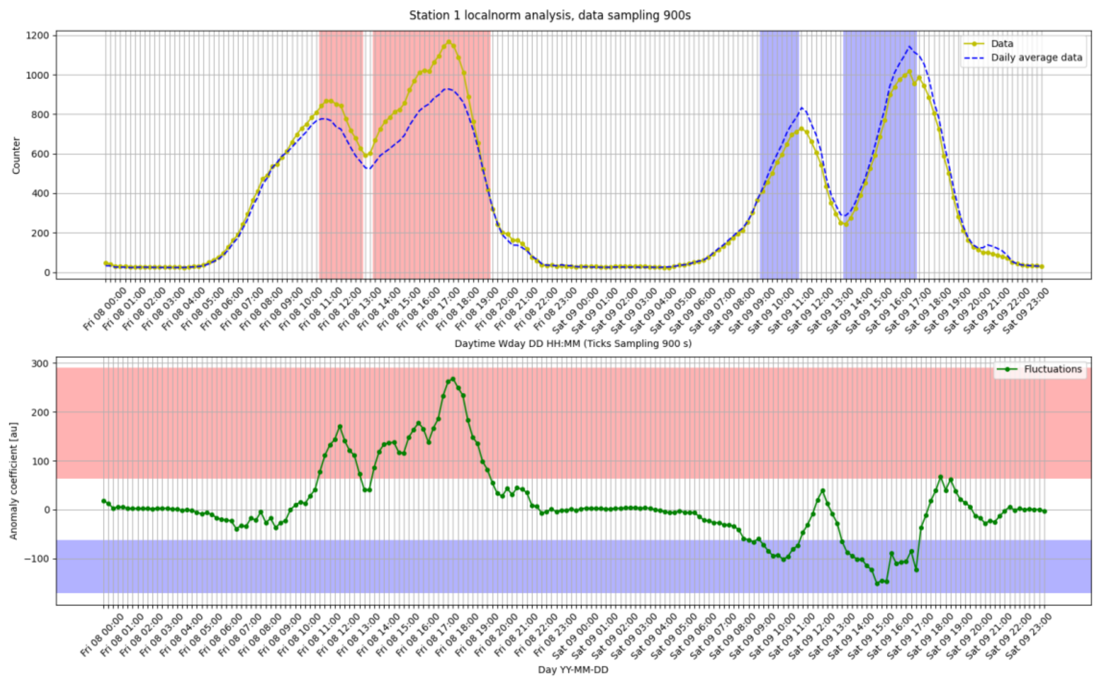

Figure 1.12: Comparison between the signals recorded by the Wi-Fi sensor installed at near the train station in Ferrara during the last weekend of July 2020; the red band (resp. blue band) highlights the presence of an

anomalous increasing (resp. decreasing) of the visitors flows. The corresponding differences are shown in the figure below.

To forecast the evolution of the tourist flows is performed by the visitor mobility model by forecasting the evolution of the incoming flows from the sources using the real time data and a predictor of the circadian rhythms from the historical data. The predictor is implemented by scaling an expected average evolution to take into account the amount of the actual measured flows. This procedure allows the model to simulate the evolution of the mobility flows in the next future (the predictions are available for the whole day, but their reliability is limited to 2-3 hours). As new data arrive in the datahub, the prediction can be updated. Finally, in the case of specific events, we have implemented the possibility to add new attractions in the input file that are active only during certain days of the year, so that they are considered in the mobility agenda only during predefined dates.

2. Experimental Campaign and Model Simulations for the city of Sibenik

The experimental campaign in Sibenik has been performed using video-camera analysis to detect the tourist flows. The map in Figure 2.1 shows the location of the video-camera positions at entry points for the tourist flows in Sibenik. The location of the four cameras has been decided in collaboration with the tourist agency of Sibenik.

Figure 2.1: Location of the three video cameras installed in Sibenik to measure the tourist flows.

The videos are collected on a dedicated server and they are analyzed in real time by a software developed by the Cast-Unibo unit of the SLIDES project. In this way we are able to count how many individuals are present in each area monitored by the camera, to tracking their trajectories and to count how many individuals are crossing some virtual barriers in a given time interval. The data acquisition system is described in the WP 3.2.1. The data are collected in the datahub to be visualized and to be integrated in the visitor mobility models. We have developed a model for the pedestrian mobility in Sibenik using the same procedure developed in the case of Ferrara. Starting from the Open Street Map cartography we have derived a road network for the simulations (see Fig. 2.2). We have introduced the entry points and the attractions in the considered area following the suggestions of the Sibenik tourist office. The path length distribution and the visit duration distribution (see Fig. 2.3) show that the model associates a propensity of a visit with an average path length of 4.0 Km and a duration of 3. h: this is a consequence of the spreading of attraction points in the Sibenik. Indeed, the mobility agenda consider the possibility of inserting of 3 or 4 attractions in the agenda during the visit (see Fig. 2.4). In Fig. 2.5 we show some entry points (sources) and attraction points considered in the

Sibenik visitor mobility models and the expected incoming flows used in the simulations: we assume a visitor flow of ~1500 people per day since the tourist activity was reduced during this year due to the Covid-19 epidemic and real flows recorded by the video camera were small.

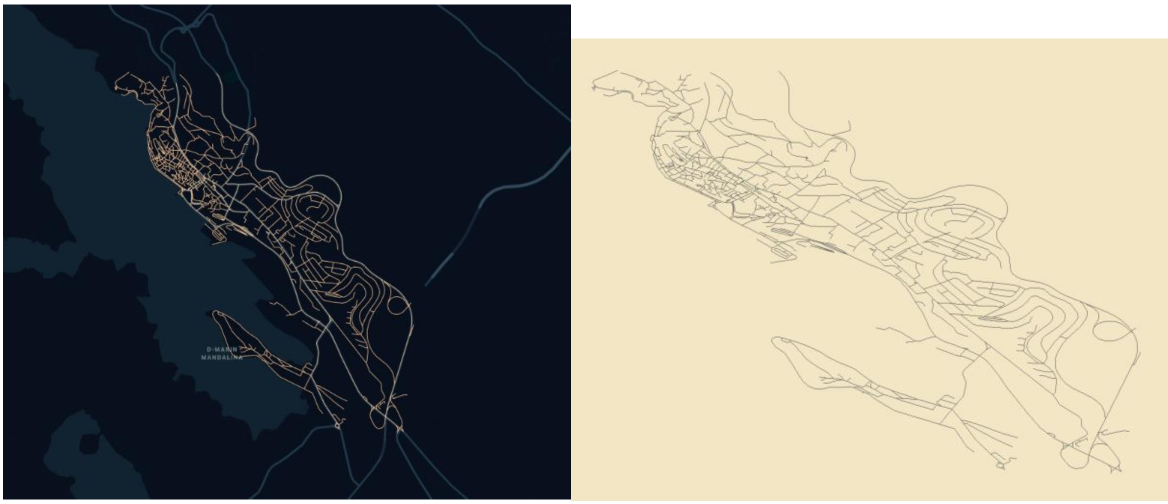

Figure 2.2: The road network of the Sibenik as provided by the Open Street Maps (left picture) and as implemented in the visitors' dynamical models (right picture).

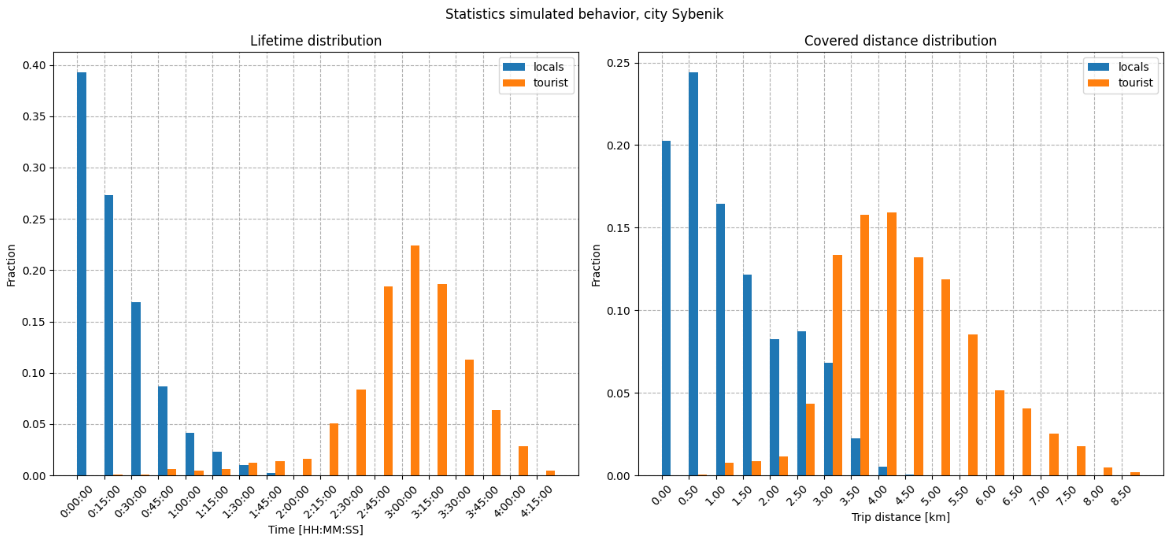

Figure 2.3: (Left) distribution of the time duration of resident paths(blue) and the visit duration of the tourists (orange). (Right) Path length distribution simulated in Sibenik for the resident paths (blue) and the tourist paths (orange).

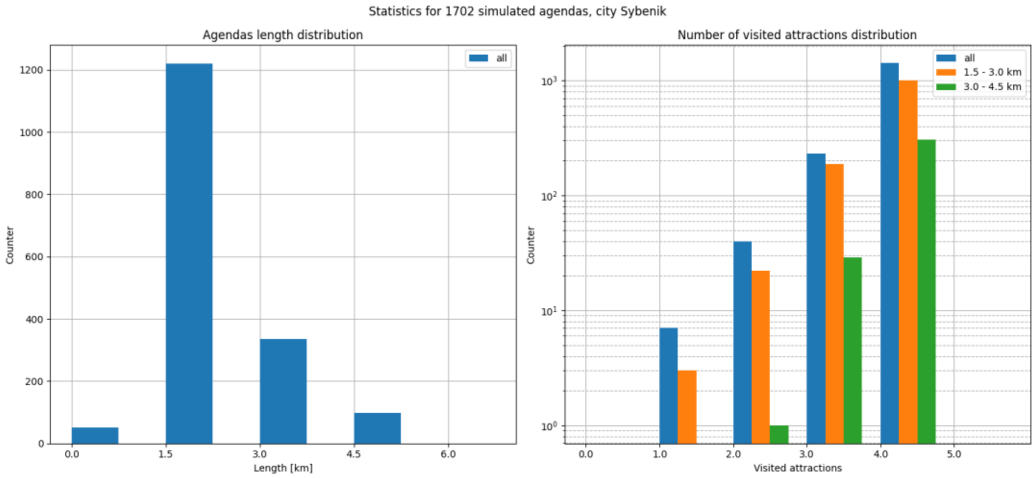

Figure 2.4: (Left) expected best path length associated to the mobility demand in Sibenik (both for tourists and residents) and the number of attraction points inserted by the model in the tourist mobility agenda disaggregated on the expected path lengths (right); i.e., the longer paths are associated to a greater number of visited attractions.

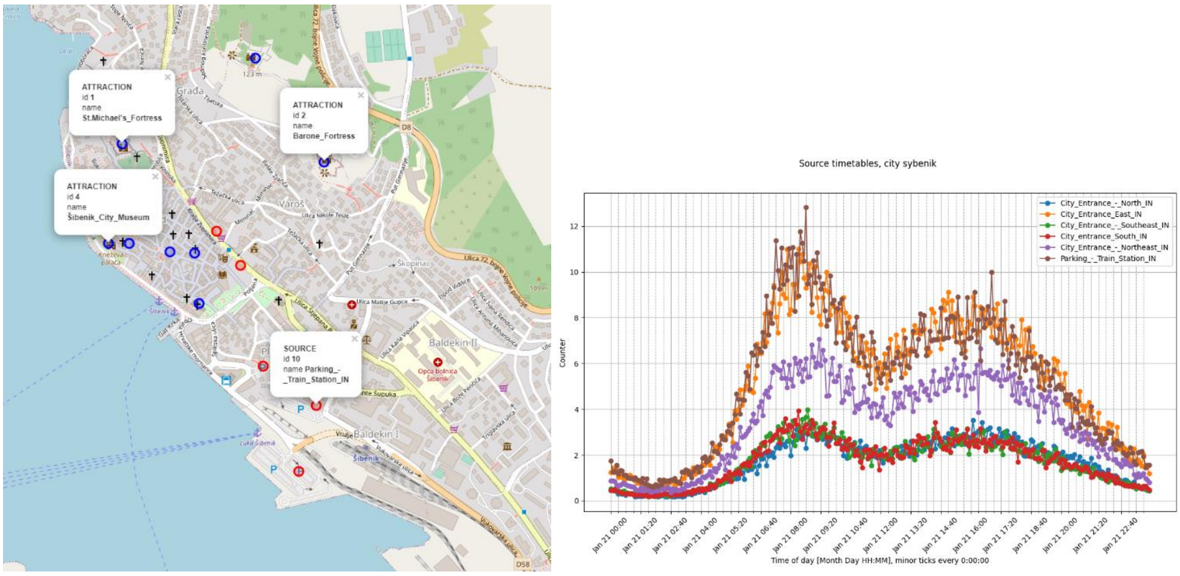

Figure 2.5: (Left) Locations of source entry points (red circle) and attractions (blue circle) in Sibenik. (Right) Incoming visitor flows from the sources (number of individuals per 5 minutes) used in the simulations: we have assumed the arrival of 2000 visitors.

A snapshot of the graphic interface of the visitor mobility model is shown in the Figure 2.6 (left) where the points give the position of a single individual along a road. The simulation results provide a dynamic flow map for the reconstructed mobility flows that is elaborated in the project dashboard according to a colour scale (see Figure 2.6- right).

To study the existence of crowding effects the model allow to plot a heatmap of the people distribution in Sibenik: an example is show in Figure 2.7 where we remark the individuals concentrate at the entry points as the port and the historical area. Both the dynamics flows maps and the heat map can be computed for shorter time intervals so that is is possible to get a dynamc evolution of the mobility in the road network during the considered day.

The simulation also gives the evolution of the expected presences (occupancy) at the main attraction points as it is shown in Figure 2.8: we observe as the presence of many attraction points reduces the attractivity of the Aquarium and the Assumption of Mary Church that are considered less relevant by the model in the construction of the tourist mobility agenda.

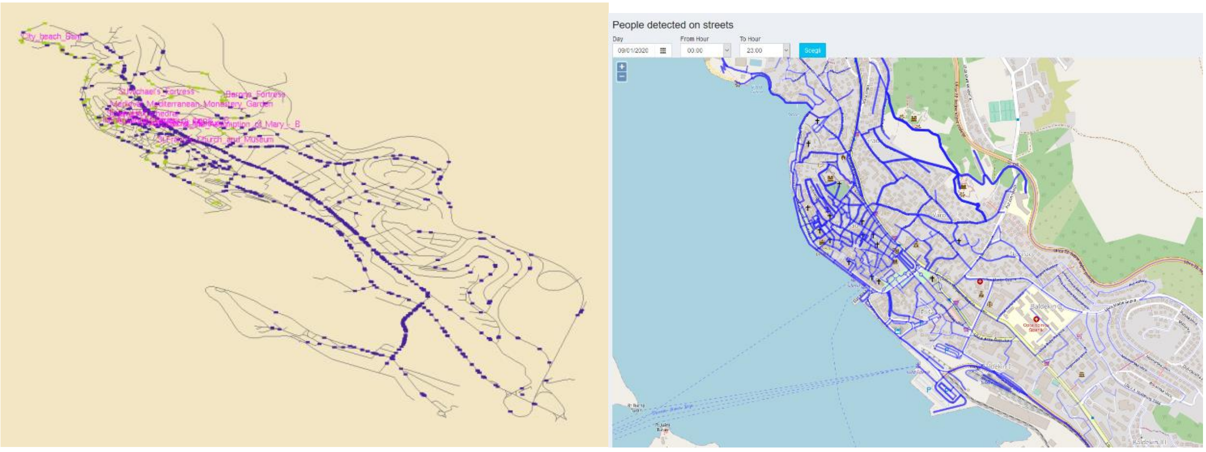

Figure 2.6: (Left) snapshot of the graphic interface of the visitor mobility model that simulates the invidual mobilily (dots) in the raod network realizing a dynamical model based on the existence of a foundamental diagram for pedestrian mobility. (Right) Dynamic flow map for the daily mobility in Sibenik simulated by the model, as plotted by the dashboard.

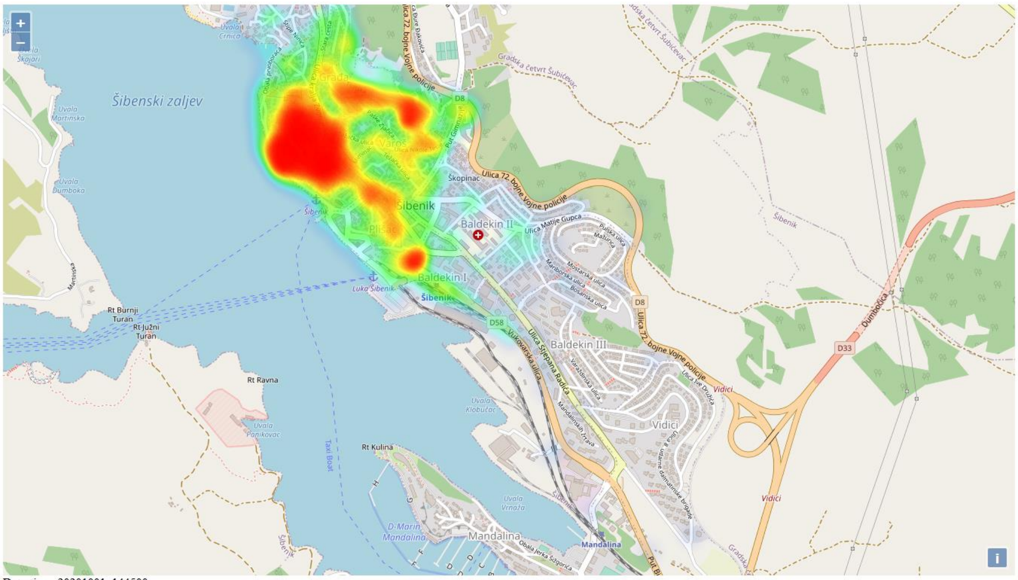

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Figure 2.7: Heatmap of the daily presences simulated by the visitor mobility model in Sibenik. The people distribution is mainly concentrated at the entry points (ex. the port) and the historical area.

As in the case of Ferrara the model allows also to perform a short-term forecasting of the mobility using the real time data collected by the video cameras. The software implemented to measure the tourist flows allow to get a real time result each minute so that we can give alerts in the case of anomalous incoming visitors flow and the model provides a future evolution of the mobility during the day using the average daily behaviour of the incoming fluxes (computed from the previous days) scaled by the actual data.

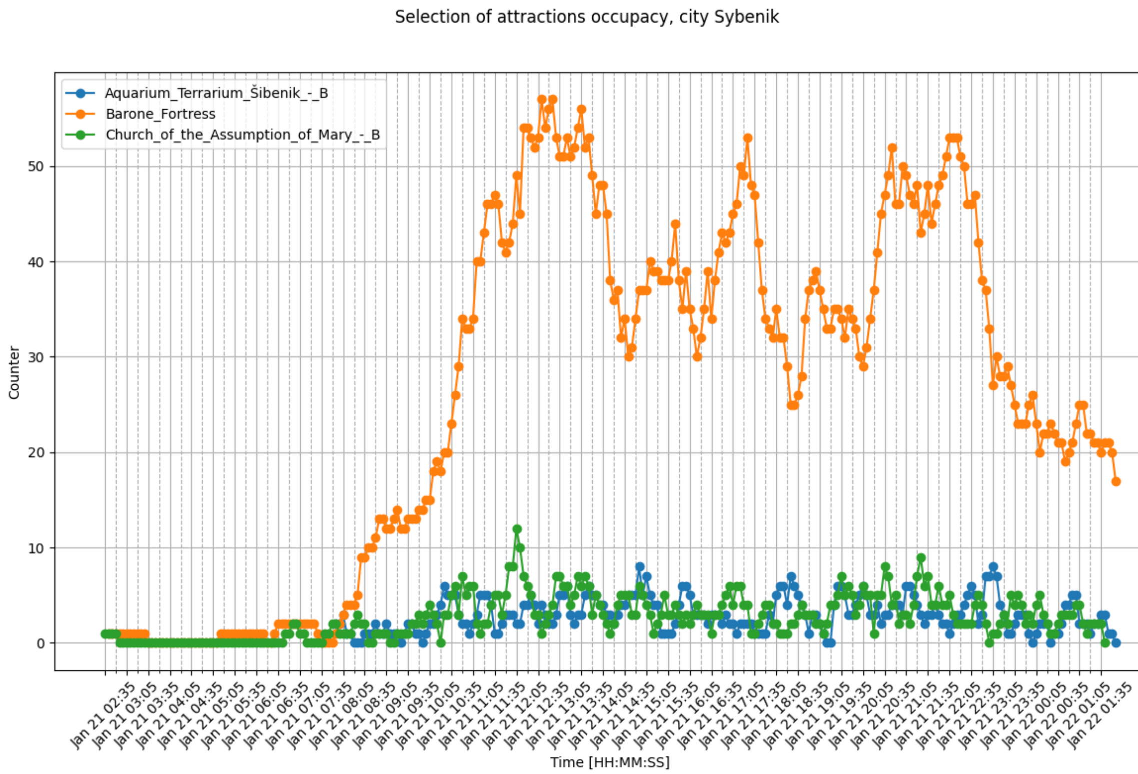

Figure 2.8: Daily evolution of the presences (occupancy) at the main attractions in Sibenik as simulated by the Visitor mobility models: the list of the attractions considered by the visitor's mobility model is given in the figure. The presence of many attractions reduces the attractivity of the Aquarium and Assumption of Mary Church.

3. Experimental Campaign and Model Simulations for the city of Dubrovnik

The experimental campaign in Dubrovnik has been implemented by using a system to detect the presence of a mobile phone connected to the Wi-Fi access points present in the city. This system integrates the video camera system that is just present in the city at the entrances of the historical centre and allow to get information on a larger area both on the tourist presences at different points of interest (to each connected device it is associated an anonymous id) and on the mobility agenda (i.e., the presence of the same device at different points at different times). The distribution of the monitored wife access point is shown in Figure

3.1. As it is shown by the figure, due the presence of multiple access points in some location we have performed a clustering procedure for the data analysis.

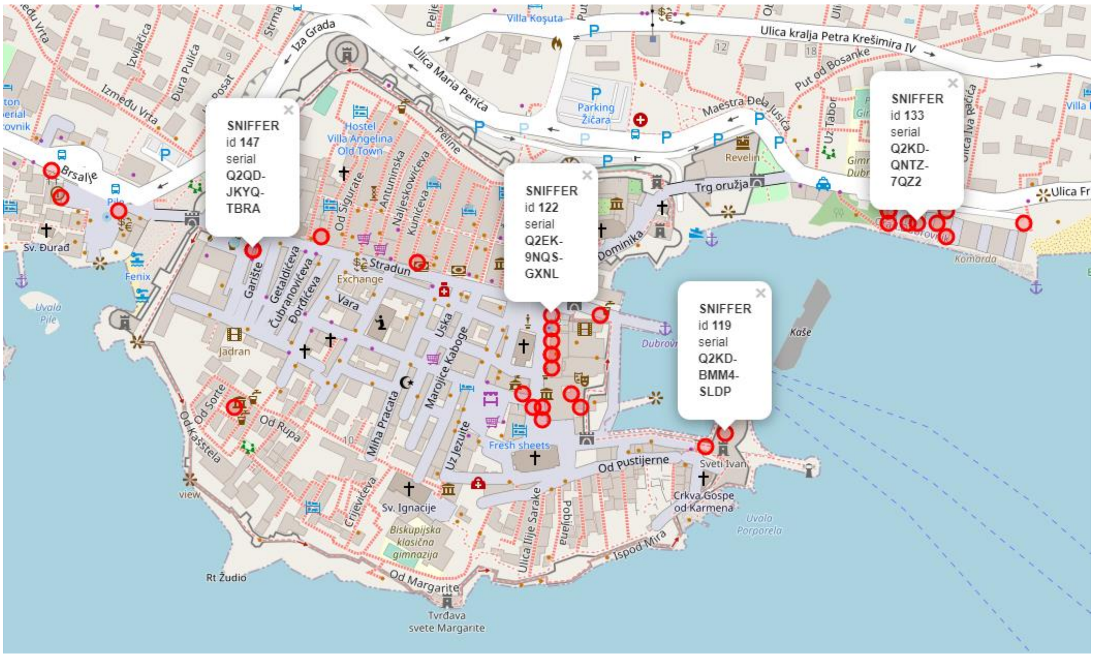

Figure 3.1: The red circles show the location of the Wi-Fi access points able to detect the presence of mobile device Wi-Fi connected in the Dubrovnik historical centre to perform the experimental campaign.

In Figure 3.2 we give an example of the total unique presences recorded by the sensors during some days of January 2021: the data are actually recorded by the SLIDES datahub and the comparison between the presences during winter and the presences in summer would allow to measure the visitors flow in the area.

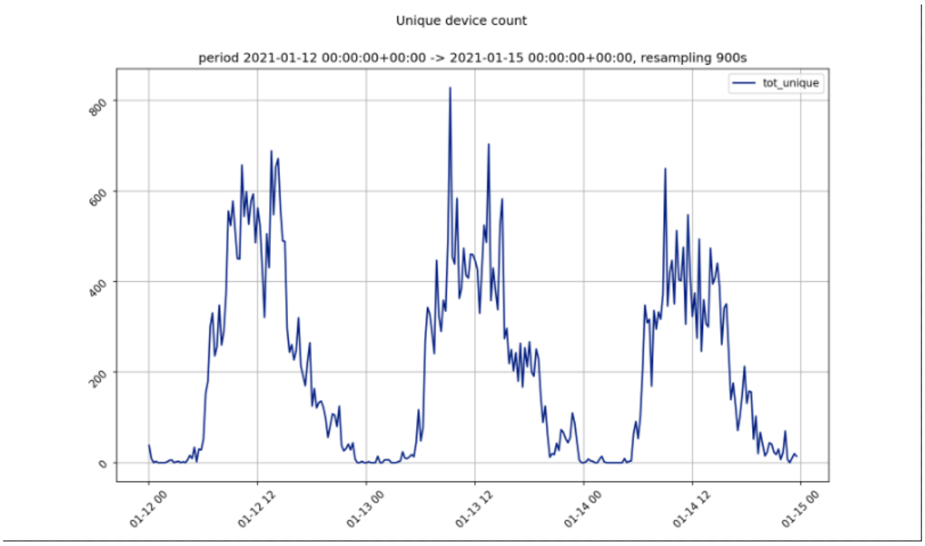

Figure 3.2: total unique presences recorded by the Wi-Fi access points in Dubrovnik during three days of January 2021. The data are consistent with the flow recorded by the video cameras installed at the entrances of the historical city.

The data are integrated in the visitor mobility model for Dubrovnik and the sources considered in the model are plotted in Figure 3.3. We remark as some of the Wi-Fi accesses are used to derive the incoming visitors flows whereas other Wi-Fi accesses can be used to perform a validation procedure.

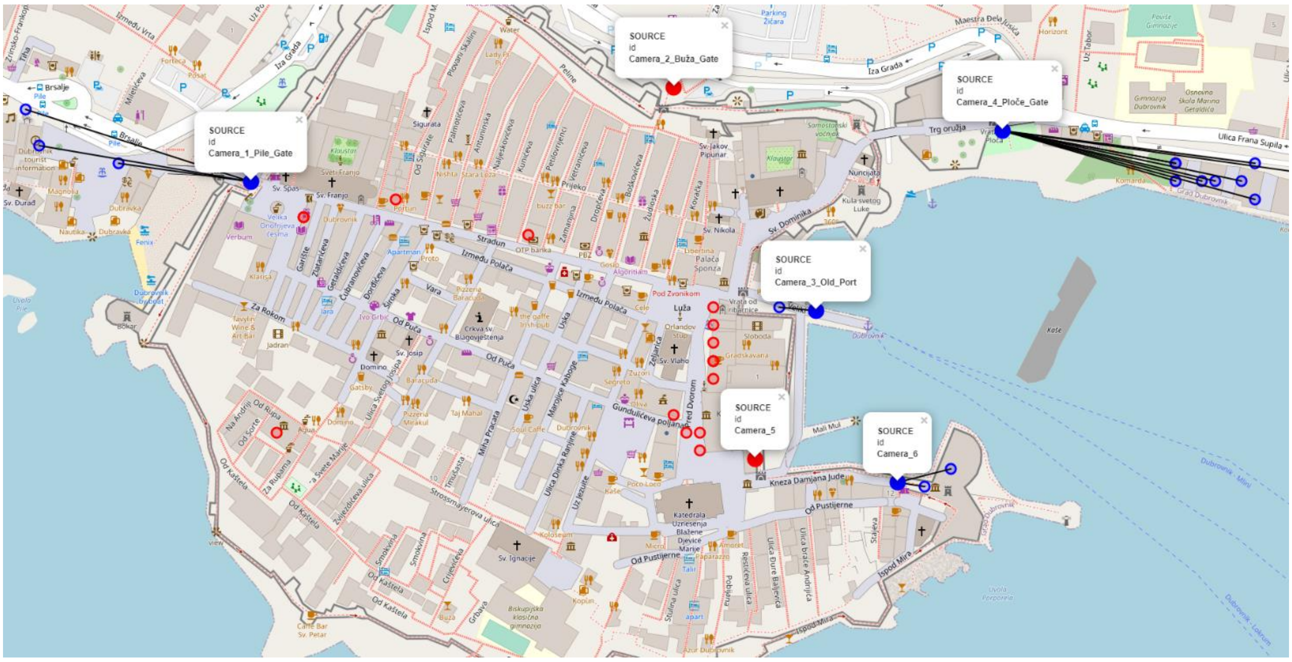

Figure 3.3: The location of the source points considered in the simulations of visitor mobility in Dubrovnik: the blue dots denote the model sources whereas the blue circles denote the sensors' location that can be used to infer the incoming visitor flows. The red dots are the sources inferred by the model from the video cameras data and the red circles are the location of the other Wi-Fi access points that are used to calibrate the model parameter and performing validation procedures.

We have developed a model for the pedestrian mobility in Dubrovnik using the same procedure developed in the case of Ferrara. Starting from the Open Street Map cartography we have derived a road network for the simulations (see Figure 3.4). We have introduced the entry points and the attractions in the considered area following the suggestions of the Dubrovnik municipality (a list in given in Figure 3.6). The path length distribution and the visit duration distribution (see Figure 3.4) show that the model simulates visits with an average path length of 3.0 Km (due to the size of the historical centre) and a duration of 4.5 h. Indeed, the mobility agenda consider the possibility of inserting 4 attraction points in the agenda during the visit (see Figure 3.4). The difference between the best path length and the mobility path length denotes a strong component of random mobility in the area that is of great historical interest. In Figure 3.5 we show some entry points (sources) and attraction points considered in the Dubrovnik visitor mobility models and the expected incoming flows used in the simulations: we assume a visitor flow of 2500 people per day (using the data recorded by the Wi-Fi access points that reflect the reduction of the tourist activity during the Covid-19 epidemic.

Figure 3.3: The road network of the Dubrovnik as provided by the Open Street Maps (left picture) and as implemented in the visitors' dynamical models (right picture).

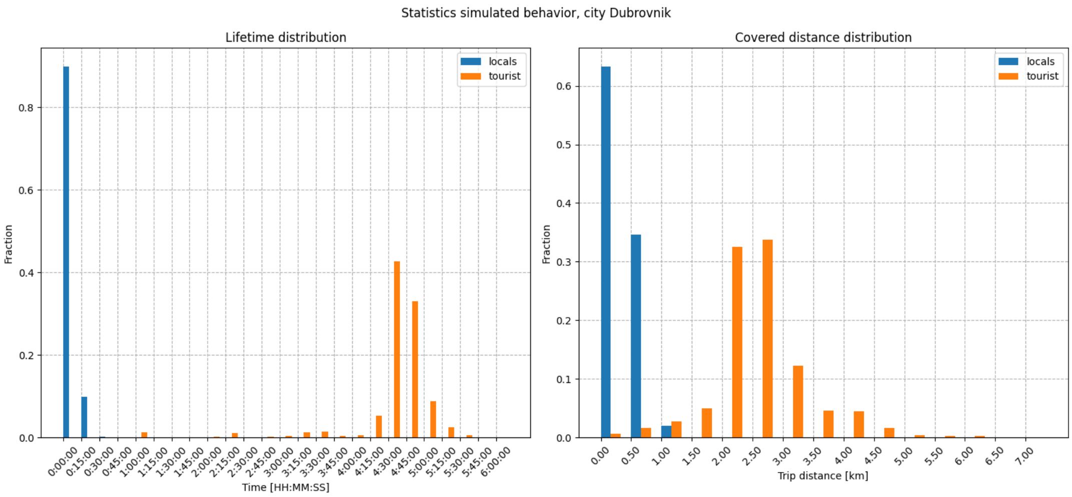

Figure 3.3: (Left) Path length distribution simulated in Dubrovnik for the resident paths (blue) and the tourist paths (orange). (Right) distribution of the time duration of resident paths(blue) and the visit duration of the tourists (orange).

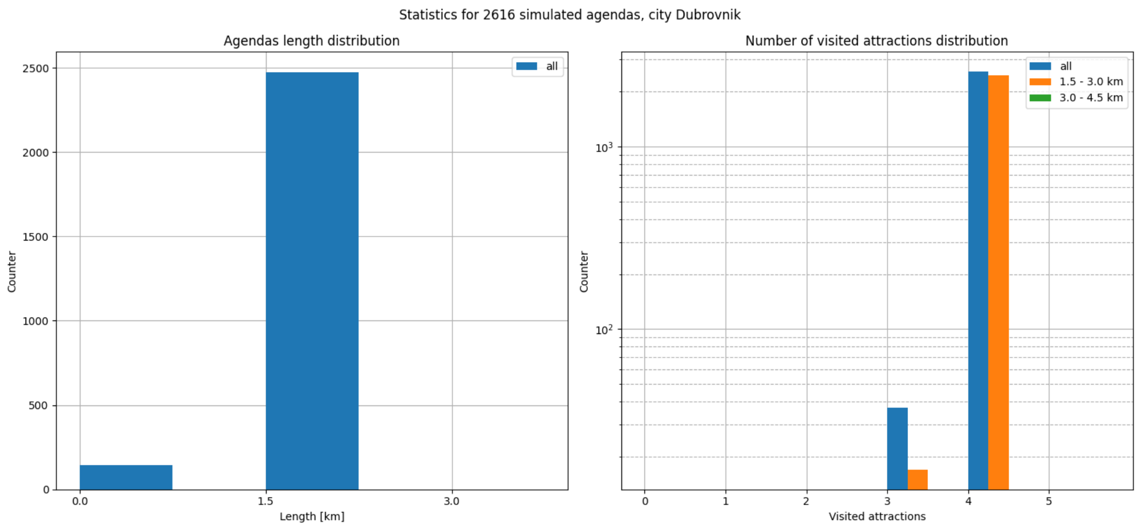

Figure 3.4: (Left) expected best path length associated to the mobility agenda of the tourist visiting the Duborvnik historical centre and (right) the number of attraction points inserted by the model in the tourist mobility agenda.

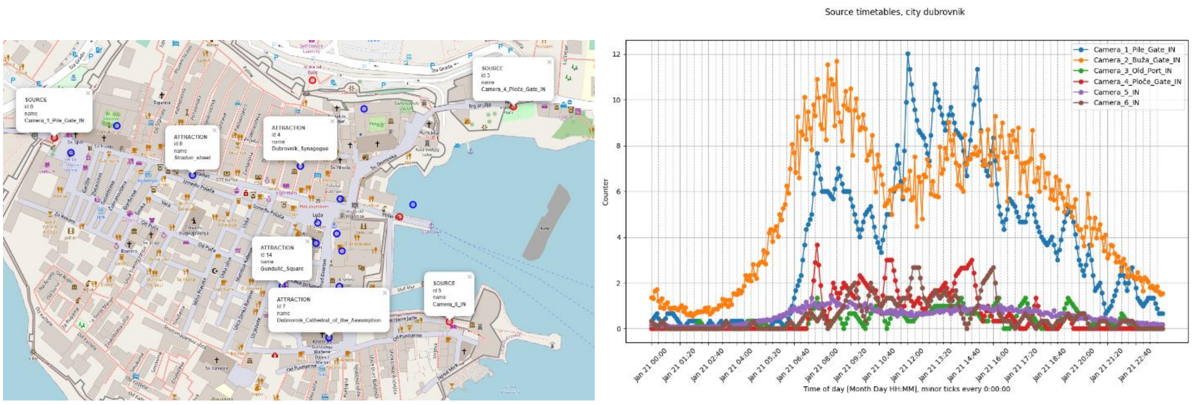

Figure 3.5: (Left) Locations of source entry points (red circle) and attractions (blue circle) in Dubrovnik. (Right) Incoming visitor flows from the sources (number of individuals per 5 minutes) used in the simulations: we have assumed the arrival of 2500 visitors.

A snapshot of the graphic interface of the visitor mobility model is shown in the Figure 3.6 (left) where the points give the position of a single individual along a road. The simulation results provide a dynamic flow map for the reconstructed mobility flows that is elaborated in the project dashboard according to a colour scale (see Figure 3.6- right).

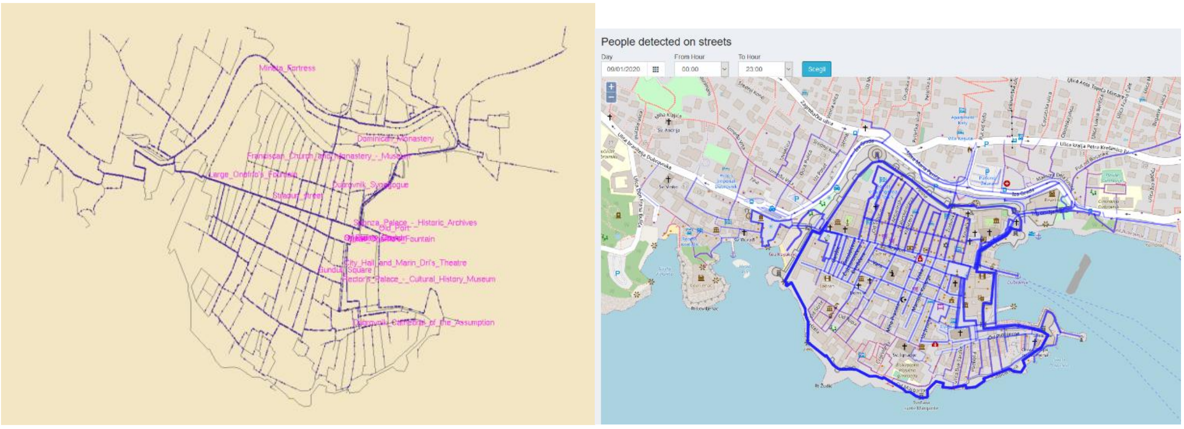

Figure 3.6: (Left) snapshot of the graphic interface of the visitor mobility model that simulates the invidual mobilily (dots) in the raod network realizing a dynamical model based on the existence of a foundamental diagram for pedestrian mobility. (Right) Dynamic flow map for the daily mobility in Duborvnik simulated by the model, as plotted by the dashboard.

To study the existence of crowding effects the model allow to plot a heatmap of the people distribution in Dubrovnik: an example is show in Figure 3.7 where we remark the individuals concentrate at the entry points and the attarction points in the historical centre. Both the dynamics flows maps and the heat map can be computed for shorter time intervals so that is is possible to get a dynamc evolution of the mobility in the road network during the considered day.

The simulation also gives the evolution of the expected presences of some attraction points as it is shown in Figure 3.8.

As in the case of Ferrara the model allows also to perform a short-term forecasting of the mobility using the real time data collected by the video cameras. The software implemented to measure the tourist flows allow to get a real time result each minute so that we can give alerts in the case of anomalous incoming visitors flow and the model provides a future evolution of the mobility during the day using the average daily behaviour of the incoming fluxes (computed from the previous days) scaled by the actual data.

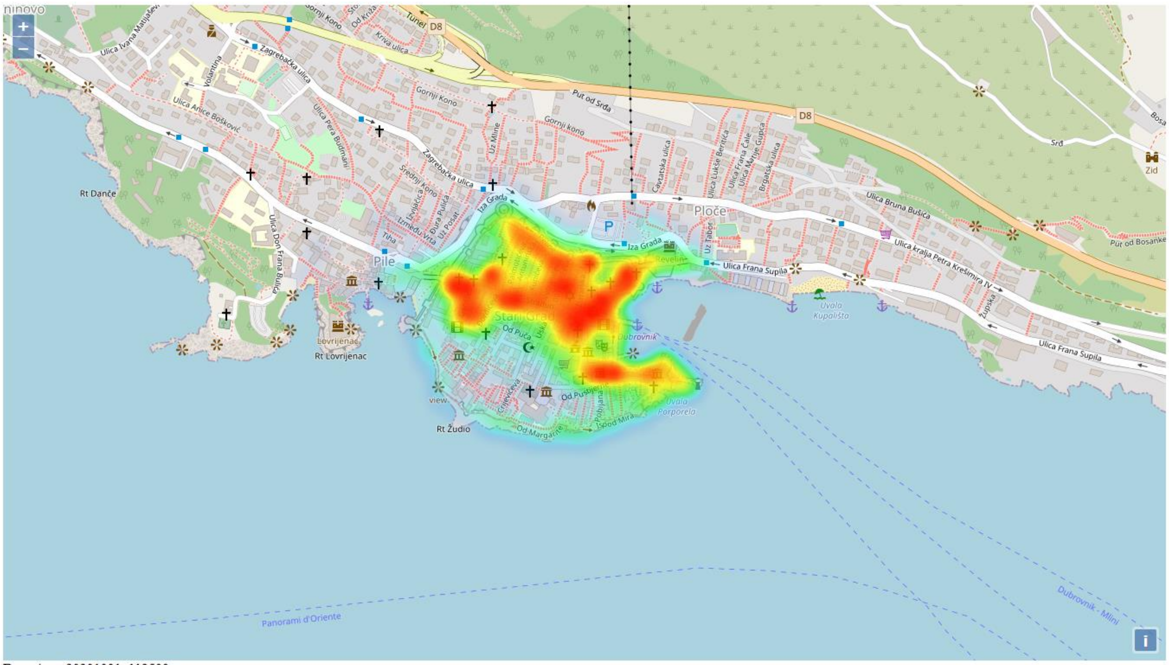

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Figure 3.7: Heatmap of the daily presences simulated by the visitor mobility model in Dubrovnik. The people distribution is mainly concentrated at the entry points and the attractions in the historical area.

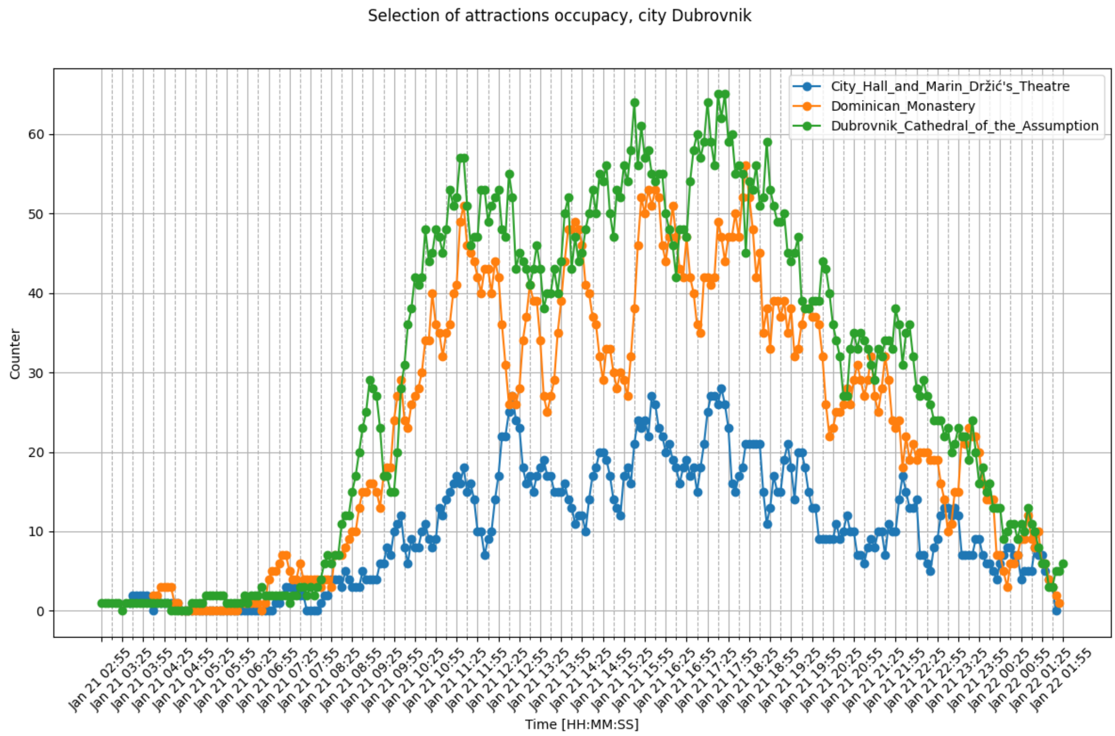

Figure 3.8: Daily evolution of the presences (occupancy) at some attractions in Dubrovnik as simulated by the Visitor mobility models: the list of the attractions considered by the visitors mobility model is given in the figure.

4. Experimental activity and model simulations for the city of Venice

In the city of Venice, there are installed ~40 people and flow counter sensors that collect real time data in the framework of the Smart Control Room project (see Figure 4.1). These data will be available for the tuning of the Visitors' Mobility Models developed in the SLIDES project thanks to an agreement with the Venice Municipality for a period that will be defined when the social restriction due to COVID-19 pandemic will be finished and the tourist flows restart in Venice. Moreover, in the framework of the SLIDES project we have implemented the possibility of performing a real time crowd counting in San Marco Square using the installed video cameras to complete the information recorded by the distributed sensors on the road network. The video analysis will be performed by the same algorithms developed by the CAST-UNIBO partner based on a deep learning neural network (see WP 3.2.1). In Figure 2.2 we show an example of the counting detection from the video analysis in San Marco Square (the video has been recorded before the restrictions of social activities due to the COVID-19 pandemic.

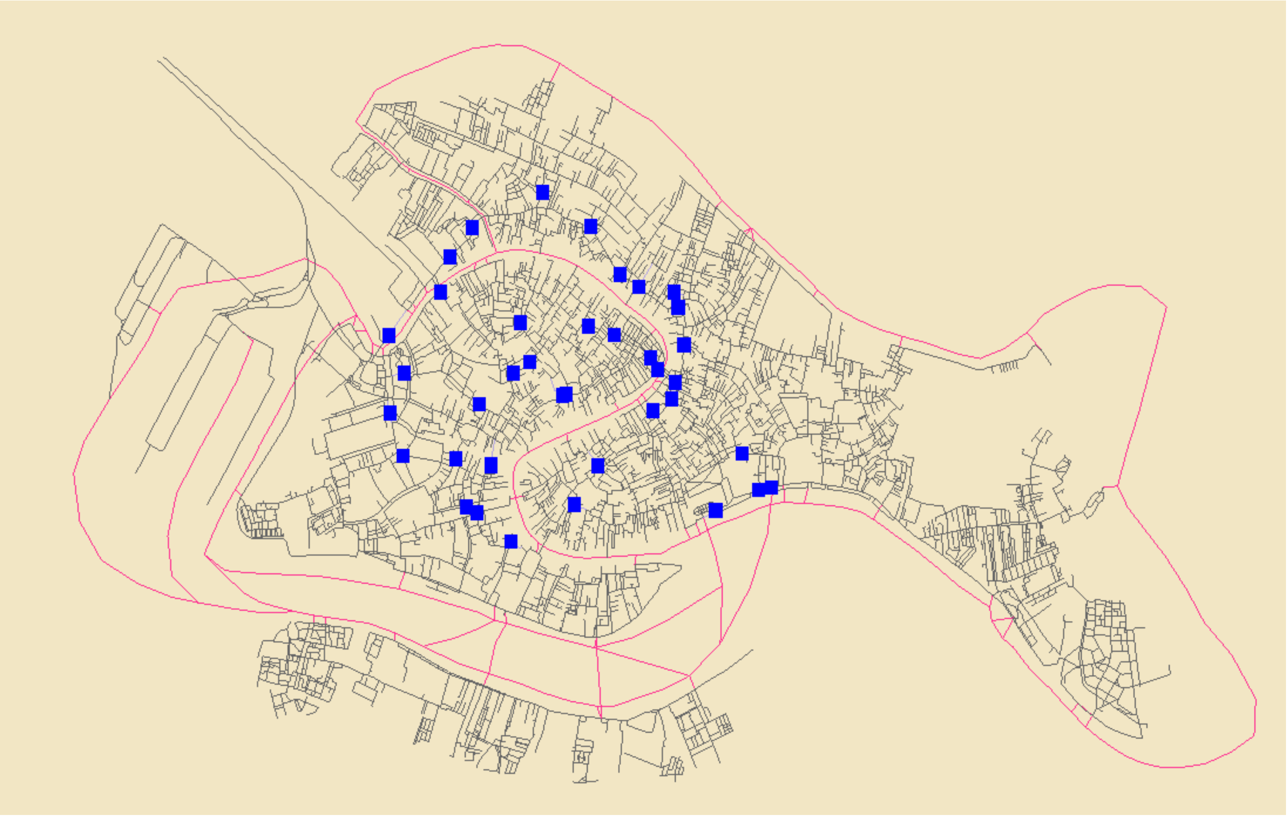

Figure 4.1: The blue square denotes the position of the people and flow counters installed in Venice in the framework of the Smart Control Room project.

Figure 4.2: Example of crowd counting in San Marco Square in Venice: the number is an id associated to each detected individual and the curves denote the reconstructed trajectories from the video analysis.

The visitor's mobility model of Venice historical centre has been conceived to integrate the mobile sensors data both at sources points and on the check points along the road network. The location of the people counting sensors (Figure 4.1) allows to directly measure the incoming pedestrian flows in the Venice historical centre. We have developed a model for the pedestrian mobility in Venice using the same procedure developed in the case of Ferrara. Starting from the Open Street Map cartography we have derived a road network for the simulations (see Figure 4.3). We have introduced the entry points and the attractions in the considered area following the suggestions of the Venice municipality. The path length distribution and the visit duration distribution (see Figure 4.4) shows that the model associated a propensity of visits with long average path length (5.5 Km) due to the extension of the Venice historical centre and an average visit duration of 4. h. Indeed, the mobility agenda consider the possibility of inserting 4 attraction points in the agenda during the visit (see Figure 4.5). The difference between the best path length and the mobility path length denotes a strong component of random mobility in the historical centre that is of great historical interest. In Figure 4.6 we show some entry points (sources) and attraction points considered in the Venice visitor mobility models and the expected incoming flows used in the simulations: we assume a visitor flow of 20000 people per day expecting the recovering of the tourist flows after the pandemic.

Figure 4.3: The road network of the Venice as provided by the Open Street Maps (left picture) and as implemented in the visitors' dynamical models (right picture).

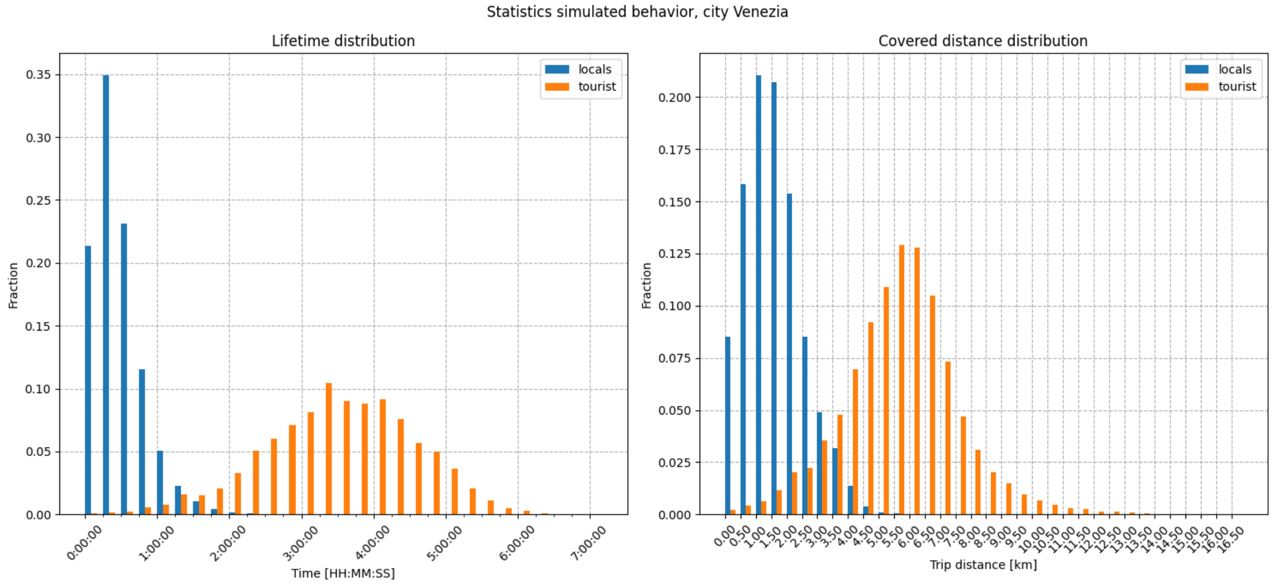

Figure 4.4: (Left) Path length distribution simulated in Venice for the resident paths (blue) and the tourist paths (orange). (Right) distribution of the time duration of resident paths(blue) and the visit duration of the tourists (orange).

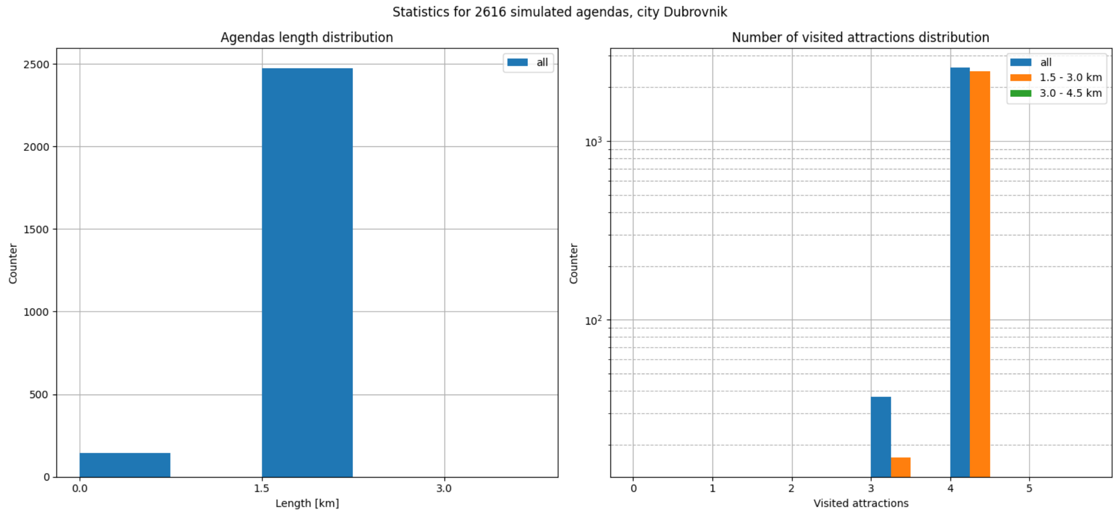

Figure 4.5: (Left) expected best path length associated to the mobility agenda of the tourist visiting the Venice historical centre and (right) the number of attraction points inserted by the model in the tourist mobility agenda.

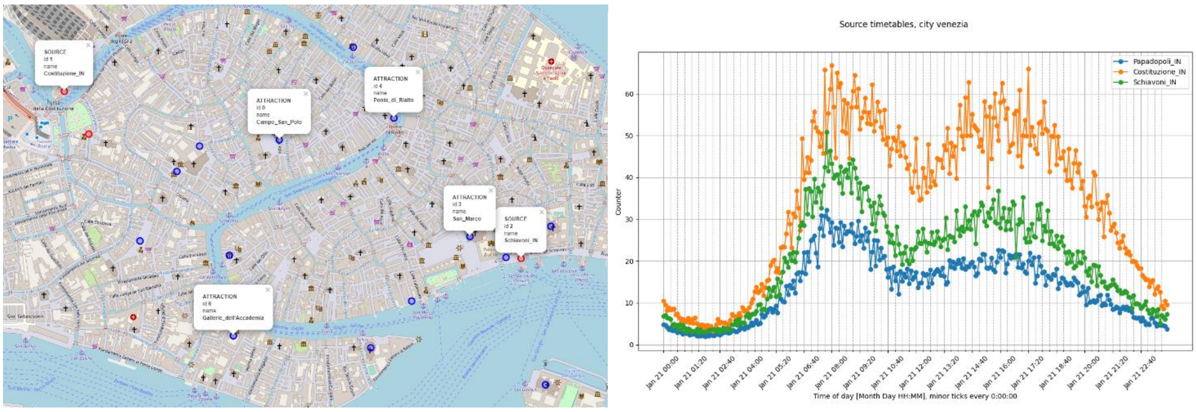

Figure 4.6: (Left) Locations of some source entry points (red circle) and attractions (blue circle) in Venice. (Right) Incoming visitor flows from some entry points (number of individuals per 5 minutes) used in the simulations: we have assumed the arrival of 20000 visitors.

A snapshot of the graphic interface of the visitor mobility model is shown in the Figure 4.7 (left) where the points give the position of a single individual along a road. The simulation results provide a dynamic flow map for the reconstructed mobility flows that is elaborated in the project dashboard according to a colour scale (see Figure 4.7-right) and heatmap of the people distribution in the historical centre (see Figure 4.8).

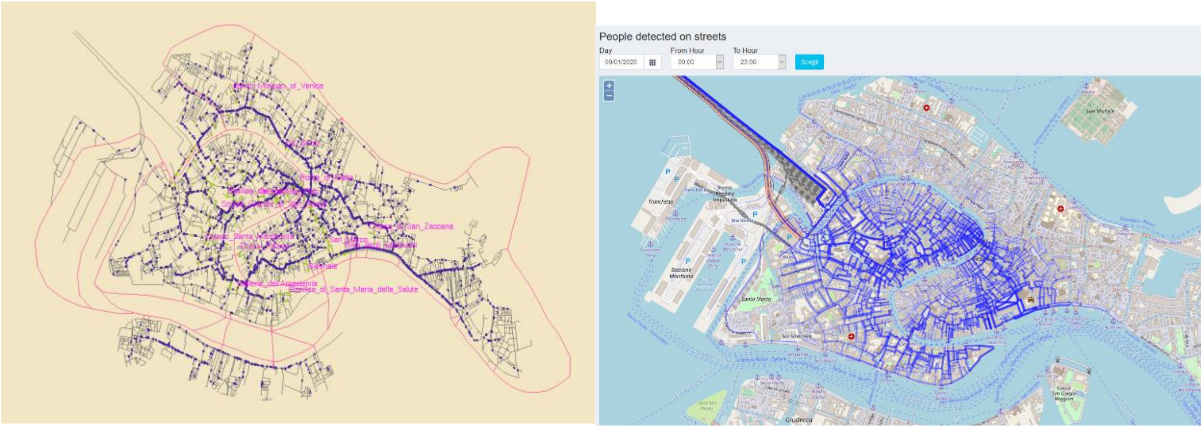

Figure 4.7: (Left) snapshot of the graphic interface of the visitor mobility model that simulates the invidual mobilily (dots) in the rodd network realizing a dynamical model based on the existence of a foundamental diagram for pedestrian mobility. (Right) Dynamic flow map for the daily mobility in Venice simulated by the model, as plotted by the dashboard.

The existence of crowding effects will be performed in San Marco square using the video cameras analysis and the simulation results on the expected presences of some attraction points as it is shown in Figure 4.9.

As in the case of Ferrara the model allows also to perform a short-term forecasting of the mobility using the real time data collected by the video cameras and the evolution of incoming visitors flows computed from available statistical data recorded by the sensors.

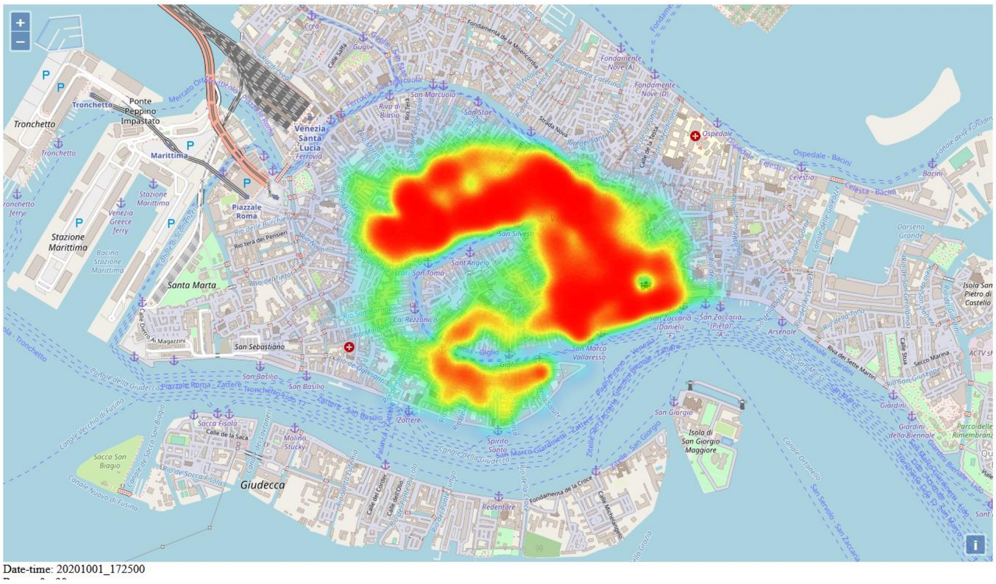

Figure 4.8: heatmap of the daily presences simulated by the visitor mobility model in Venice. The people distribution is mainly concentrated in the areas of Strada Nova and Rialto bridge towards the area Marciana.

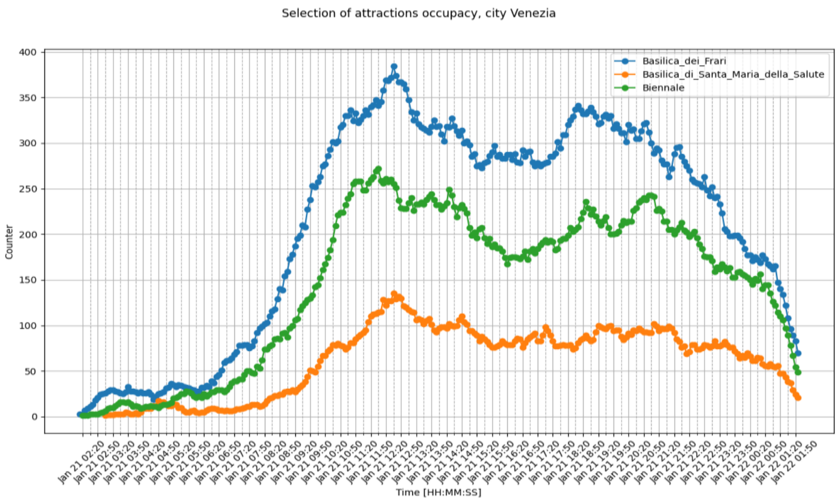

Figure 4.9: Daily evolution of the presences (occupancy) at some selected attractions in Venice as simulated by the Visitor mobility models: the list of the attractions considered by the visitors mobility model is given in the figure.

5. Data collections and Model Simulations for the city of Bari

The city of Bari has decided to take advantage from the installed video cameras between the station and the historical centre by upgrading these systems to people flow sensors. The location of the video cameras available for upgrading to people counting sensors is shown in Figure 5.1. The system is completed by a server that collects the videos and perform a real time data analysis. The measures will be collected at the SLIDES dashboard and made available for further analysis and for the model simulations.

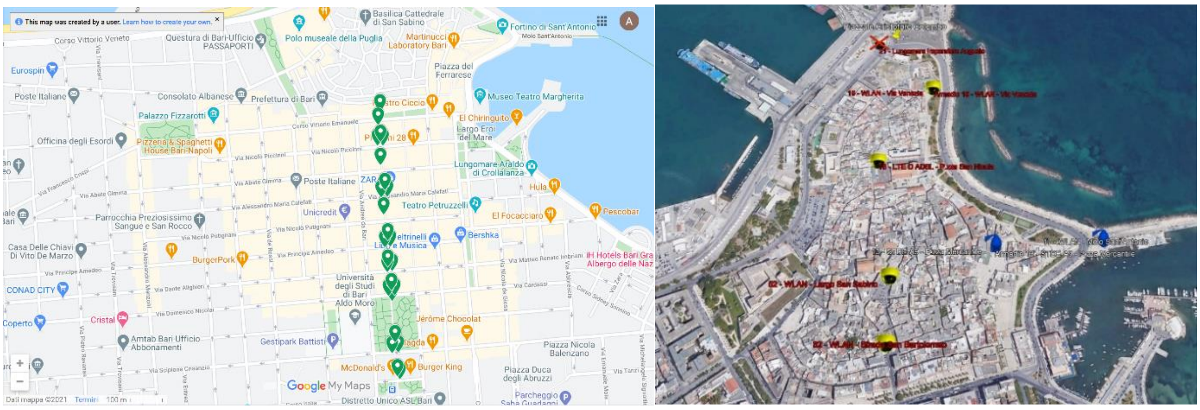

Figure 5.1: The markers indicate the location of the video cameras available to perform people counting in Bari: the left picture shows the cameras along via Sparano (the main pedestrian area between the station and the historical centre), whereas the right pictures show other cameras available in the historical town.

We have developed a model for the pedestrian mobility in Bari using the same procedure developed in the case of the other cities. Starting from the Open Street Map cartography we have derived a road network for the simulations (see Figure 5.2). We have introduced the entry points and the attractions in the considered area following the suggestions of the Bari municipality. The path length distribution and the visit duration distribution (see Figure 5.3) show that the model associates a propensity of a visit with an average path length of 4.5 Km and a duration with two peaks: one at 4h, that corresponds to short visits of passing visitors and another one at 5.5h due to daily visitors. The mobility agenda consider the possibility of inserting of 3 or 4 attractions in the agenda during the visit (see Figure 5.4), but the visit duration is short. In Figure 5.5 we show some entry points (sources) and attraction points considered in the Bari visitor mobility models and the expected incoming flows used in the simulations: we assume a visitor flow of ~15000 people per day.

Figure 5.2: The road network of the Bari as provided by the Open Street Maps (left picture) and as implemented in the visitors' dynamical models (right picture).

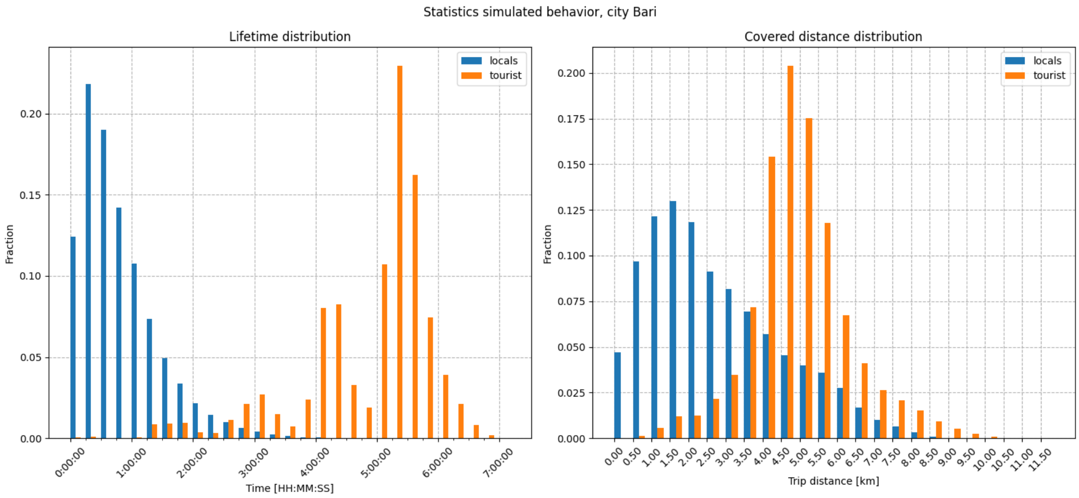

Figure 5.3: (Left) distribution of the time duration of resident paths(blue) and the visit duration of the tourists (orange). (Right) Path length distribution simulated in Bari for the resident paths (blue) and the tourist paths (orange).

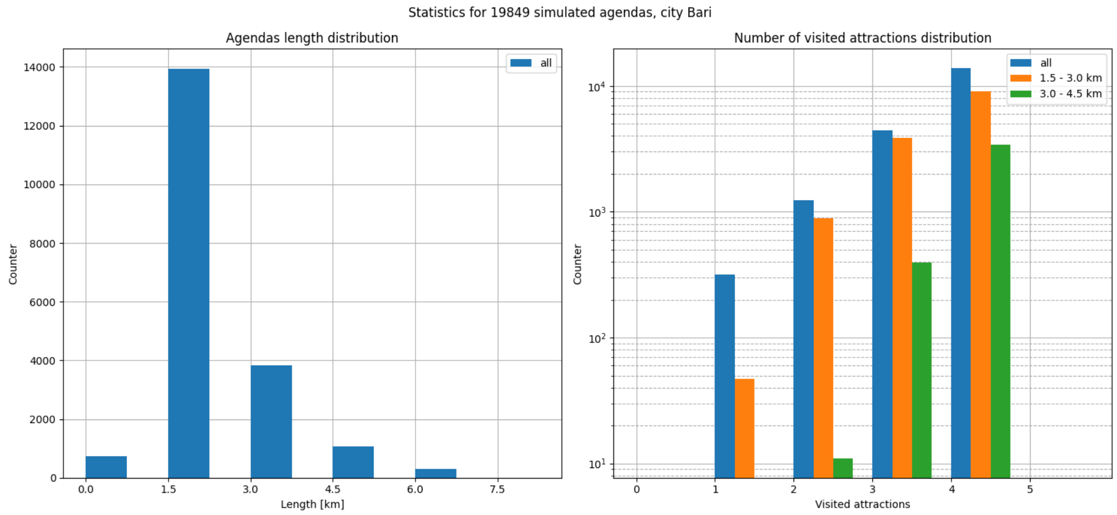

Figure 5.4: (Left) expected best path length associated to the mobility demand in Bari (both for tourists and residents) and the number of attraction points inserted by the model in the tourist mobility agenda disaggregated on the expected path lengths (right); i.e., the longer paths are associated to a greater number of visited attractions.

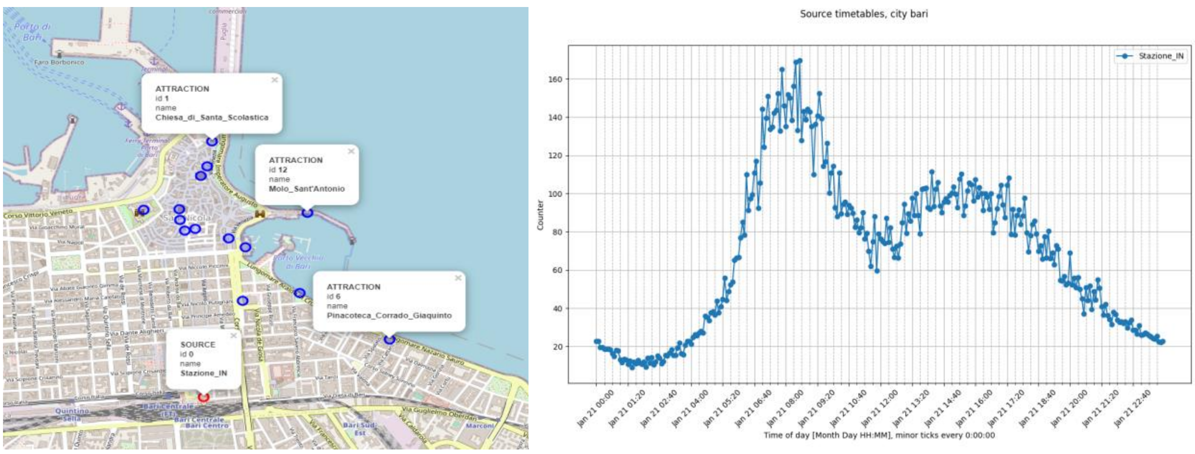

Figure 5.5: (Left) Locations of source entry points (red circle) and attractions (blue circle) in Bari. (Right) Incoming visitor flows from the station (number of individuals per 5 minutes) used in the simulations: we have assumed the arrival of 2000 visitors.

A snapshot of the graphic interface of the visitor mobility model is shown in the Fig. 5.6 (left) where the points give the position of a single individual along a road. The simulation results provide a dynamic flow map for the reconstructed mobility flows that is elaborated in the project dashboard according to a colour scale (see Fig. 5.6- right).

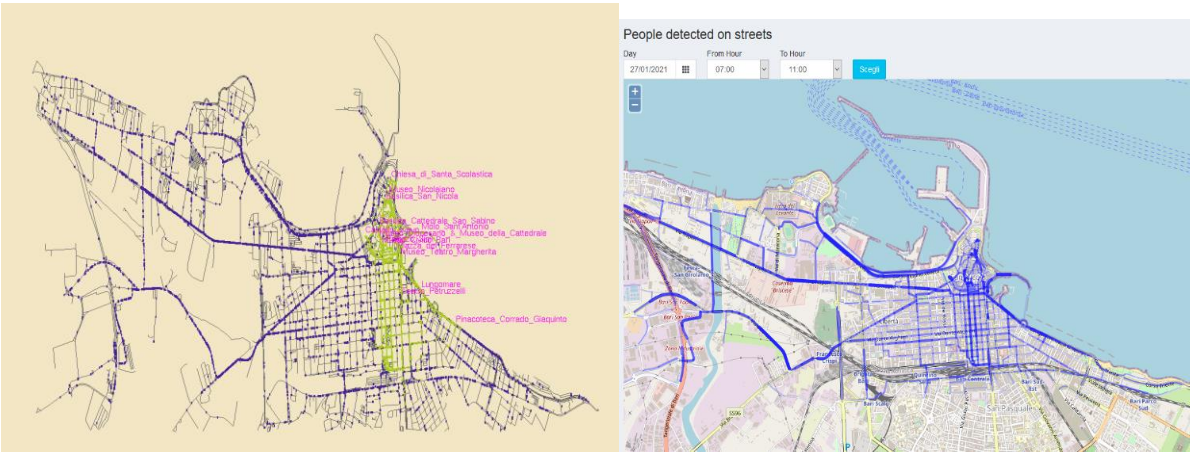

Figure 5.6: (Left) snapshot of the graphic interface of the visitor mobility model that simulates the invidual mobilily (dots) in the raod network realizing a dynamical model based on the existence of a foundamental diagram for pedestrian mobility. (Right) Dynamic flow map for the daily mobility in bari simulated by the model, as plotted by the dashboard.

To study the existence of crowding effects the model allow to plot a heatmap of the people distribution in Bari: an example is show in Fig. 5.7 where we remark the individuals concentrate at the station and the historical centre. Both the dynamics flows maps and the heat map can be computed for shorter time intervals so that is is possible to get a dynamc evolution of the mobility in the road network during the considered day.

The simulation also gives the evolution of the expected presences (occupancy) at the main attraction points as it is shown in Fig. 5.8: we observe as the tourist presences at the attraction points follow the circadian rhythms.

As in the case of Ferrara the model allows also to perform a short-term forecasting of the mobility using the real time data collected by the video cameras. The software implemented to measure the tourist flows allow to get a real time result each minute so that we can give alerts in the case of anomalous incoming visitors flow and the model provides a future evolution of the mobility during the day using the average daily behaviour of the incoming fluxes (computed from the previous days) scaled by the actual data.

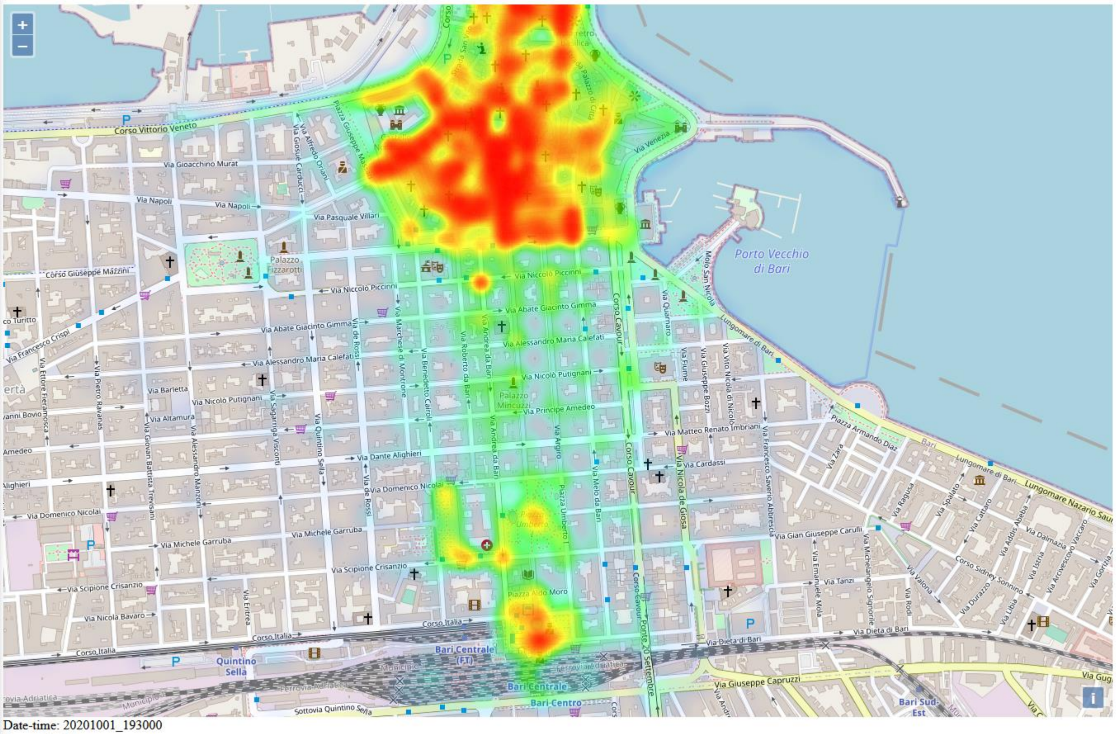

Figure 5.7: heatmap of the daily presences simulated by the visitor mobility model in Bari. People distribution is mainly concentrated at the entry points (ex. the station) and the historical centre.

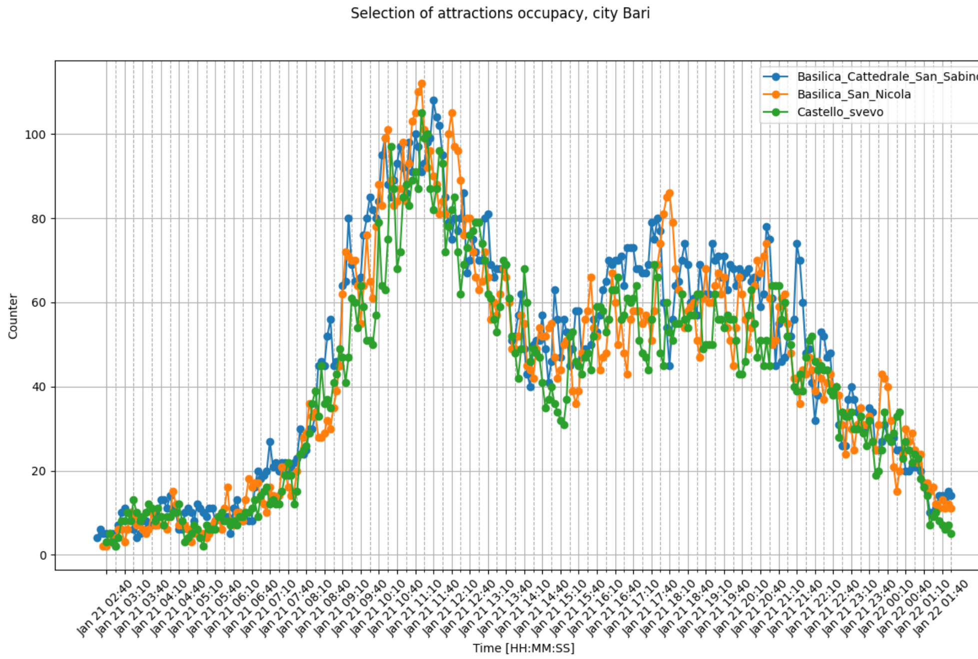

Figure 5.8: Daily evolution of the presences (occupancy) at the main attractions in Bari as simulated by the Visitor mobility models: the list of the attractions considered by the visitors' mobility model is given in the figure. The tourist presences follow the circadian rhythms.