UNIVERSITÀ DEGLI STUDI FIRENZE | DINFO DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE | DISIT DISTRIBUTED SYSTEMS AND INTERNET TECHNOLOGIES LAB

SNAP4CITY KM4CITY

https://www.Snap4City.org

Digital Twin with AI/XAI for Management and What-if Analysis

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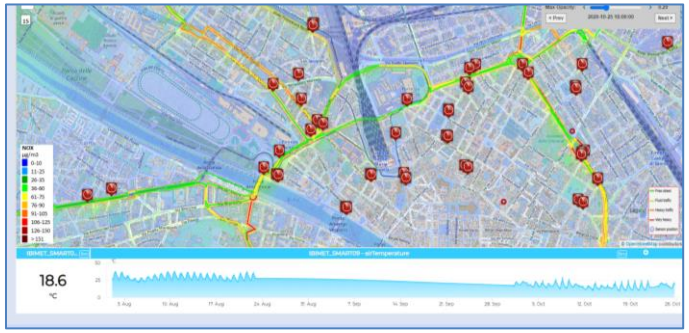
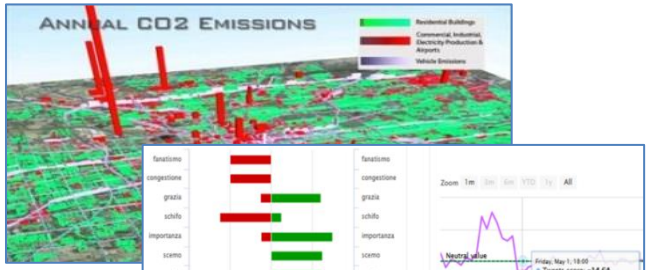
Convegno Nazionale

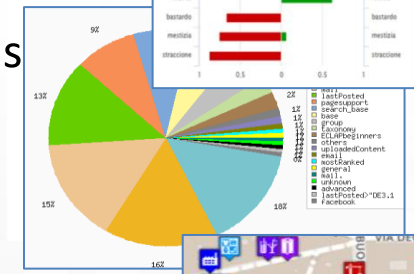
Sul Presente e il Futuro delle Smart Cities e Smart Communities:
Un Dialogo Interdisciplinare

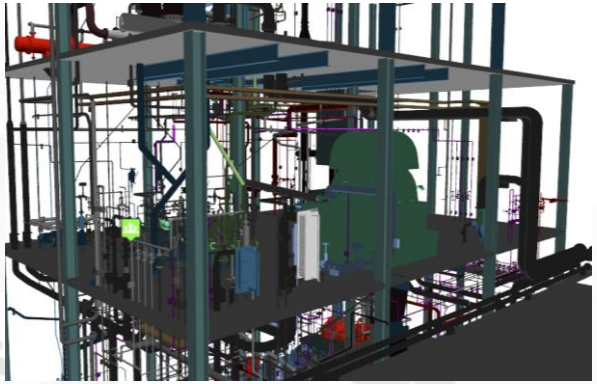
Digital Twin

- **Digital Twin**
  - **Connected** with real systems
  - **Modelling** aspects: structural, visual, informative, real time data sensors (context), POI, functional, resources, etc.
  - **Integration:** AI/XAI techniques, simulations, users' needs, etc.
- **Utility to**
  - Experiment via simulations and analysis by case
    - Reduction of costs to experiments new solutions
    - Share the possibilities with city users
  - Virtual Representation
    - Easier to understand the context, review from multiple points of view
  - Who
    - Discussion with city users, decision makers
    - Support: decision makers, proposers of solutions









100% OPEN SOURCE

Powered by FIWARE

FREE TRIAL

PEN Test Passed

EU GDPR COMPLIANT

SNAP4 Appliances and Dockers Installations

EUROPEAN OPEN SCIENCE CLOUD

Node-RED

JS Foundation

EØ15 digital ecosystem

NVIDIA

SNAP4CITY

KM4CITY

SMART SOLUTIONS AND DECISION SUPPORT SYSTEMS

CONTROL ROOMS - DECISION SUPPORT SYSTEMS - WHAT-IF ANALYSIS - BUSINESS INTELLIGENCE - SIMULATIONS - SMART APPLICATIONS

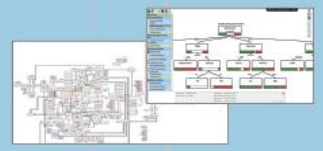
DASHBOARDS - VISUAL ANALYTICS - SYNOPTICS - DIGITAL TWIN - GRAPHICAL WIDGETS - ANALYTICS - GUI CUSTOM STYLES - VISUAL PROGRAMMING

DASHBOARDS, WIDGETS
TEMPLATES

PREDICTION - ANOMALY DETECTION - CLUSTERING - ROUTING - SENTIMENT NLP - TRAFFIC FLOW
PEOPLE FLOWS - SDG - 15 MIN CITY INDEX - KPI - HEATMAPS - ORIGIN DESTINATION - ETC...

API - MICROSERVICES - GIS - BPM
VIDEO - REPORTS - MAPS - 3D ...

ANY: DATA, BROKER, NETWORK AND VERTICAL



EXPERT SYSTEM, KNOWLEDGE BASE
SEMANTIC REASONING
SMART DATA MODEL
IOT DEVICE MODELS, STORAGE

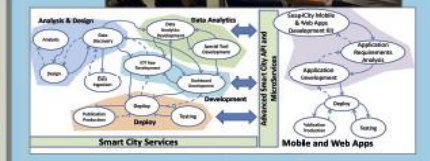
BIG DATA ANALYTICS, ARTIFICIAL INTELLIGENCE
EXPLAINABLE AI, MACHINE LEARNING
OPERATIVE RESEARCH, STATISTICS

VISUAL PROGRAMMING, ADAPTERS
DATA FLOWS, WORKFLOWS
PARALLEL DISTRIBUTED PROCESSING
DATA DRIVEN

Native and External Applications

- Smart Parking
- Smart Light
- Smart Waste
- Smart Energy
- Social Media Analysis

...

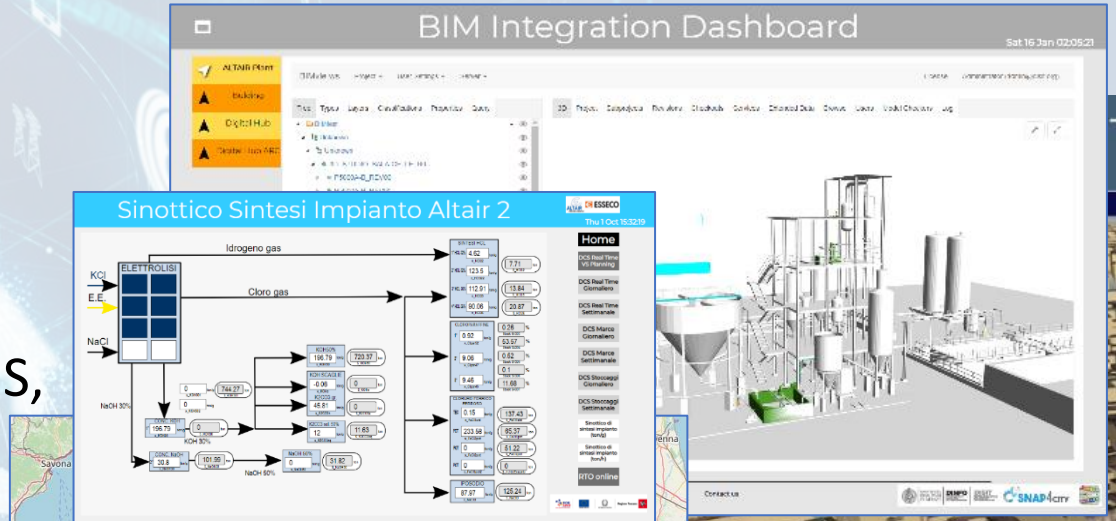


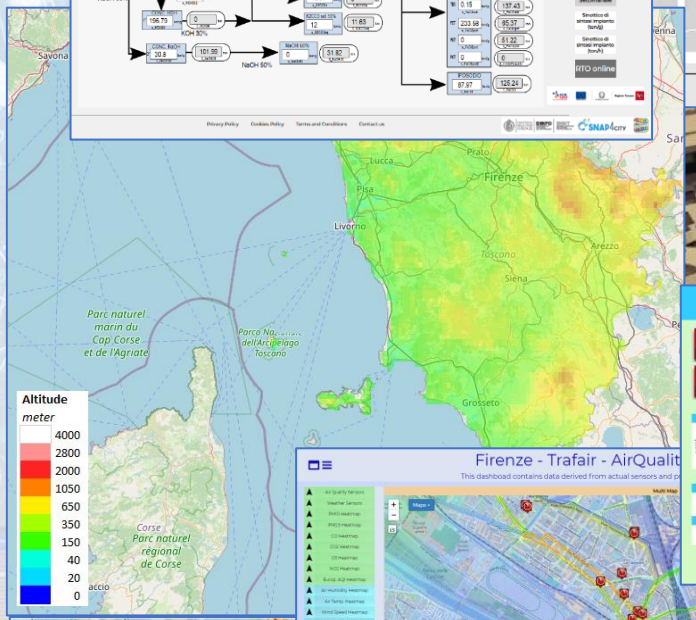
METHODOLOGIES
LIVING LABS
COURSES AND COMMUNITY
DEVELOPMENT TOOLS

High Level Types

Snap4City (C), Cagliari 2023, July 2023

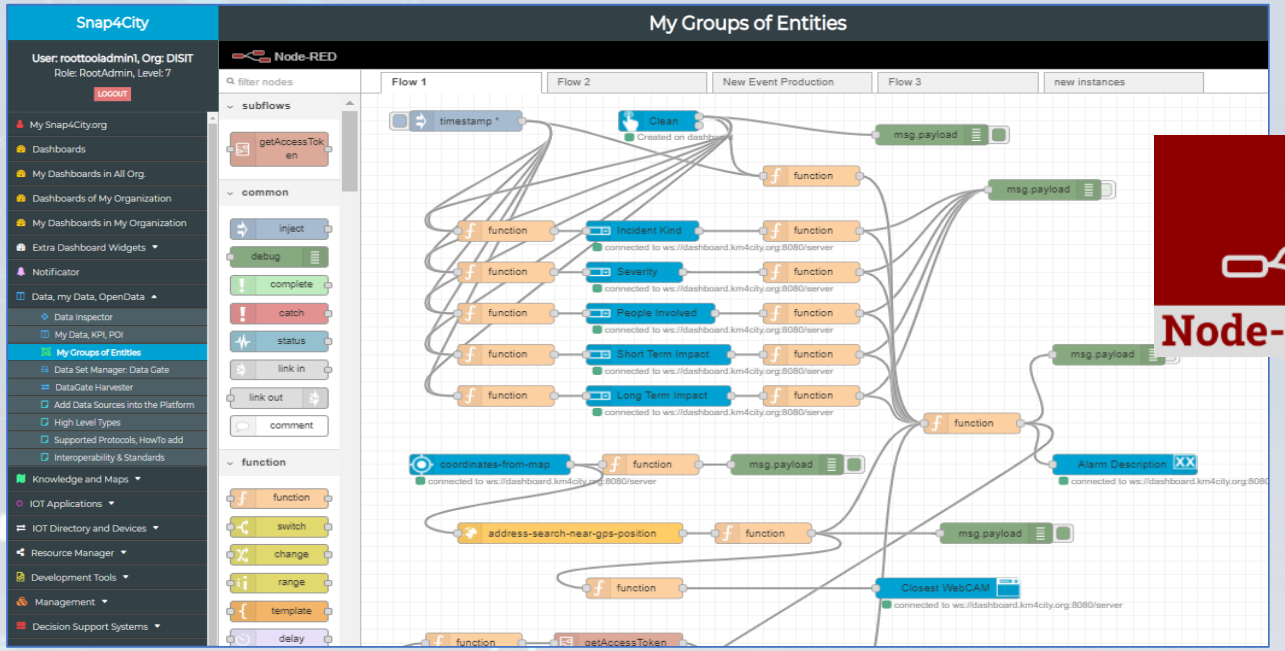
- POI, IOT Devices, shapes,..
  - FIWARE Smart Data Models,
  - IoT Device Models
- GIS, maps, orthomaps, WFS/WMS, GeoTiff, calibrated heatmaps, ..
- Satellite data, ..
- traffic flow, typical trends, ..
- trajectories, events, Workflow, ..
- 3D Models, BIM, Digital Twins, ..
- OD Matrices of several kinds, ..
- Dynamic icons/pins, ..
- Synoptics, animations, ..
- KPI, personal KPI,..
- social media data, TV Stream,
- routing, multimodal, constraints, ..
- decision scenarios, ….
- etc.

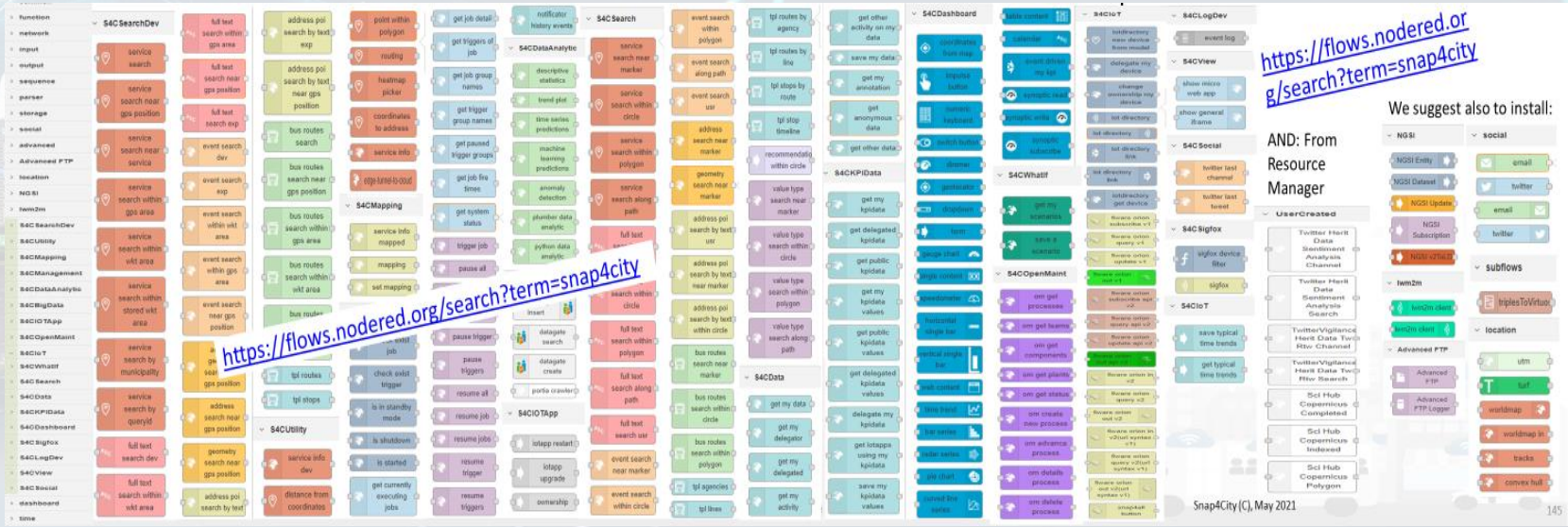




Ingestion, aggreg. → exploitation

- **IoT App Visual Programming, no coding**
  - **Data transformation**
  - **Integration, Interoperab.**
  - **Scripting Data Analytics**
  - **Data ingestion**
  - **Business logic**
- **Edge and Cloud**
- **MicroServices** data driven develop via visual language Node-RED

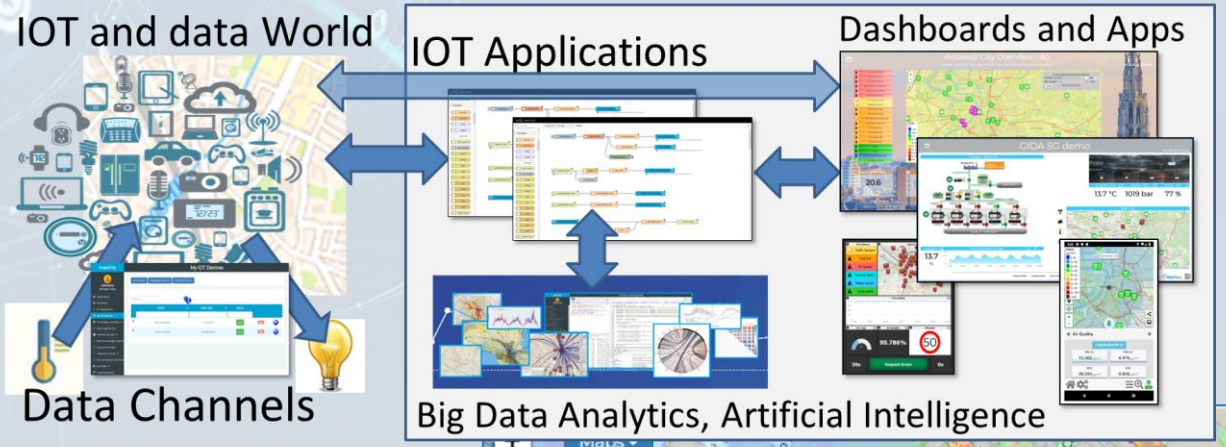


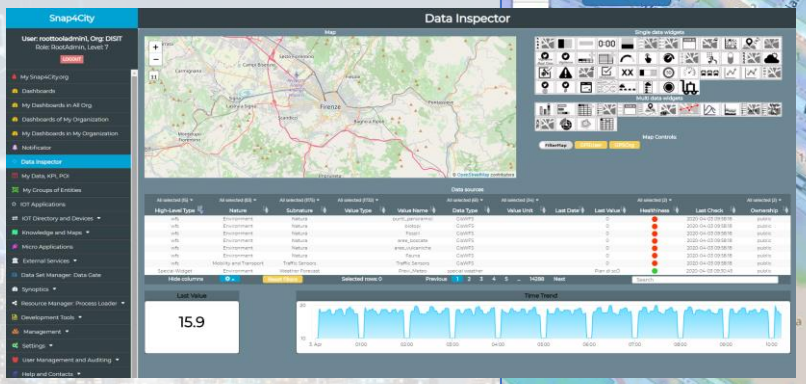


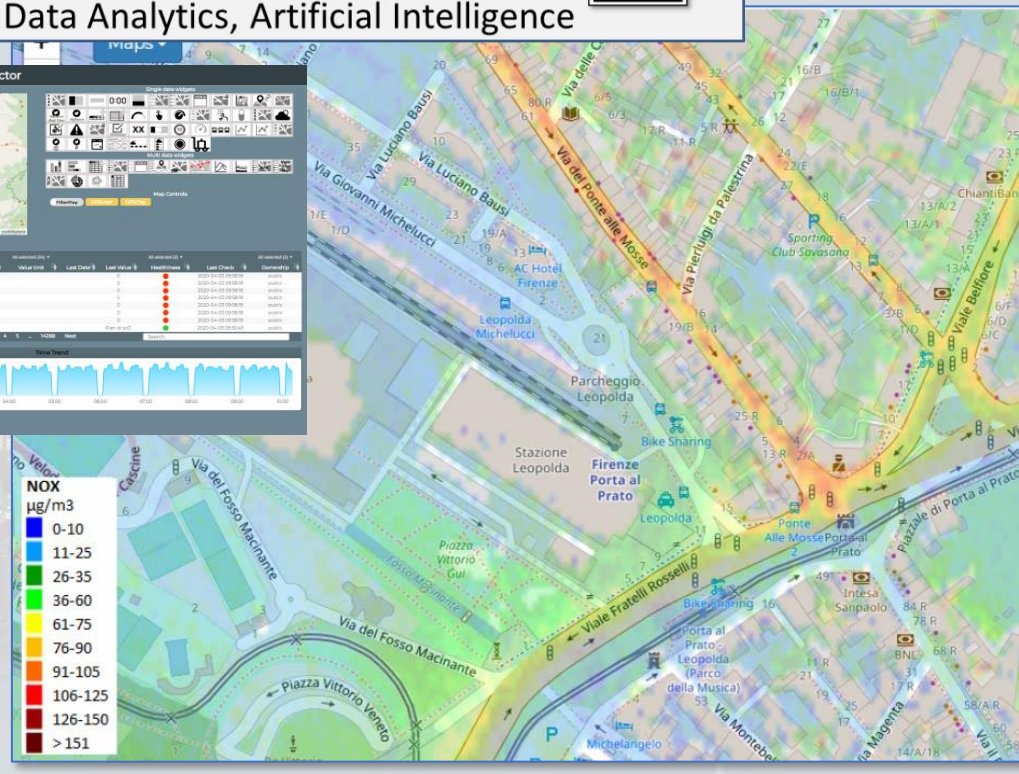
Solutions: reliable, secure and fast to realize

- **Via Snap4City tools**
  - **Dashboard Wizard**
  - **Dashboard Builder**
  - **Data/Visual Analytic**

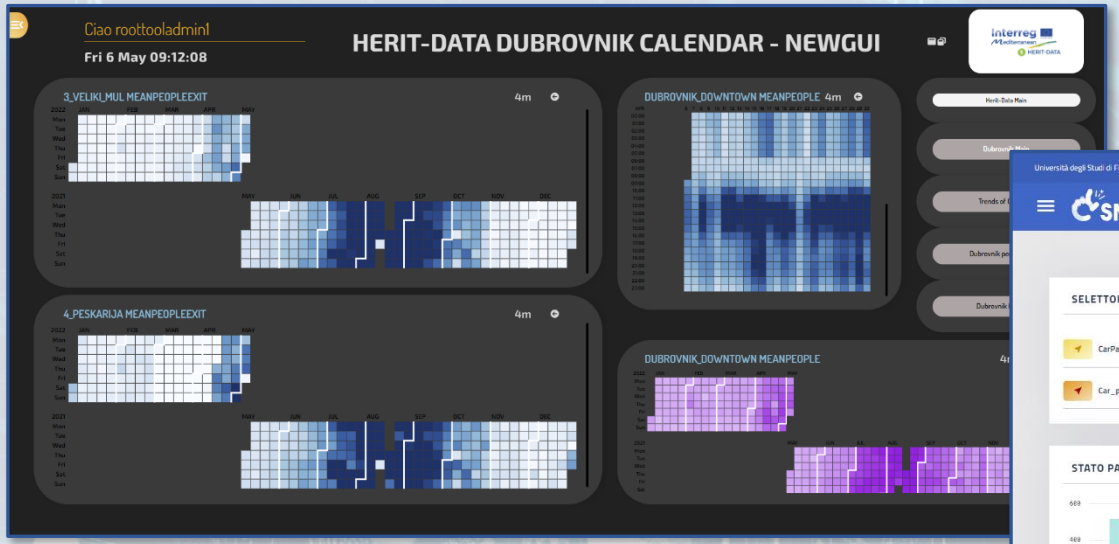
- **Smart Solutions results to be**
  - **Real time data drive**
  - **Secure end-to-end**
  - **GDPR compliant**
  - **Reliable, interoperable**
  - **Auditable, marketable**

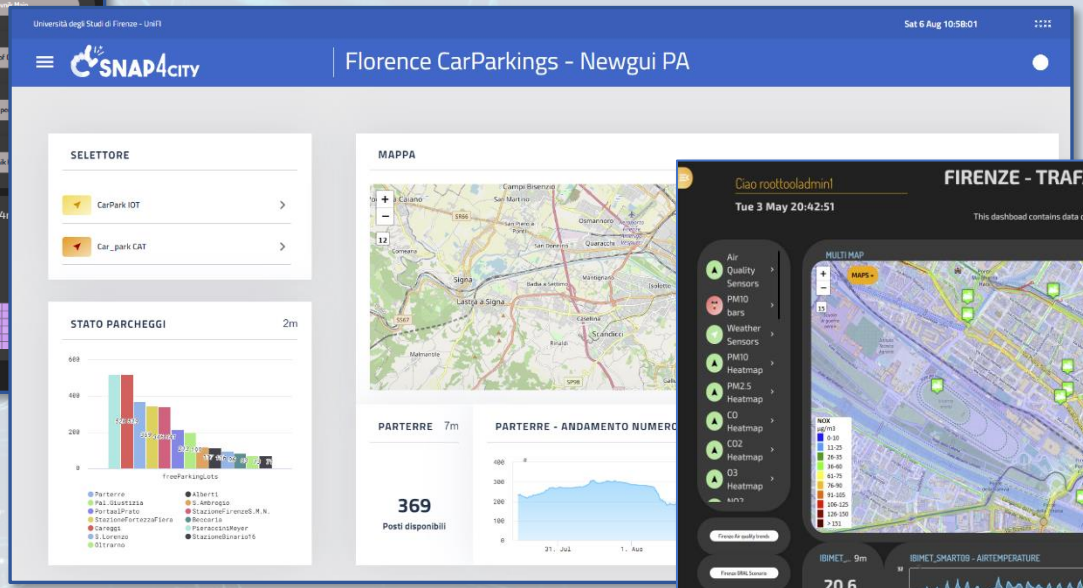


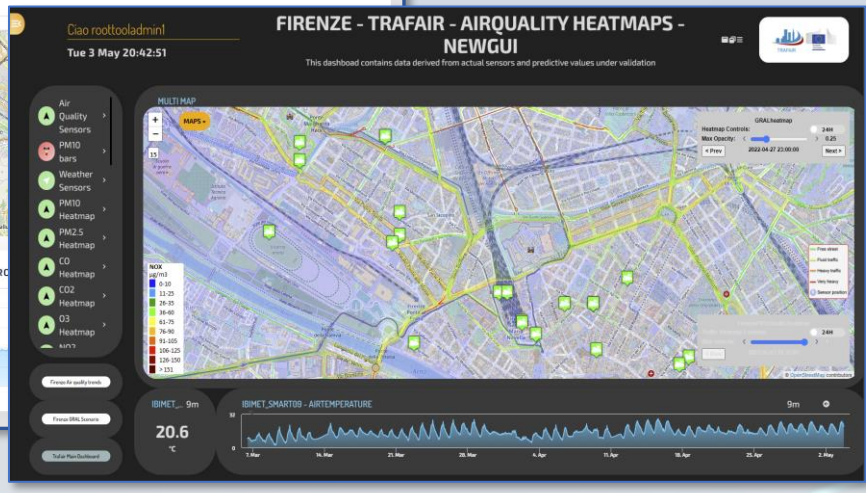


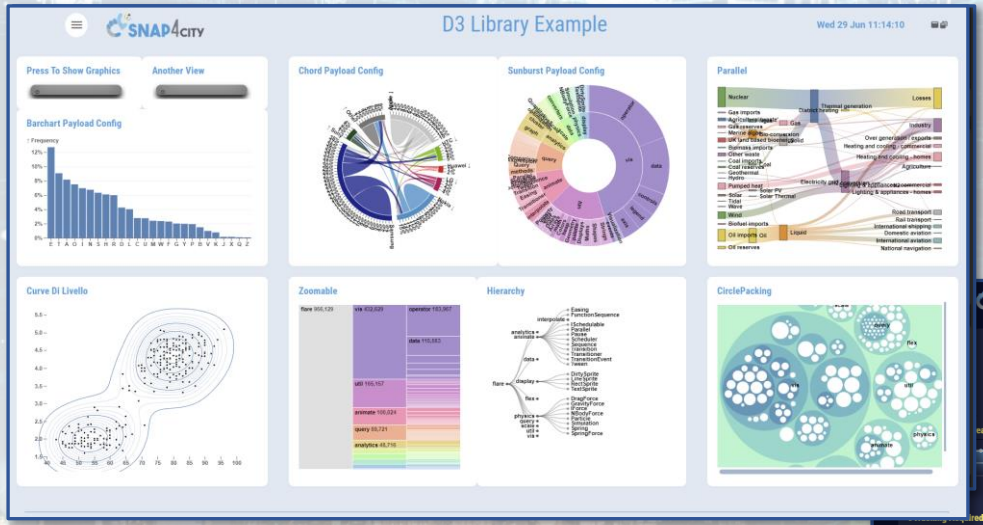


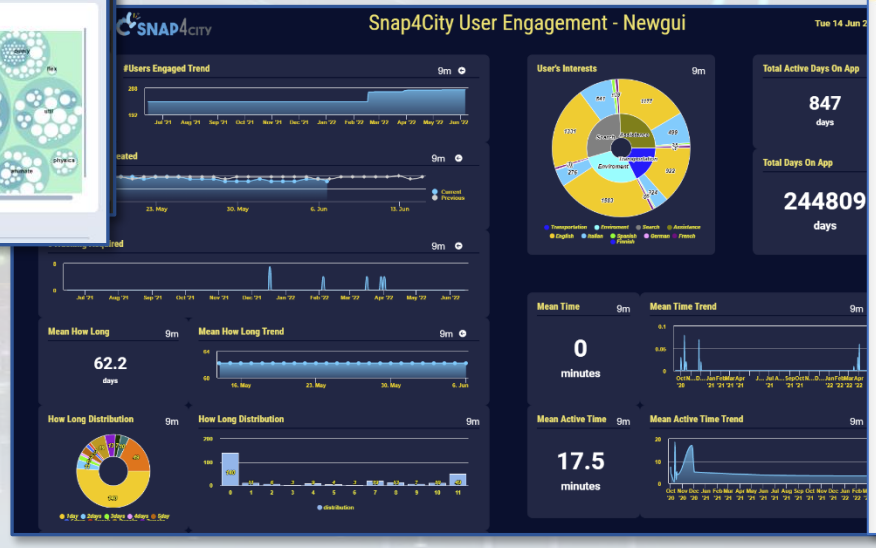
Different Themes

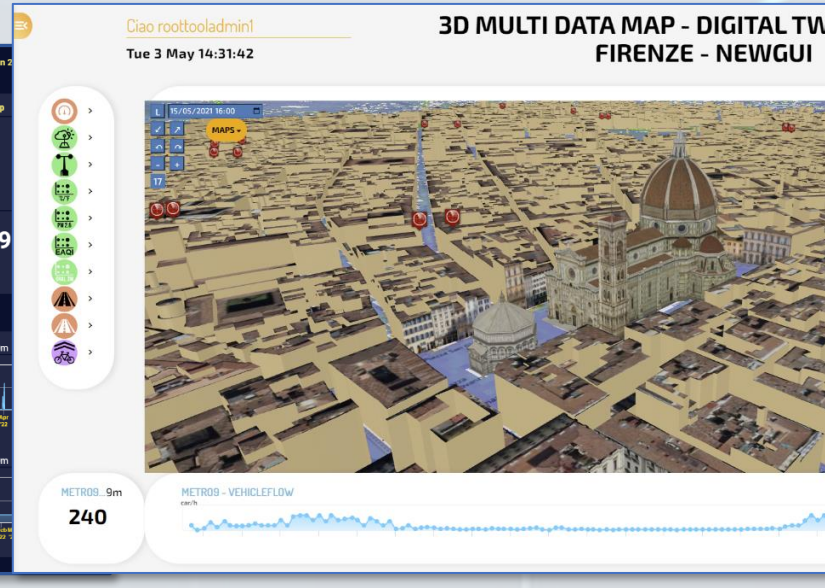






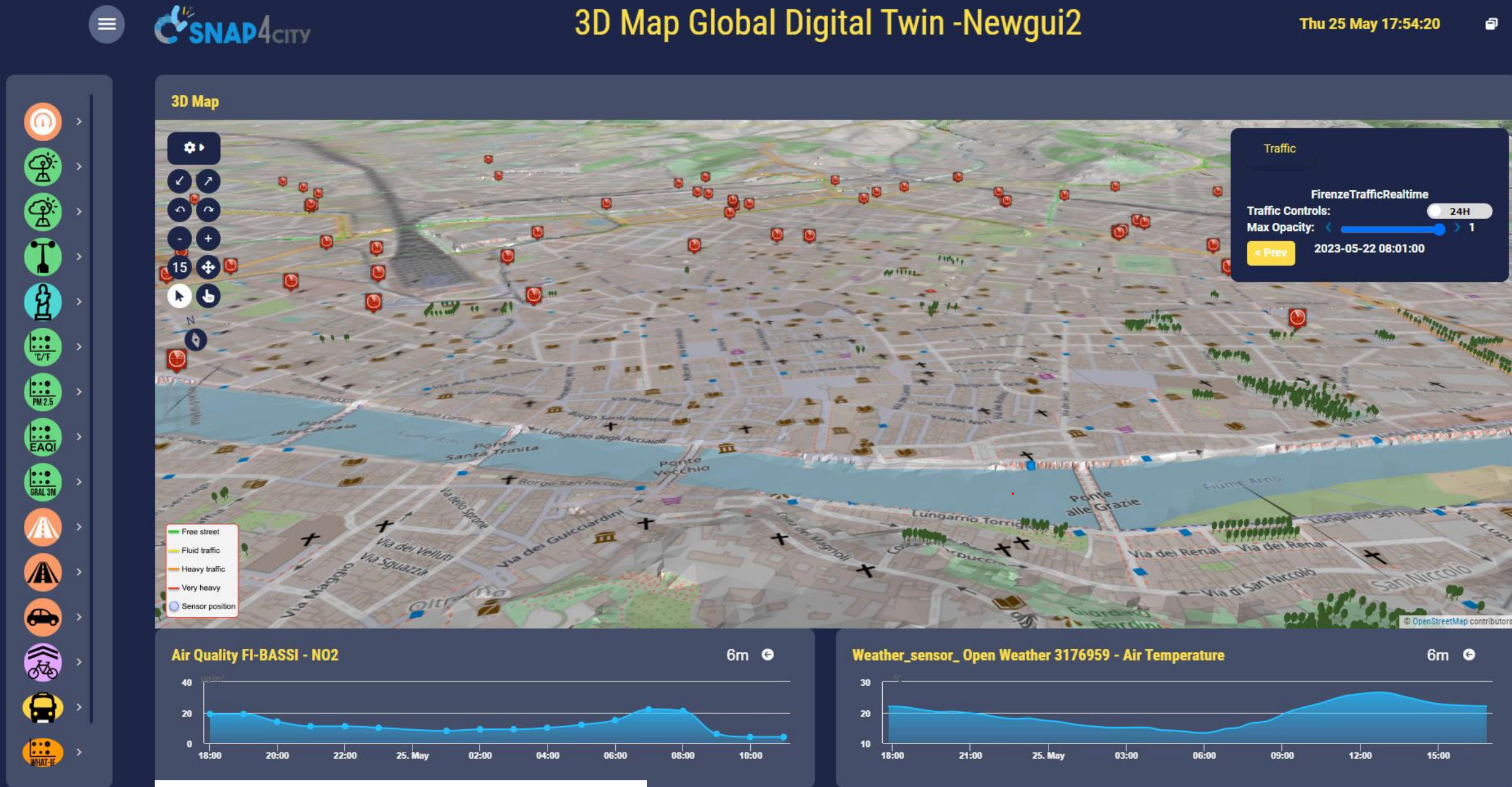




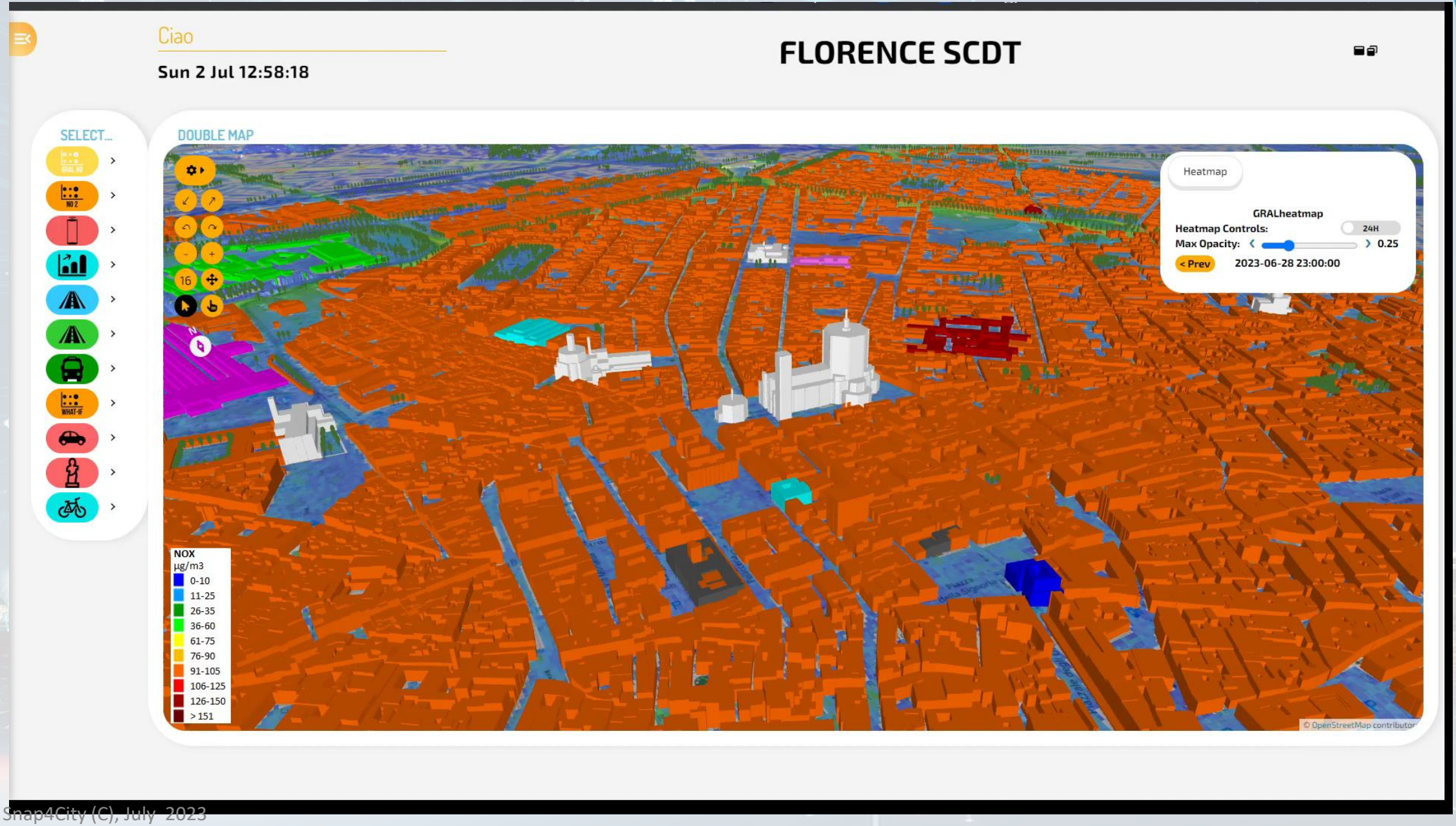


New styles/themes can be developed by specializing a few files from open source

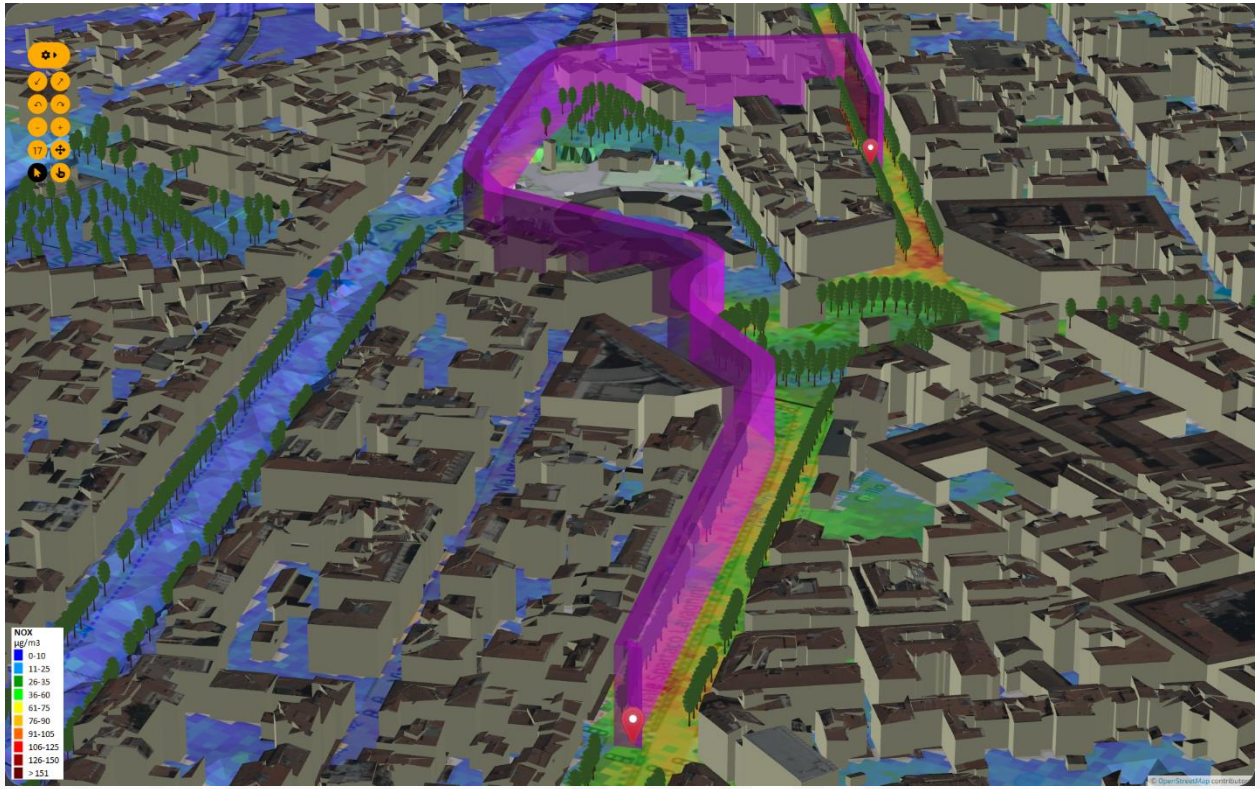
https://www.snap4city.org/793

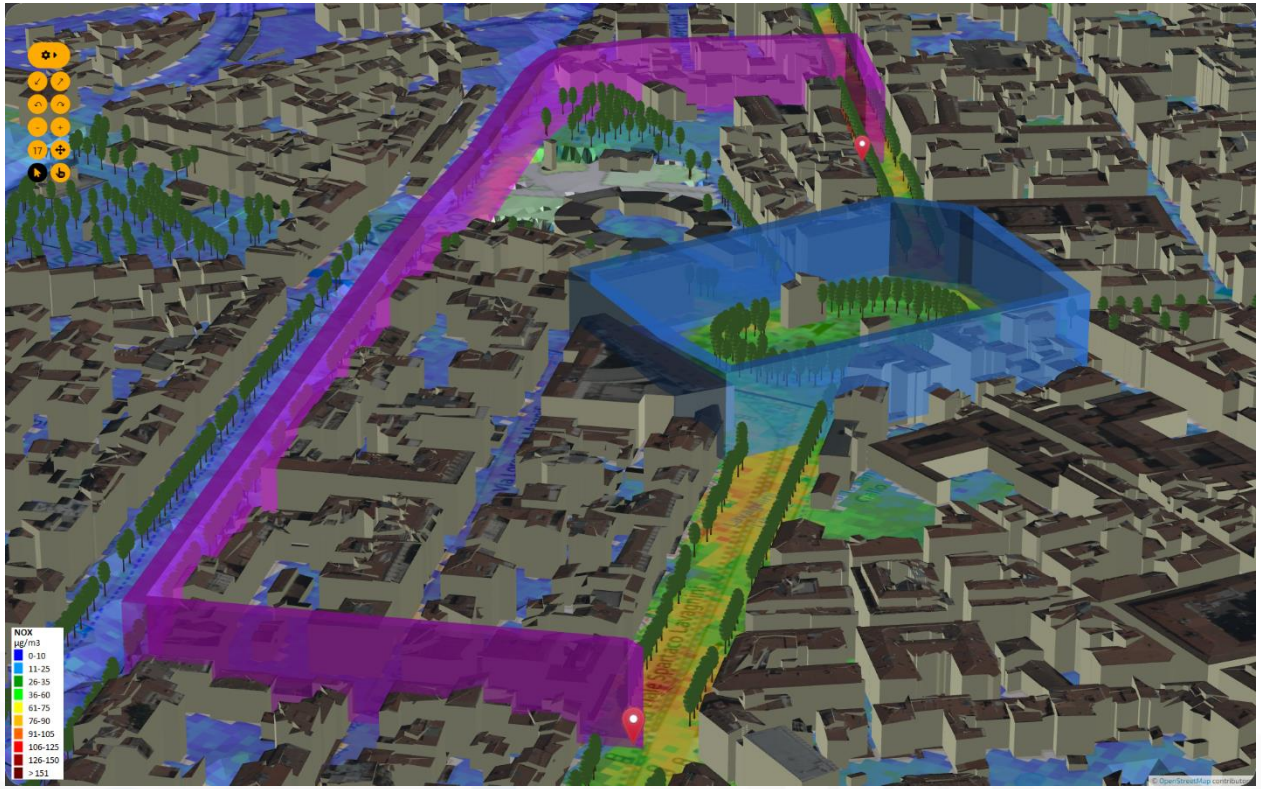


https://youtu.be/JLzT9k3Xbc0


Ciao
Sun 2 Jul 12:58:18
FLORENCE SCDT
SELECT...
DOUBLE MAP
Heatmap
GRALheatmap
Heatmap Controls:
24H
Max Opacity:
0.25
< Prev
2023-06-28 23:00:00
NOX
µg/m3
0-10
11-25
26-35
36-60
61-75
76-90
91-105
106-125
126-150
> 151
© OpenStreetMap contributors

Dyamic Routing in 3D space





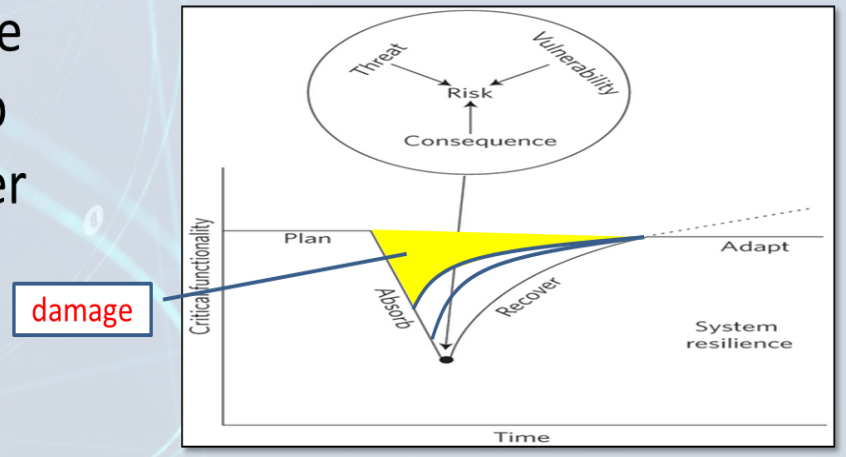
Requirements

	CityGML [3]	Helsinki [19]	Rotterdam [20]	Berlin [21]	Stockholm [22]	Wellington [23]	DUET [24]	Snap4 City (our)
RD1.i	Yes	No	No	No	No	No	Yes	Yes
RD1.ii	Yes (LoD3)	Yes	Yes (LoD2)	Yes (LoD2)	Yes (LoD3)	Yes (LoD3)	Yes (LoD2/LoD3)	Yes
RD1.iii	No	No	No	No	No	Probably	No	Yes
RD2	No	Yes	Yes (C)	Yes (C)	Yes	Yes	Yes	Yes
RD3	No	No	No	Yes	No	Probably	Yes	Yes
RD4	No	Yes (C)	Yes (C)	No (x)	Yes	Yes	No	Yes
RD5	No	No	No	No	Yes	Yes	No	Yes
RD6	Yes	Yes	No	No	Yes	Yes	Yes	Yes
RD7.i	Yes	Yes	No	No	Yes	Yes	Yes	Yes
RD7.ii	Yes	No	No	No	No	Yes	No	No
RI1	No (*)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RI2	No (*)	No	No	No	No	Yes	No	Yes
RI3	No (*)	No	Yes	No	Yes	Yes	No	Yes
RI4.i	Not clear (maybe)	Yes (s)	Yes	Yes	No	Probably	No	Yes
RI4.ii	No	No	No	No	No	Probably	No	No
RI4.iii	No	No	No	No	No	Yes	No	No
RI5	No	No	No	Yes	No	Yes	No	Yes
RI6	No (*)	No	No	No	Yes	No	Yes	Yes
RI7	No (*)	Yes (**)	Yes (**)	No (x)	No	No	No	No
RI8	No	No	No	No	Yes	Yes	No	Yes
RO1	No	No	No	No	No	No	No	Yes
RO2	No	No	No	No	No	No	No	Yes
RO3	No	No	No	No	No	No	No	Yes
RO4	No	No	No (not specified)	No	No (not specified)	No (not specified)	No	Yes
RO5	No	No	No	No	No	No	No	No
RO6.i	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
RO6.ii	n/a	Non-free	Free	Free	Non-free	Non-free	Non-free	Free
RO7	No	Yes	Possible (x)	Possible (x)	Possible	Yes	Possible	Yes
RO8.i	No	Yes	Yes	No	Yes	Yes	Not clear	Yes
RO8.ii	n/a	Non free	Non free	n/a	Non free	Non free	Not clear	Yes

Snap4City Analytics

- Decision support systems
- Improvement of life quality
- Sustainable Solutions
- Reduction of costs
- Risk Assessment
- Resilience

Prepare
Absorb
Recover
Adapt



Data Analytics

System Modeling and Simulation

Knowledge Models

Scenarious

Short Term **Predictions**

Long Term **Predictions**, Typical trends

Recommendations & Prescriptions

What-if Analysis

Anomaly Detection Early Warning

Disaster Recovery

Strategies and Plans

Partial graph

Decision Support System
targeting Indicators: Quality of Life, PUMS, SUMI, KPI, SDG, 15MinIndex,…

indicators

			WHO guidelines	
Pollutant	Averaging period	Objective and legal nature and concentration — Comments	Concentration	Comments
$PM_{2.5}$	One day		25 µg/m³ (*)	99th percentile (3 days/year)
$PM_{2.5}$	Calendar year	Target value, 25 µg/m³ — The target value has become a limit value since 1 January 2015	10 µg/m³	
PM_{10}	One day	Limit value, 50 µg/m³ — Not to be exceeded on more than 35 days per year.	50 µg/m³ (*)	99th percentile (3 days/year)
PM_{10}	Calendar year	Limit value, 40 µg/m³ (*)	20 µg/m³	
O_3	Maximum daily 8-hour mean	Target value, 120 µg/m³ — Not to be exceeded on more than 25 days per year, averaged over three years	100 µg/m³	
NO_2	One hour	Limit value, 200 µg/m³ (*) — Not to be exceeded more than 18 times a calendar year	200 µg/m³ (*)	
NO_2	Calendar year	Limit value, 40 µg/m³	40 µg/m³	

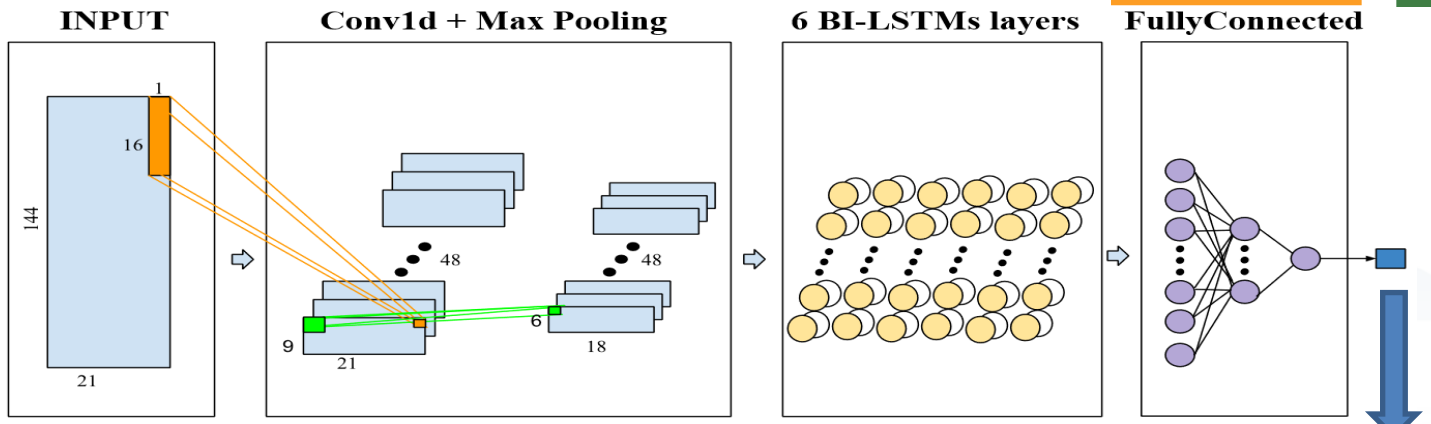
- **United Nations Sustainable Development Goals, SDGs** (for which cities can do more to achieve some of the 17 SDGs, https://sdgs.un.org/goals);
- **15 minutes cities** (where primary services must be accessible within 15 minutes on foot);
- **objectives of the European Commission** in terms of pollutant emissions for: NO2, PM10, PM2.5 (https://environment.ec.europa.eu/topics/air_en);
- **PUMS: mobility and transport vs wnv**
- **SUMI: mobility and transport vs env**
- **ISO indicators: city smartness, digitization. Tech level**
- ….

Global Vs Local

Mobility and Transport

- **Public Transportation**: Ingestion and modelling of GTFS, Transmodel, etc. (DP)
  - Analysis of the **demand mobility vs offer transport** of according to public transportation and multiple data sources (Simulation)
  - Assessing **quality of public transportation** (analysis)
- **Accidents** heatmaps, anomaly detection (analysis, ML)
- **Predictions** for: traffic flow, smart parking, smart bike sharing, people flows, etc. (ML, DL)
- **What if analysis**: routing, traffic flow, demand vs offer, pollutant, etc. (Simulation + ML)
- **Traffic flow reconstruction** from sensors and other sources (simulation + ML)
- **Tracking fleets**, people, via devices: OBU, OBD2, mobile apps, etc. (DP)
- **Routing** and multimodal routing (multistop travel planning), constrained routing, dynamic routing (DA)
- Computing **Origin Destination Matrices** from different kind of data (analysis, DP, DP)
- Computing **typical trajectories** on the basis of tracks (analysis, ML)
- Computing Messages for Connected drive (DP)
- Slow and Fast Mobility **15 Minute City Indexes** (analysis, DP, …ML)
- Computing and comparing traffic flow on devices and at the city border (analysis)
- **Typical time trends** for traffic flow and IoT Time series. (analysis, ML)
- **Impact of COVID-19** on mobility and transport
- Computing **SUMI, PUMS**, etc. (mainly DP)
- Etc.

Short-Term Prediction of City Traffic Flow via Convolutional Deep Learning

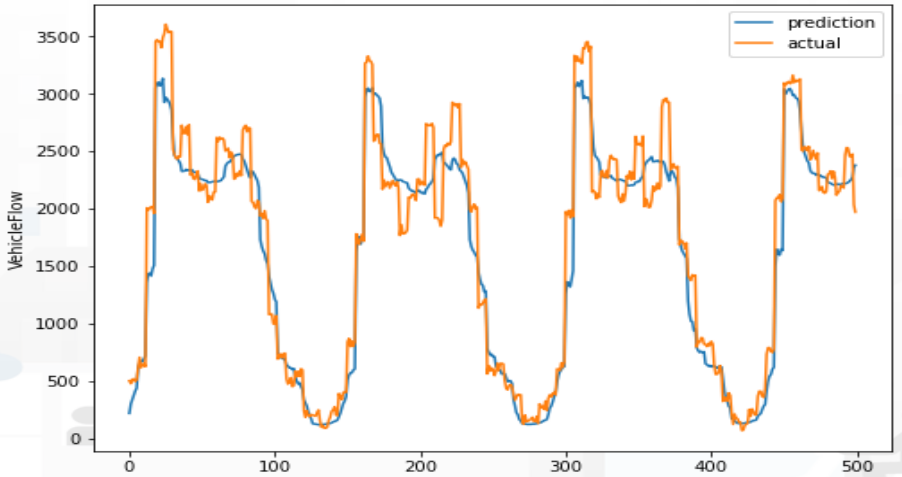


Urban data:

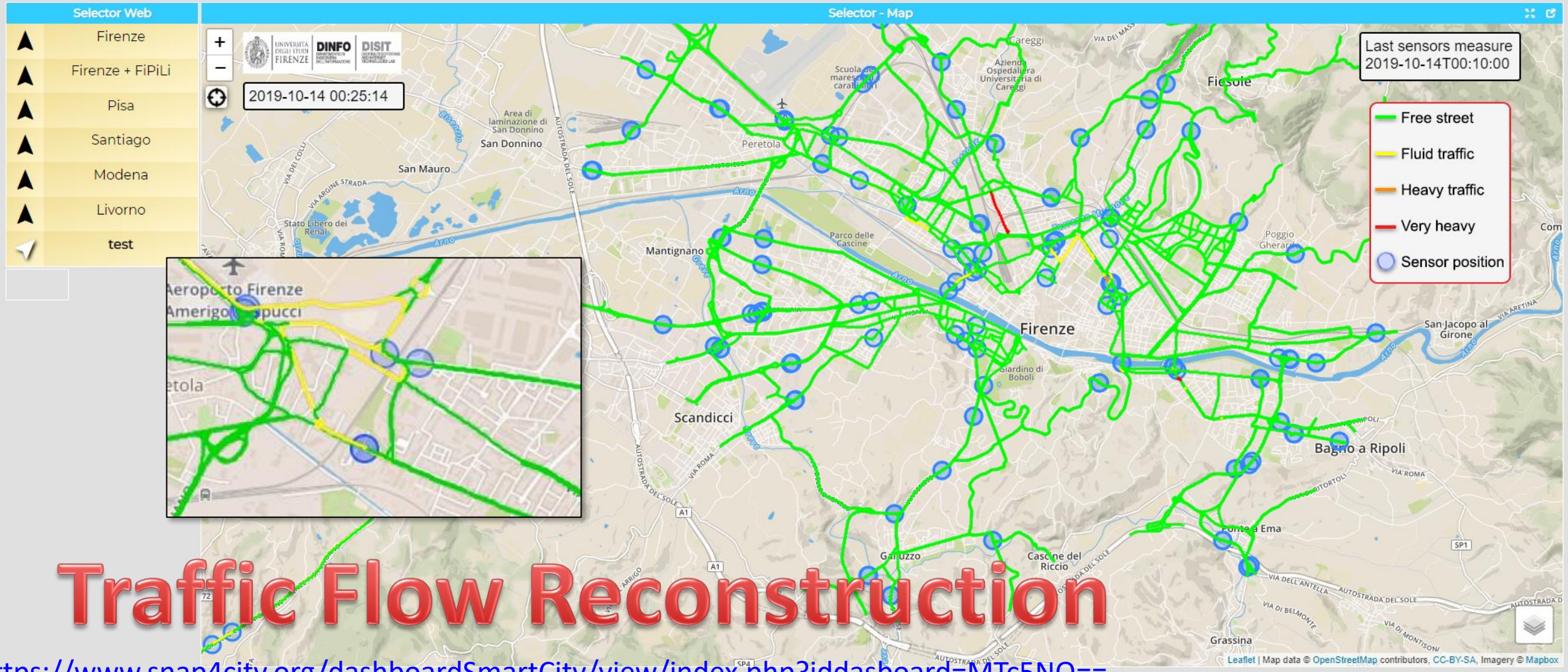
- Date-time
- Traffic
- Temporal
- Seasonality
- Pollution
- Weather

RF
XGBOOST
DNN
LSTM
BI-LSTM
Autoencoder BI-LSTM
Attention CONV-LSTM
CONV-BI-LSTM

CONV-BI-LSTM



Traffic Flow Reconstruction for the cities

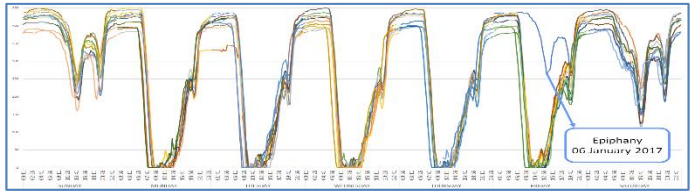


Traffic Flow Reconstruction

https://www.snap4city.org/dashboardSmartCity/view/index.php?iddasboard=MTc5NQ==

Parking predictions

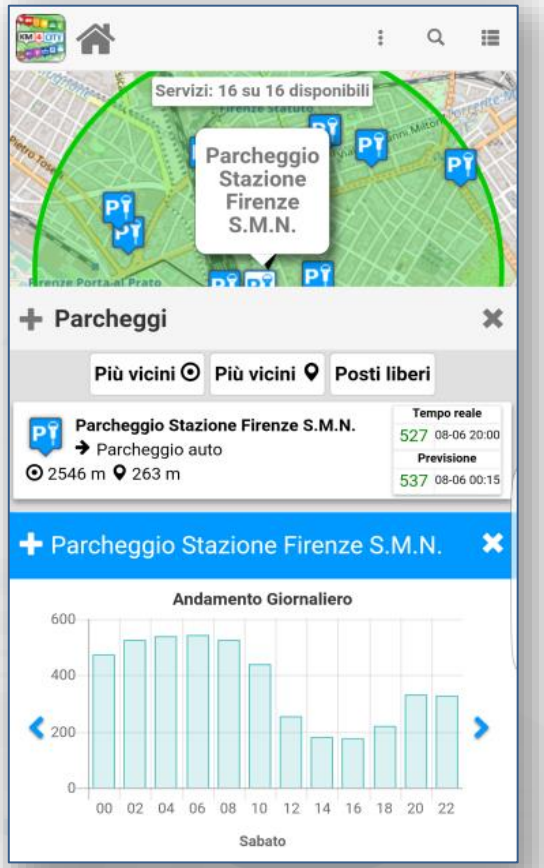
I would arrive to surely Park in 45 Minutes??



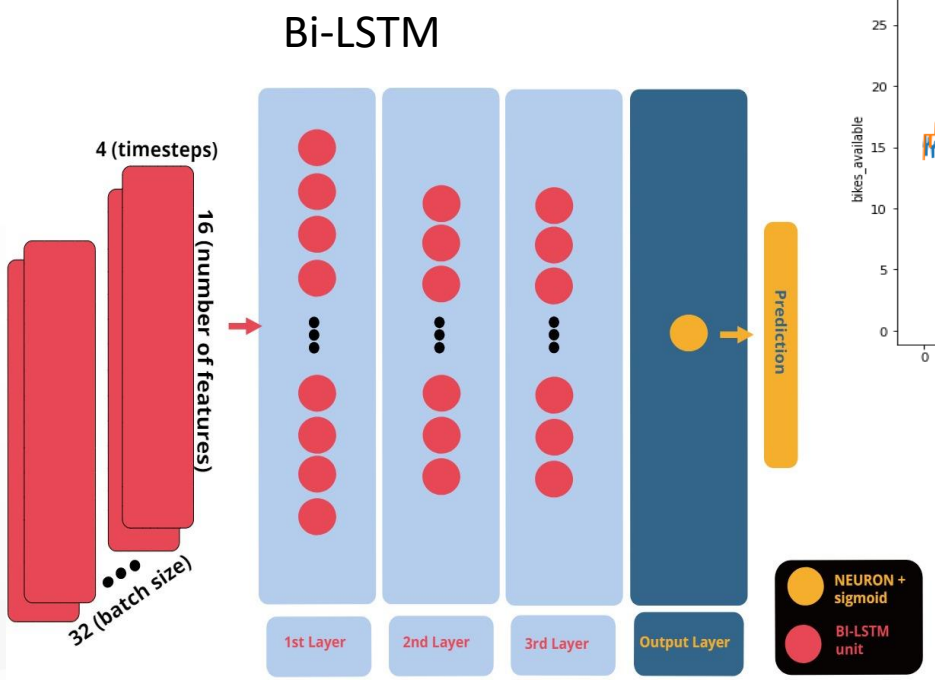
Category	Features	Description of features variable
Baseline features of free slot data	Free parking slots	Real number of available slots recorded every 15 minutes
	Time	Hours and minutes
	Month	Month of the year (1-12)
	Day	Day of the month (1-31)
	Day week	Day of the week (0-6)
	Weekend	0 for working days, 1 else
	Previous observation's difference (POD)	Difference between the number of free spaces at time i and number of free spaces at time (i − 15 minutes) recorded in the previous week
	Subsequent observation's difference (SOD)	Difference between the number of free spaces at time i, and the number of free spaces at time (i + 15 minutes) recorded in the previous week
Weather features	Temperature	City temperature measured one hour earlier than Time (°C)
	Humidity	City humidity measured one hour earlier than Time (%)
	Rainfall	City rainfall measured one hour earlier than Time (mm)
Traffic Sensors features	Average Vehicle Speed	Average speed of vehicles on the road being closest to the parking, over one-hour period (km/h)
	Vehicle Flow	Number of vehicles passing by closest to the parking, over one-hour period
	Average Vehicle Time	Average of distance between vehicles, over one-hour period
	Vehicle Concentration	Number of vehicles per kilometer, over one-hour period

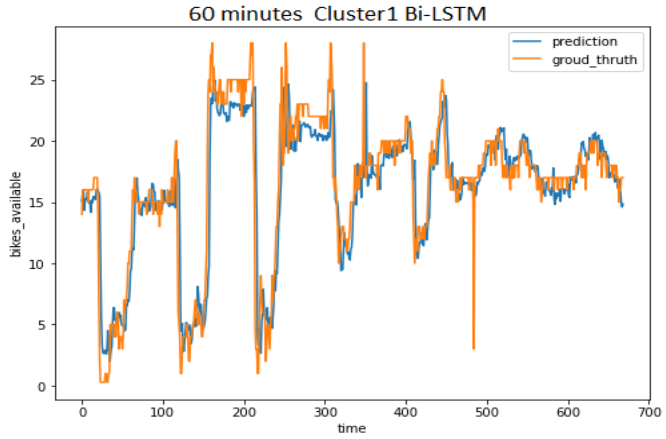
Artificial Intelligence Predictions

97% of precision



Deep Learning for Short-Term Prediction of Available Bikes on Bike-Sharing Stations



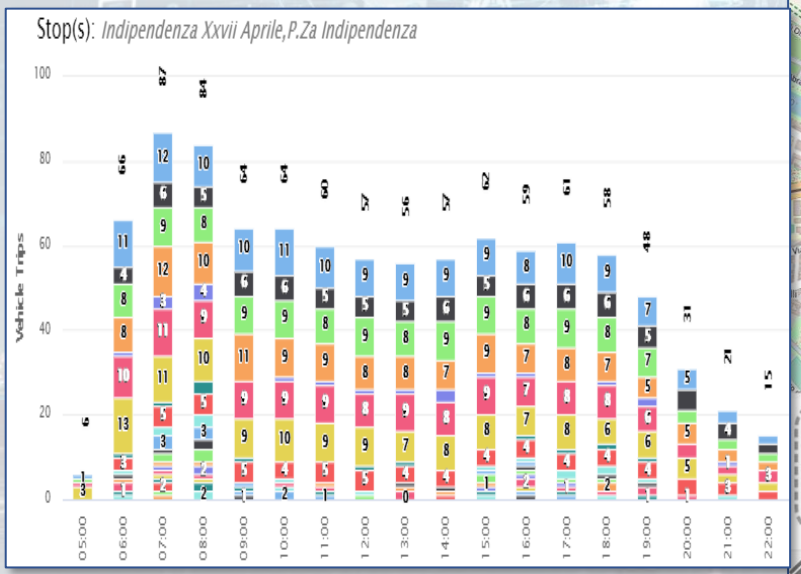


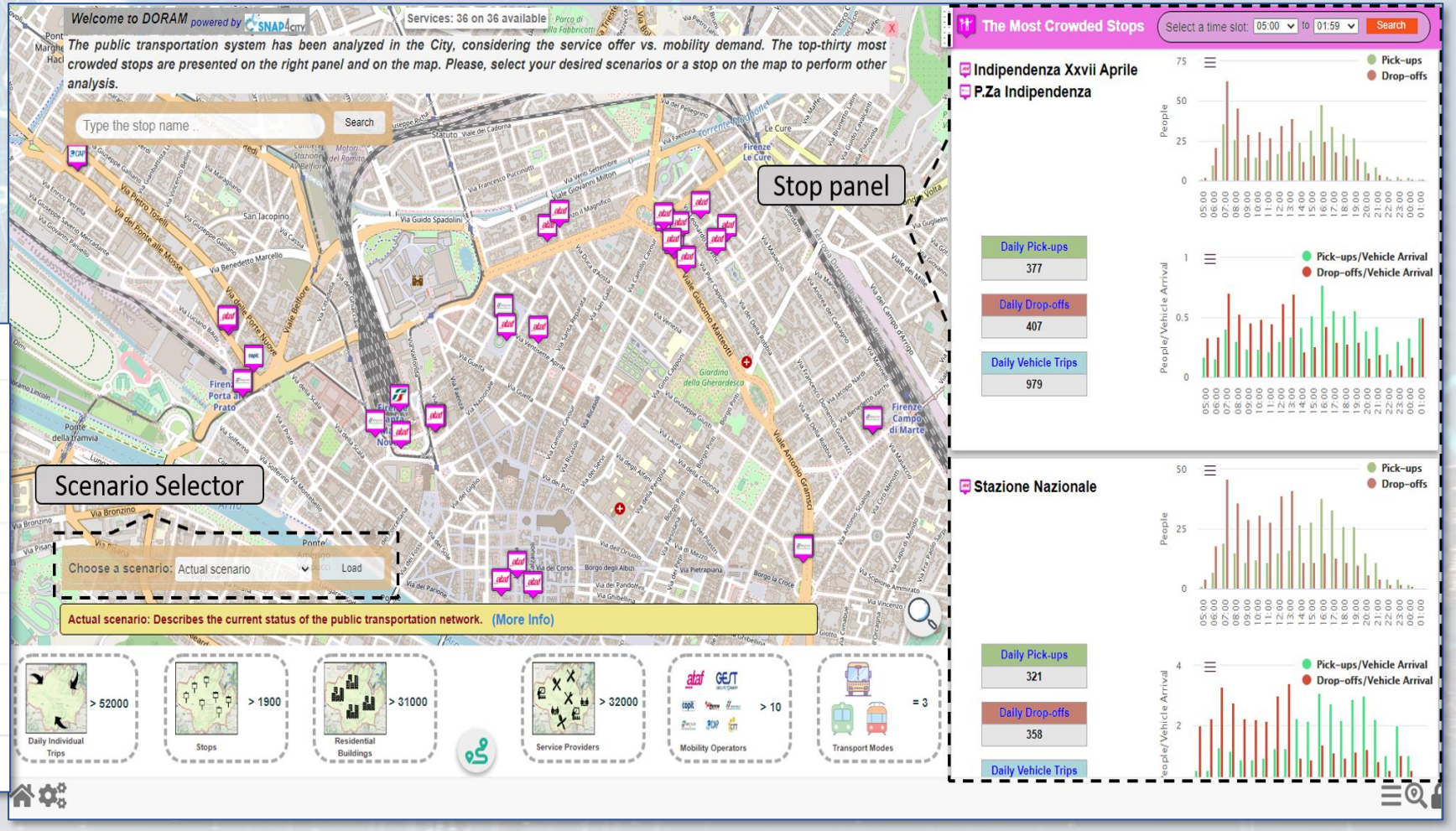
E. Collini, P. Nesi and G. Pantaleo, "Deep Learning for Short-Term Prediction of Available Bikes on Bike-Sharing Stations," in *IEEE Access*, vol. 9, pp. 124337-124347, 2021, doi: 10.1109/ACCESS.2021.3110794.
https://ieeexplore.ieee.org/abstract/document/9530580

What-if Analysis on Pub Transport

- Definition of scenarious impact on
  - Traffic, Pollutant, parking, public transport, private flows, etc.
  - KPI analysis

Public Services





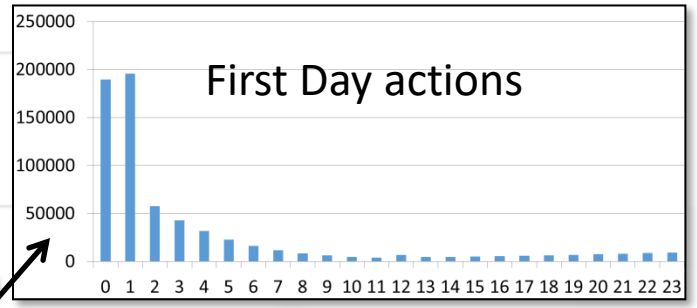
City Users Behavior and Social Analysis

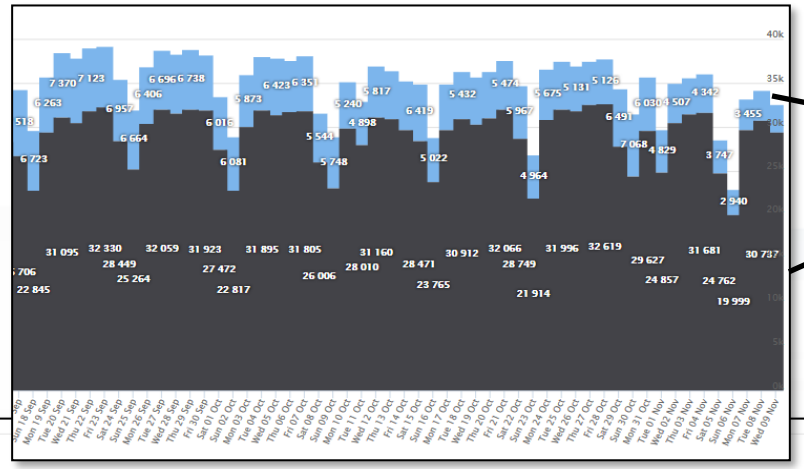
- **People detection and classification**: persona, strollers, bikes, etc. (ML, DL)
- **people counting** and tracking, head counting (via thermal cameras, ML, DL)
- **People flows prediction** and reconstruction, (ML, DL)
  - Wi-Fi data, mobile apps data, Mobile Data, etc.
- **User's behaviour analysis**, **People flow analysis** from PAX Counters and heterogenous data sources (ML, AI)
  - origin destination matrices, hot places, time schedule,
  - Recency and frequency, permanence, typical trajectory, etc.
- **Computing User engagement and suggestions** for sustainable mobility (Rule Based, ML)
- **Social media analysis** on specific channel, specific keywords: see Twitter Vigilance,
  - Reputation, service assessment: MultiLingual NLP and Sentiment Analysis, SA
  - Tweet proneness, retweet-ability of tweets, impact guessing
  - Audience predictions on TV channels and physical events, locations
  - Prediction of attendance of events and on attractions
- **Virtual Assistant construction, LLM, NLP, Sentiment Analysis (DL, NLP)**
- **15 Minute City Index** , etc. (modeling and computability)
- Computing SDG, etc., (DP)
- Etc.

User Behaviour Analysis

Distinct APs: 343
Distinct APs (last 24 hours): 311
Distinct Users (last 180 days): 1102098
Distinct Excursionists (last 180 days, < 24 h): 687025

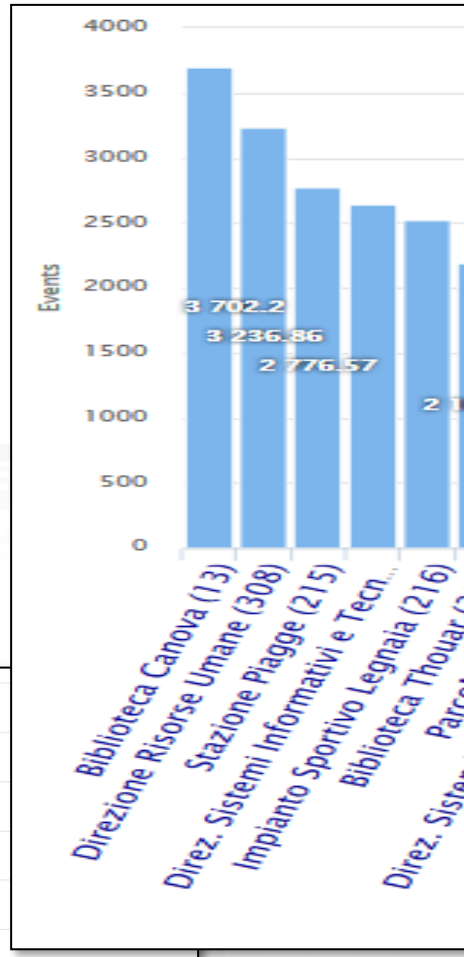
Excursionists



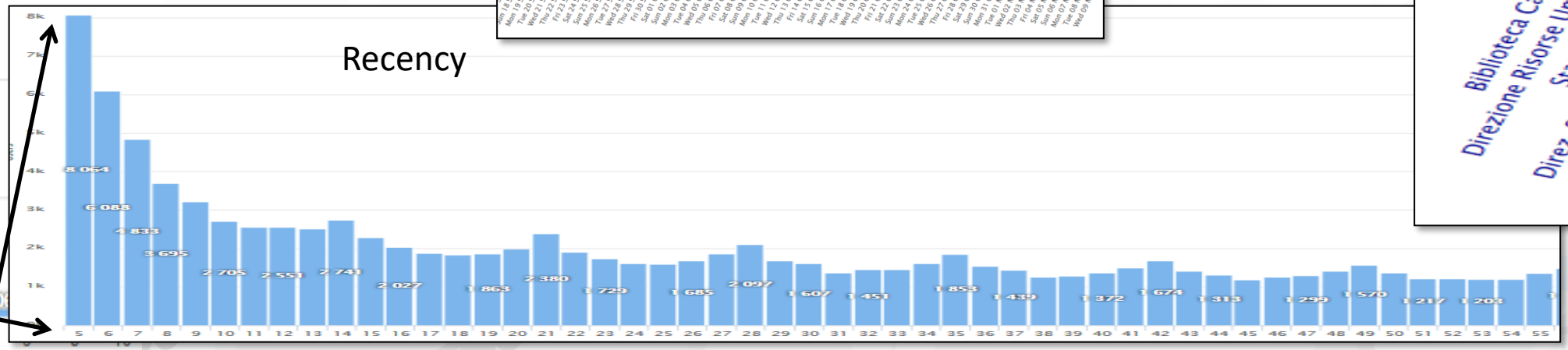


New City Users
VS
Returning

Where



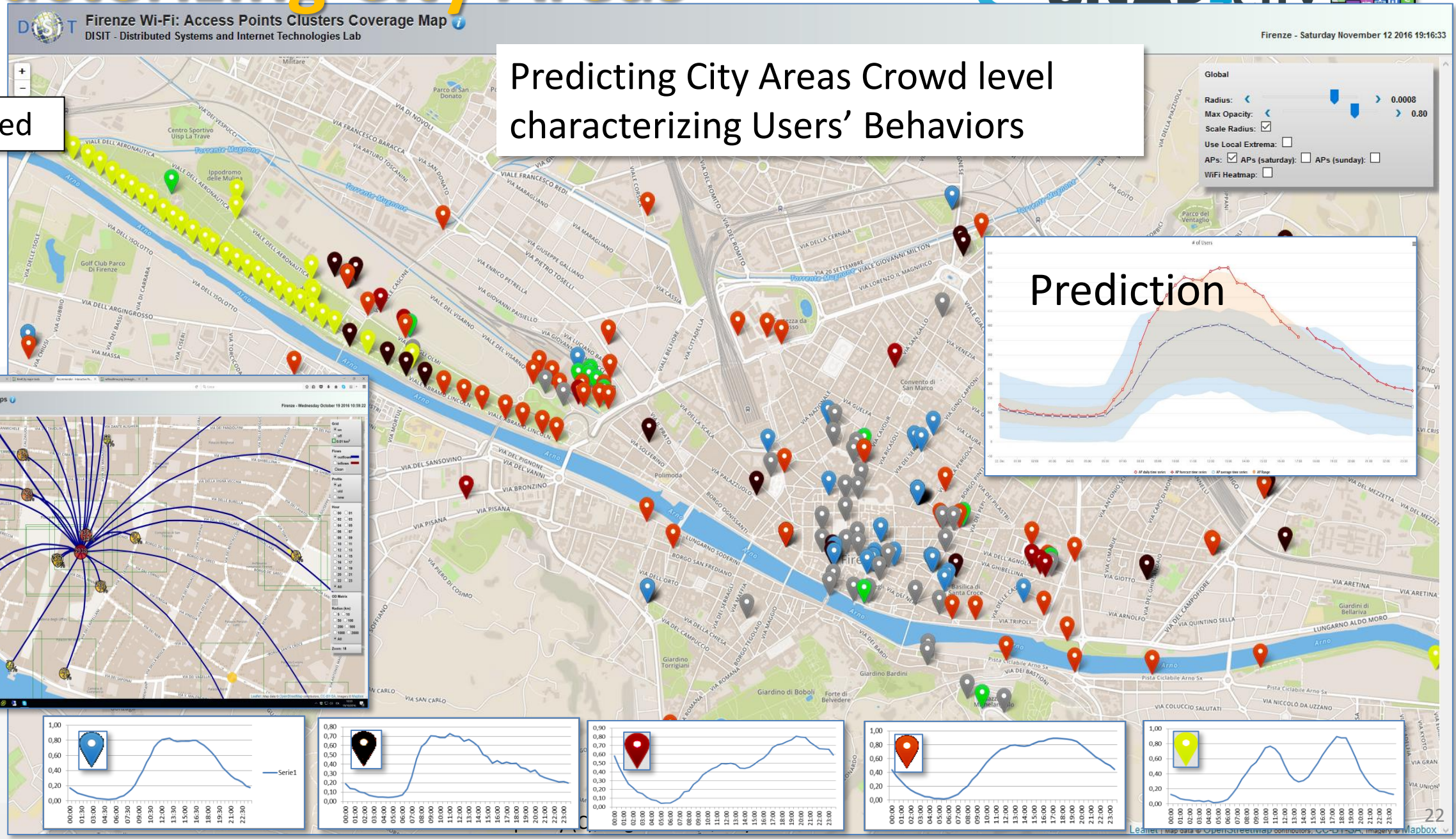
Recency



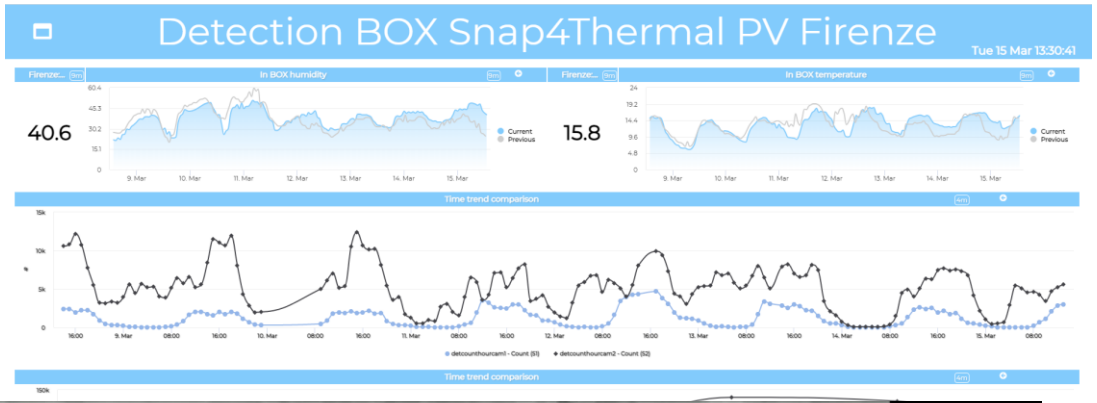
Characterizing City Areas

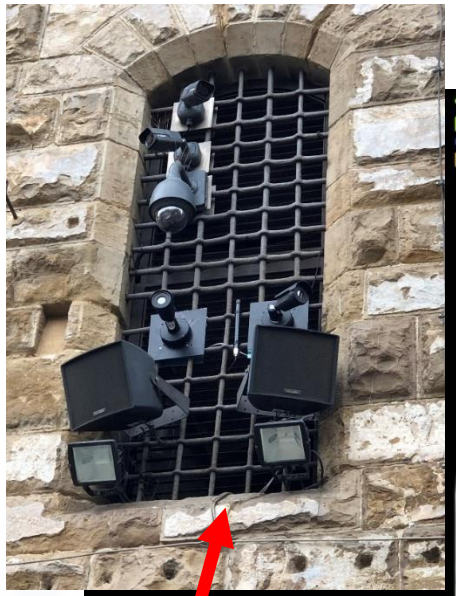
Wi-Fi based

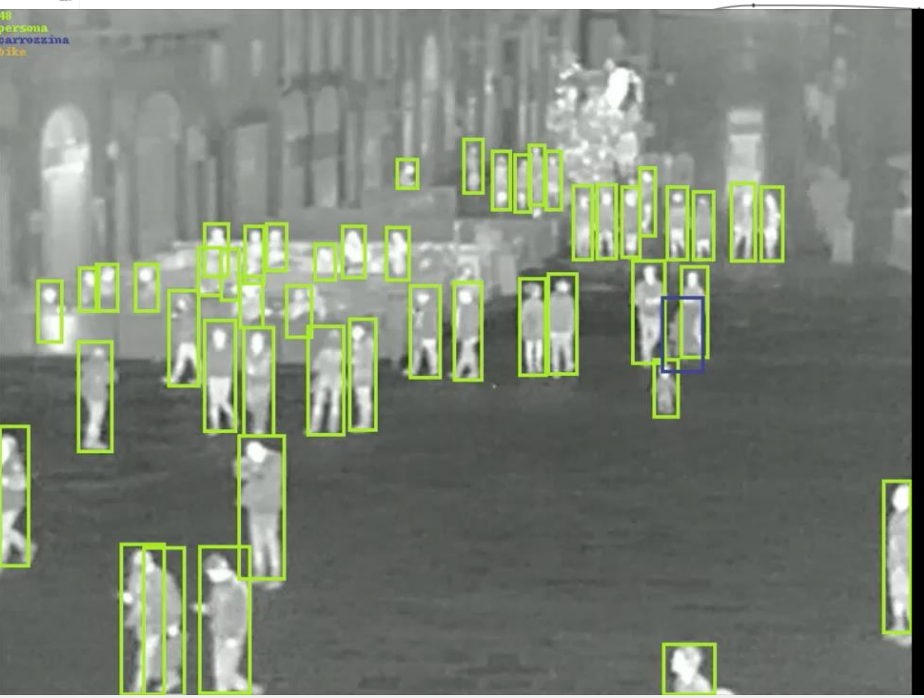
Predicting City Areas Crowd level characterizing Users' Behaviors



A view and data from the Thermal Camera







11 SUSTAINABLE CITIES AND COMMUNITIES

Environment and Weather

- **Pollutant Predictions: short, long and very long term** European Commission KPIs
  - NOX, PM10 pollution on the basis of traffic flow, 48 hours (ML, AI, DL)
  - Cumulated NO2 average value over the year, ……. (ML, AI, DL)
- **Computation of CO2** on the basis of traffic flows (DP), computing emission factor (DA)
  - each road for each time slot of the day
- **Prediction of MicroClimate** conditions for diffusion (ML, AI)
  - NO2, PM10, PM2.5, etc.
- **Prediction of landslides**, 24 hours in advance (AI, DL)
- **Heatmaps production**, dense data interpolation (DP) for
  - Weather conditions: temperature, humidity, wind, DEW
  - Pollutants and Aerosol: NO, NO2, CO2, PM10, PM2.5, etc.
- **Impact of COVID-19** on Environmental aspects (DP)
- Optimisation of **waste collection** schedule and paths (DP, ML)
- Computing **SDG, SUMI, PUMS**, .. (mainly DP)
- Etc.

Environment and Quality of Life
Air Quality Predictions

Cities of: Firenze, Pisa, Livorno

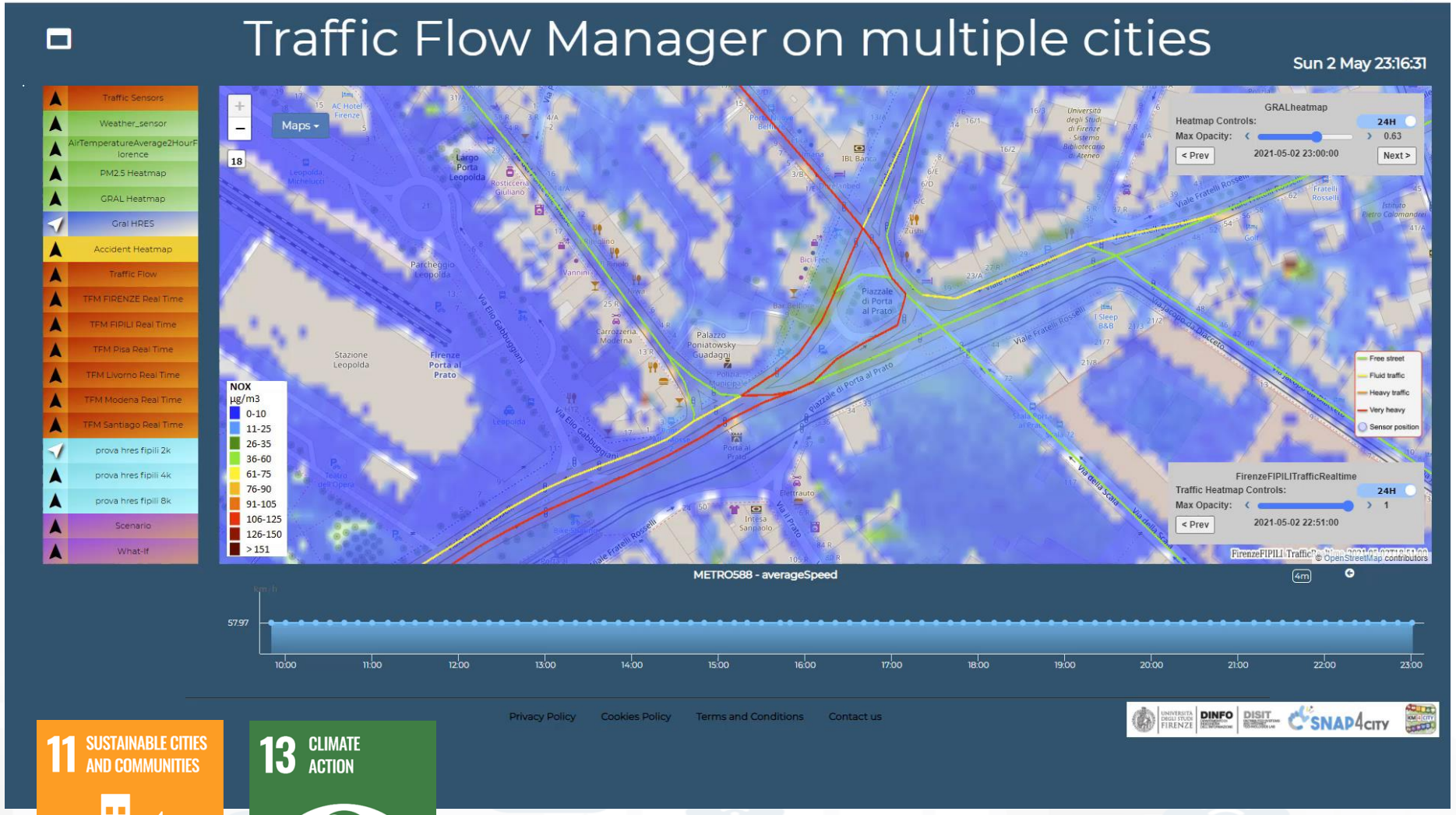
reference

- **Multiple Domain Data**
  - Traffic Flow data, Pollutant: NOX, CO2, PM10, PM2.5, O3, ….
  - 3D City structure, weather, …
- **Multiple Decision Makers**
  - Pollutant Predictions: NOX, NO2, ..
  - City officers, energy industries
  - Dashboards, What-IF analysis
  - Traffic Flow Reconstruction
- **Historical and Real Time data**
  - Billions of Data
- **Services Exploited on:**
  - Dashboards, Mobile App
- **Since 2020**

		Air Quality Directive		WHO guidelines	
Pollutant	Averaging period	Objective and legal nature and concentration	Comments	Concentration	Comments
$PM_{2.5}$	One day			25 µg/m³ (*)	99th percentile (3 days/year)
$PM_{2.5}$	Calendar year	Target value, 25 µg/m³	The targe… …come a …value …ry 2015	10 µg/m³	
PM_{10}	One day	Limit …e, 50 µ…	…t to be e…ed on more …han 35 d…s per year.	50 µg/m³ (*)	99th percentile (3 days/year)
PM_{10}	Calend…	…va… 40 µg/m… (*)		20 µg/m³	
O_3	Maximum …ly 8-hour m…n	Target value, 120 µg/m³	Not to be exceeded on more than 25 days per year, averaged over three years	100 µg/m³	
NO_2	One hour	Limit value, 200 µg/m³ (*)	Not to be exceeded more than 18 times a calendar year	200 µg/m³ (*)	
NO_2	Calendar year	Limit value, 40 µg/m³		40 µg/m³	

KPI of EC

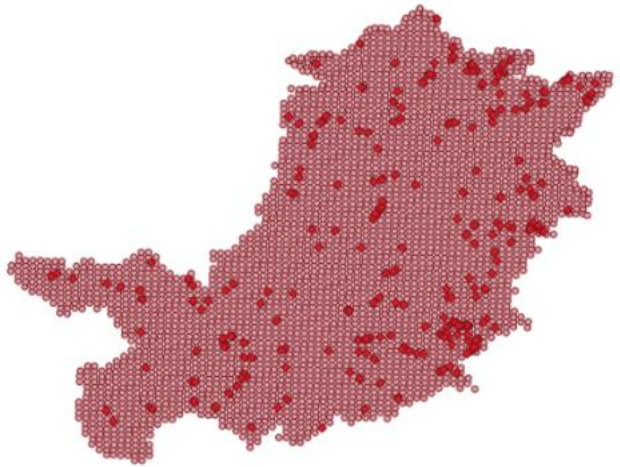
- **Prediction**
  - **NOX Pollutant** diffusion on the basis of Traffic Flow (prediction), weather and 3D structure
  - **NO2 progressive average** (Long term)
- **Project:**
  - **Trafair** CEF EC
  - Mixed solutions of Fluidinamics modeling and AI

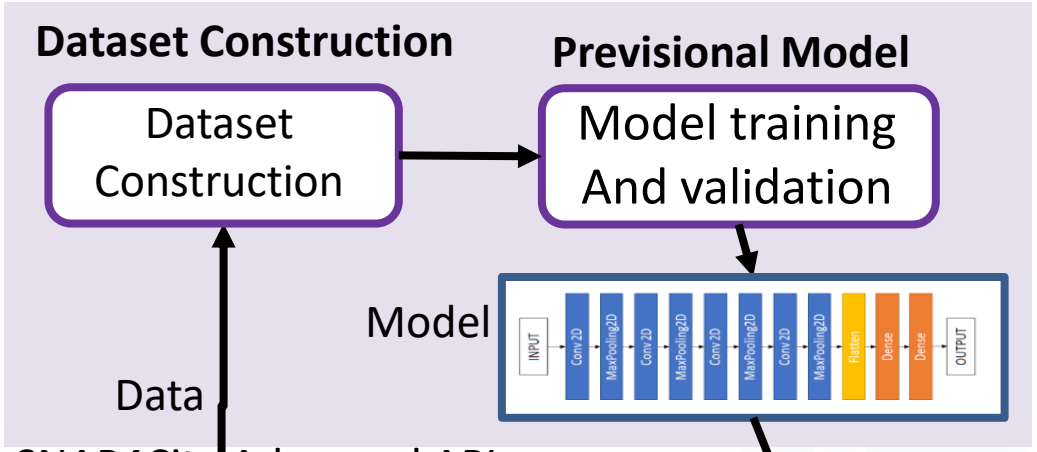


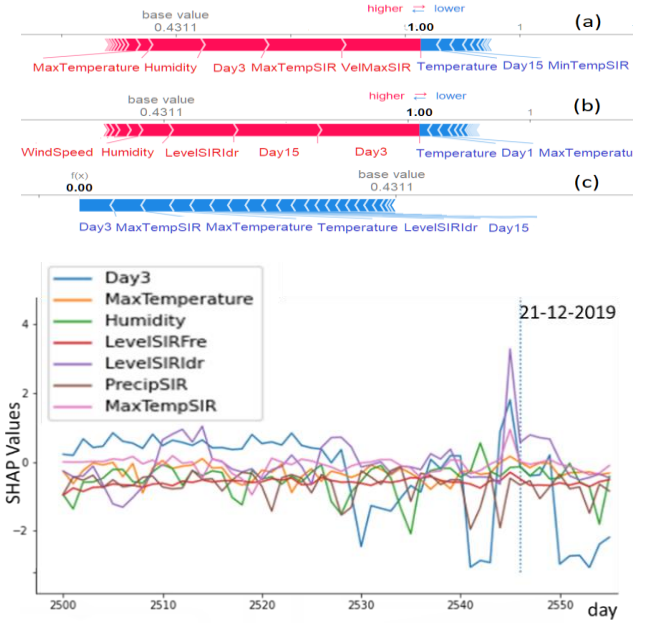
11 SUSTAINABLE CITIES AND COMMUNITIES

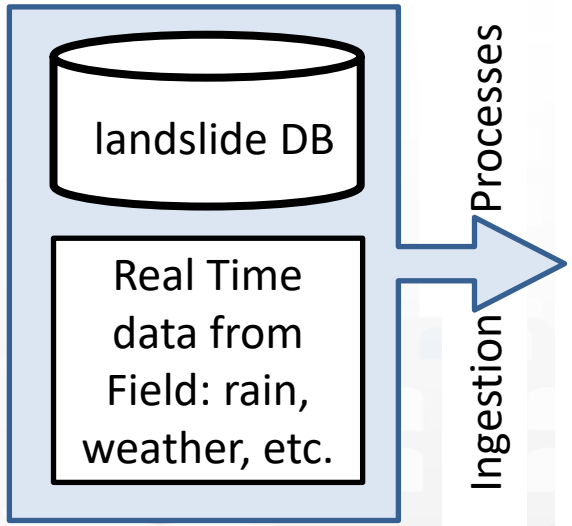
13 CLIMATE ACTION

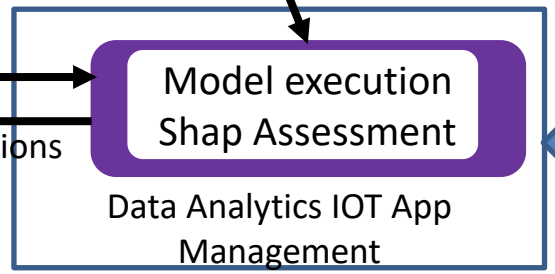
Predicting Land slides

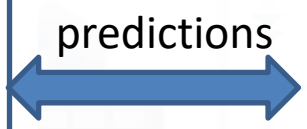








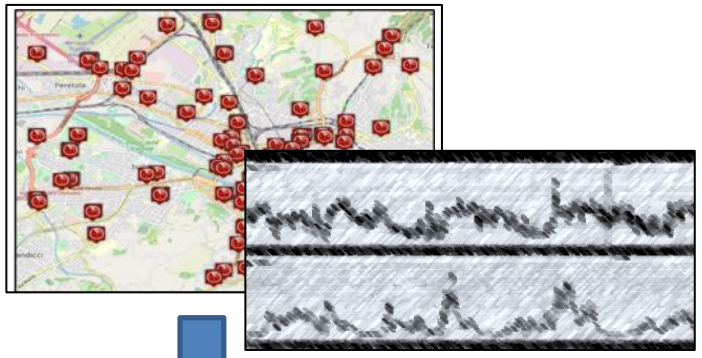




Snap4City Servers and Tools: Dashboard manager, Heatmap manager, GeoServer, Smart City API.

E. Collini, L. A. I. Palesi, P. Nesi, G. Pantaleo, N. Nocentini and A. Rosi, "Predicting and Understanding Landslide Events with Explainable AI," in *IEEE Access*, doi: 10.1109/ACCESS.2022.3158328.
https://ieeexplore.ieee.org/abstract/document/9732490

Estimating City Local CO2 from Traffic Flow Data



Computing Traffic Flow into CO2 sensor area

Traffic Flow data

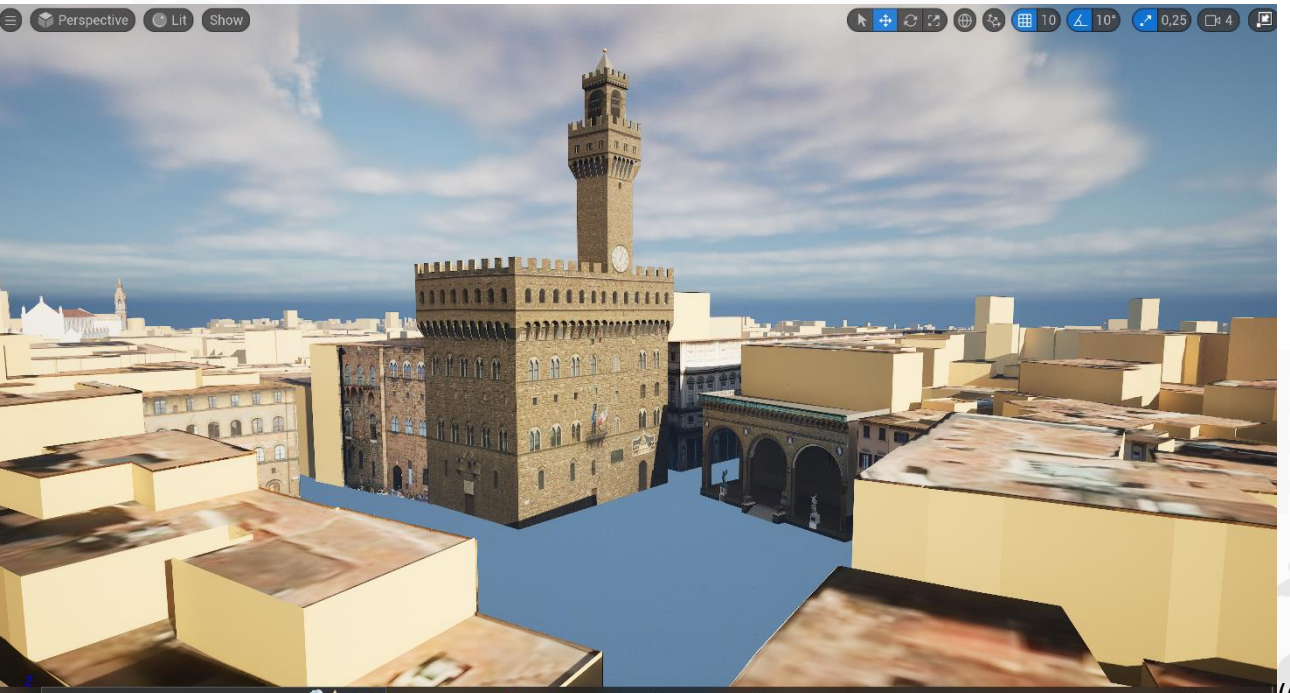
- Traffic Flow is one the main source of CO2
  - K1: Fluid Flow
  - K2: Stop and Go
- **Dense estimation of CO2 into the city** is very useful to know to target EC's KPIs

Computing CO2 on the basis of traffic flow data

CO2 estimation

S. Bilotta, P. Nesi, "Estimating CO2 Emissions from IoT Traffic Flow Sensors and Reconstruction", Sensors, MDPI, 2022. https://www.mdpi.com/1424-8220/22/9/3382/

OCULUS

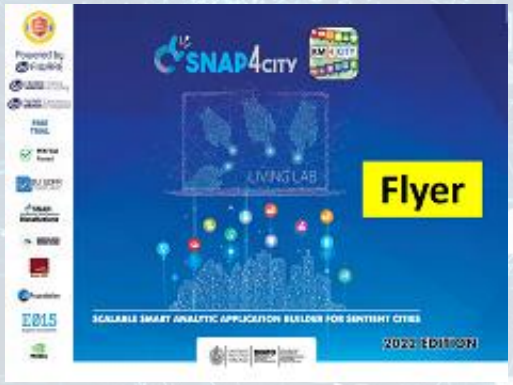


OCULUS

https://www.youtube.com/watch?v=Rcf_B2_GOio

2022 booklets

- Snap4City



https://www.snap4city.org/download/video/DPL_SNAP4CITY_2022-v02.pdf

- Snap4Industry

https://www.snap4city.org/download/video/DPL_SNAP4INDUSTRY_2022-v03.pdf

- Solutions
- Data Analytics

https://www.snap4city.org/download/video/DPL_SNAP4SOLU.pdf

Conclusions

- The **development of the SCDT of Florence** has been presented, highlighting its construction phases
- The development activities were carried out to fulfil a **series of requirements on data, on interactivity functionalities, and on the integration and distribution**
- Our SCDT is not limited to a **3D representation** of the city, but it includes **information coming from different sources**
- This capability to handle huge amount of data is powered by **Snap4City**, the IoT platform on top of which the SCDT is developed

TOP

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