UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

transform transport

Video Analytics for Understanding Pedestrian Mobility Patterns in Public Spaces

The Case of Milan

Relatore: Prof. Michele Ciavotta
Correlatrice: Dott.ssa Giulia Ceccarelli

Tesi di Laurea Magistrale di:
Lorenzo Lorgna
Matricola 829776

Anno Accademico 2021–2022

Outline

1 Introduction

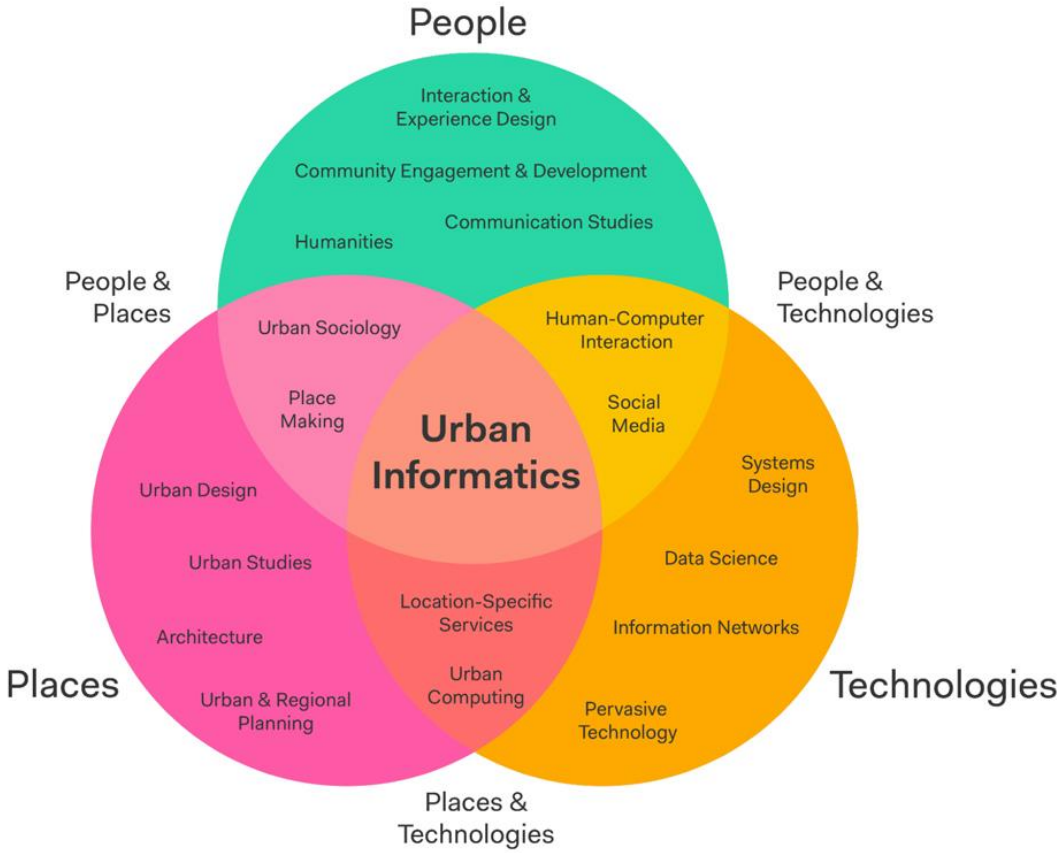
2 Methodology

3 Results

4 Conclusions and Future Work

1 - Introduction

Urban Informatics



Urban informatics is the study, design, and practice of urban experiences across different urban contexts that are created by new opportunities of real-time, ubiquitous technology and the augmentation that mediates the physical and digital layers of people networks and urban infrastructures.
(Foth, Choi, and Satchell 2011).

Problem Statement

- Video analytics techniques for urban mobility analysis: understanding potential and implications

Aim of the Study

- Characterise urban places and their users

Research Objectives

- Analyse the **distribution** of the pedestrians using specific urban planning metrics
- Identify different categories of pedestrians: **commuters and tourists**
- Investigate the presence or absence of **groups** of pedestrians

2 - Methodology

Overview

Model Selection and Dataset Collection

Model Training

Detection and Tracking

Georeferencing

Urban Analytics

Model Selection and Dataset Collection

Computer Vision Algorithms

- Object Detection: *YOLO models*
- Object Tracking: *SORT models*

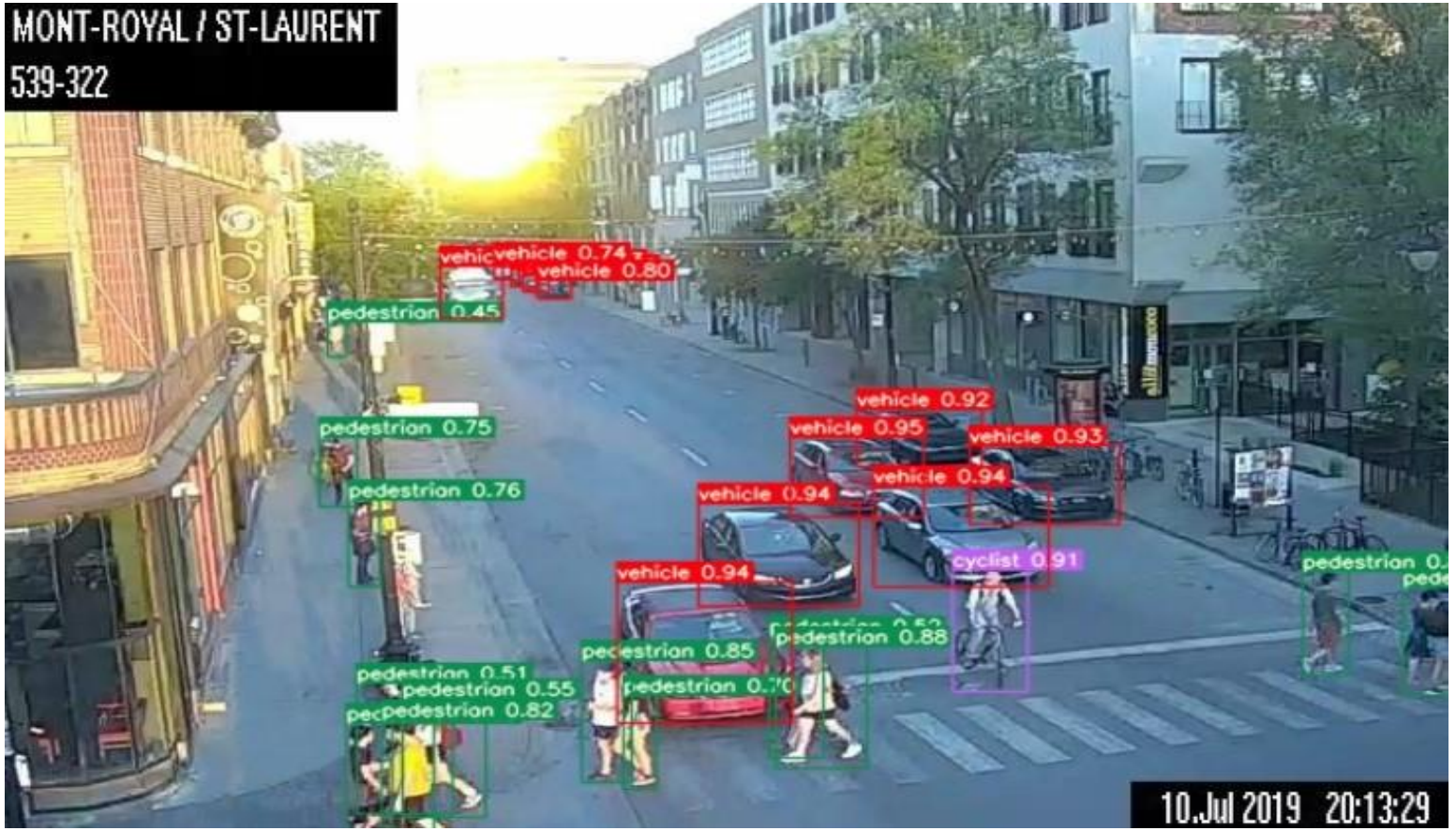
Datasets

- Training Dataset: *CGMU Montréal CCTV*
- Inference Dataset: *Piazza Duomo CCTV*

Object detection: YOLOv5 and YOLOv7

YOLOv5		
mAP_0.5	*precision*	*recall*
0.866	0.845	0.798

YOLOv7		
mAP_0.5	*precision*	*recall*
0.874	0.860	0.799



CGMU Montréal CCTV Dataset

Model Training

Untrained model

Trained model

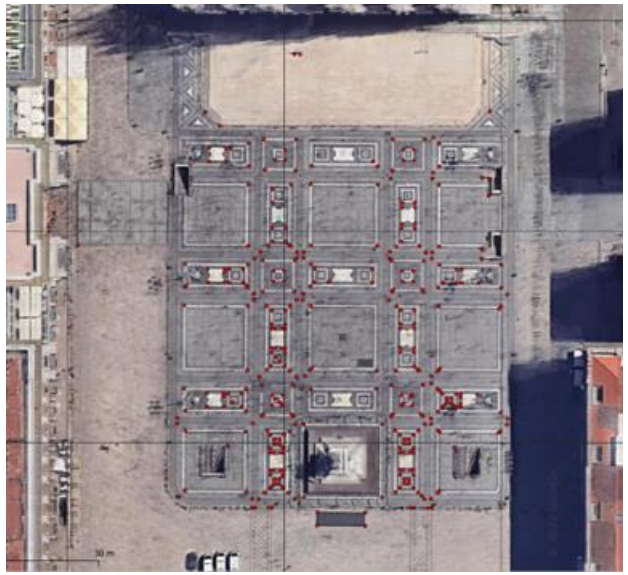
Object Tracking: SORT and StrongSORT

Execution time	
YOLOv7 + SORT	*YOLOv7 + StrongSORT*
23 ms/frame	4800 ms/frame

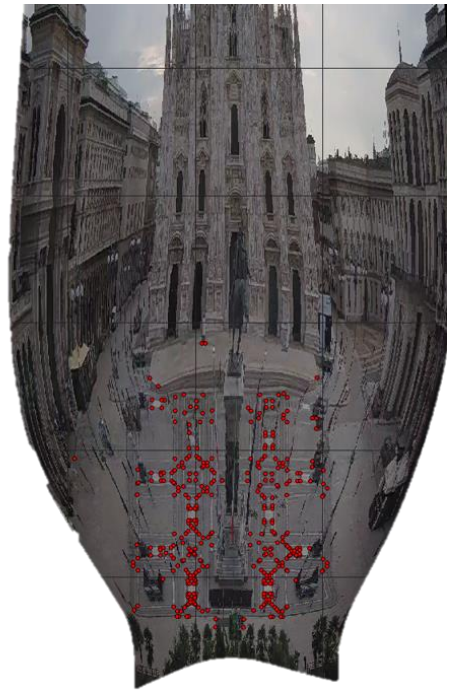
Georeferencing

- Georeferencer QGIS plugin
- Thin Plate Spline algorithm
- 354 Ground Control Points

Piazza Duomo CCTV frame



Piazza Duomo WGS84/UTM32N (EPSG: 32632)



Georeferencing result

Point Pattern Analysis

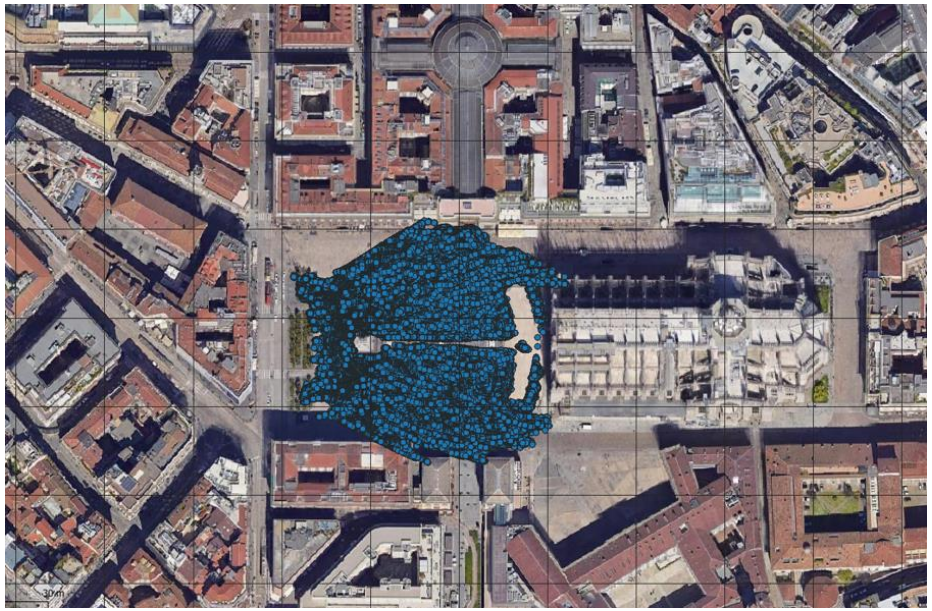
- ❑ Distribution map, Descriptive statistics
- ❑ Quadrat analysis
- ❑ Heatmap, KDE heatmap
- ❑ Standard metrics calculation (Occupancy, Density, Flow Rate)

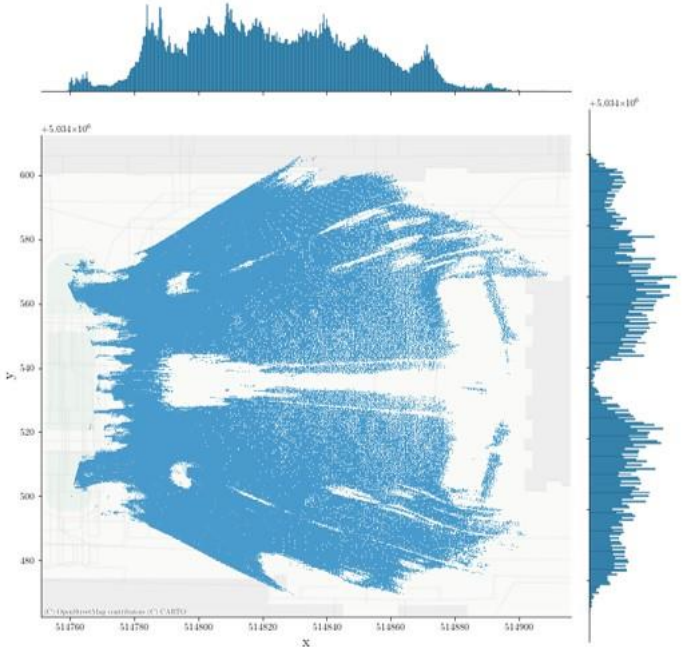
Trajectory Data Mining

- ❑ Trajectory distribution map
- ❑ Trajectory clustering
- ❑ Groups detection

3 - Results

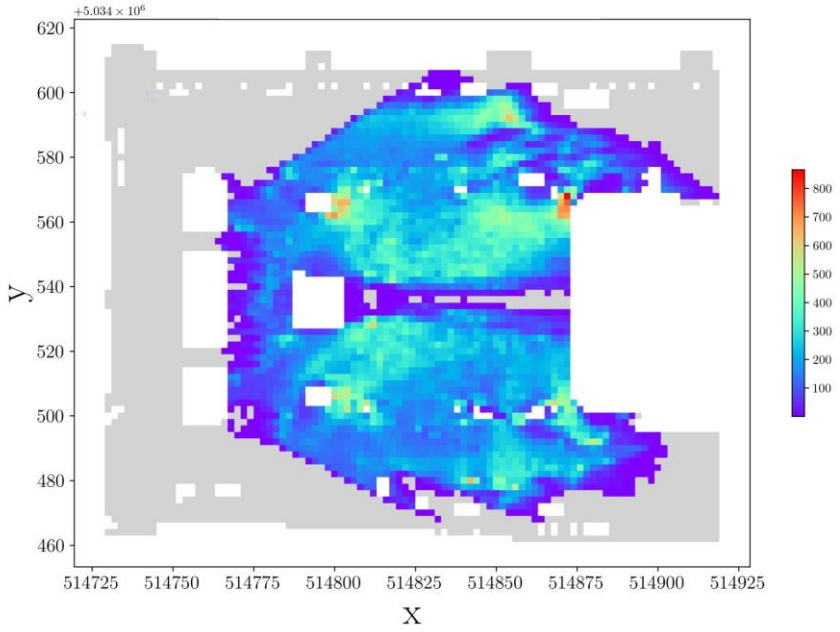
Pedestrian Distribution



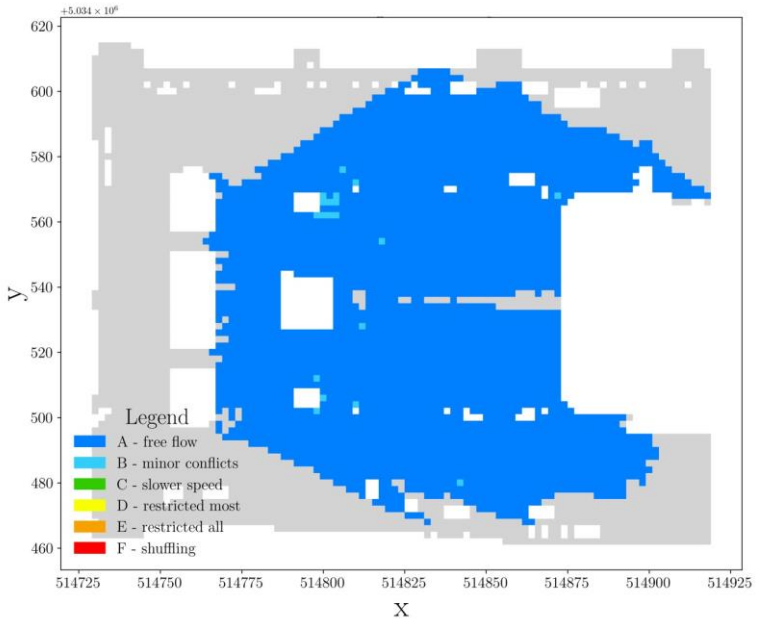


Standard Metrics

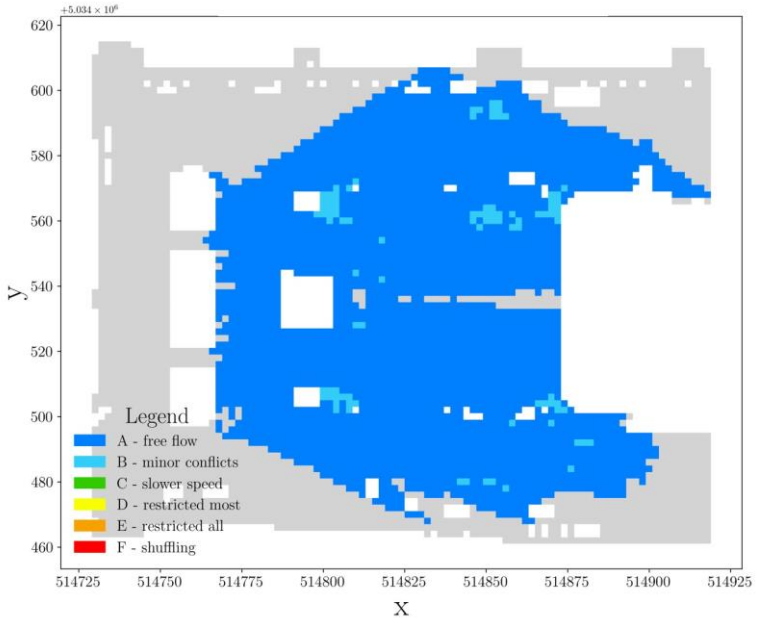
Occupancy
pedestrian/cell



Density
pedestrian/squared meter



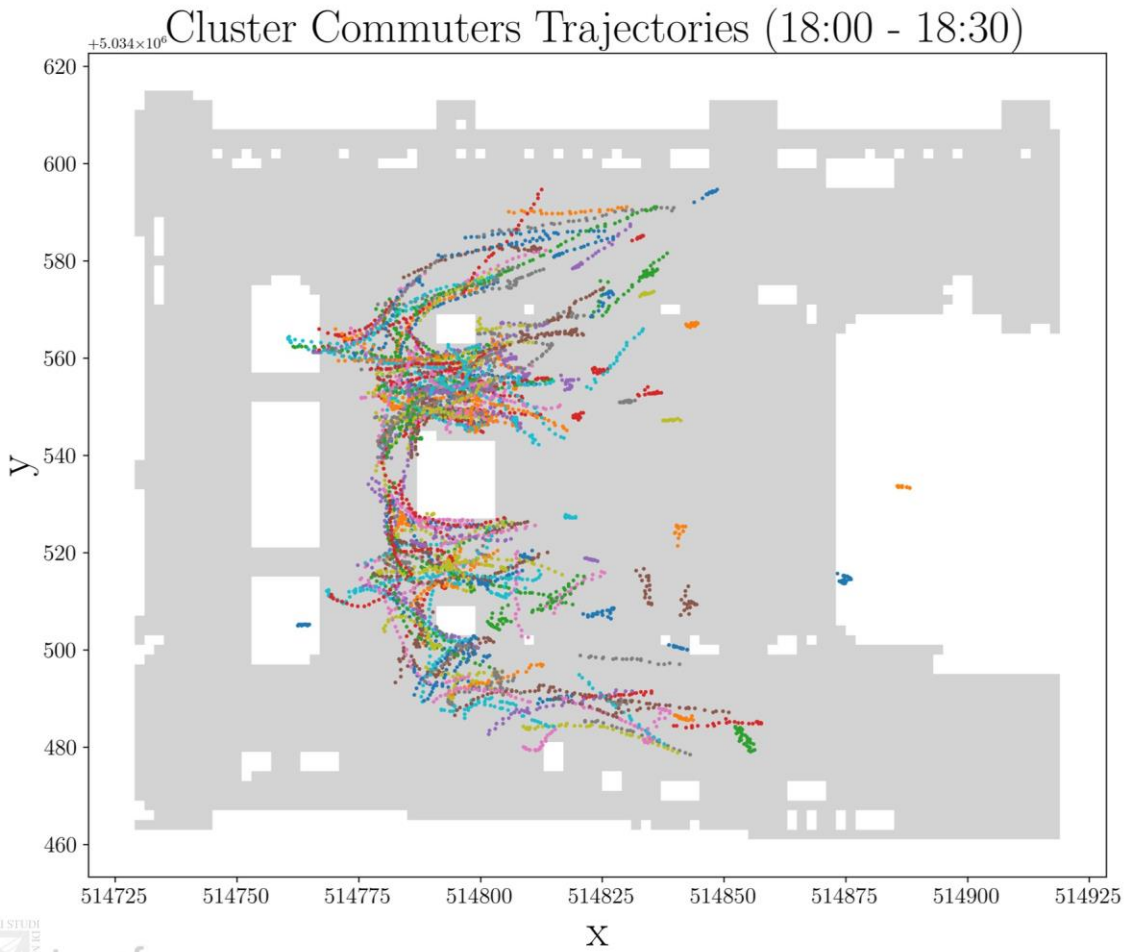
Flow Rate
pedestrian/minute/meter

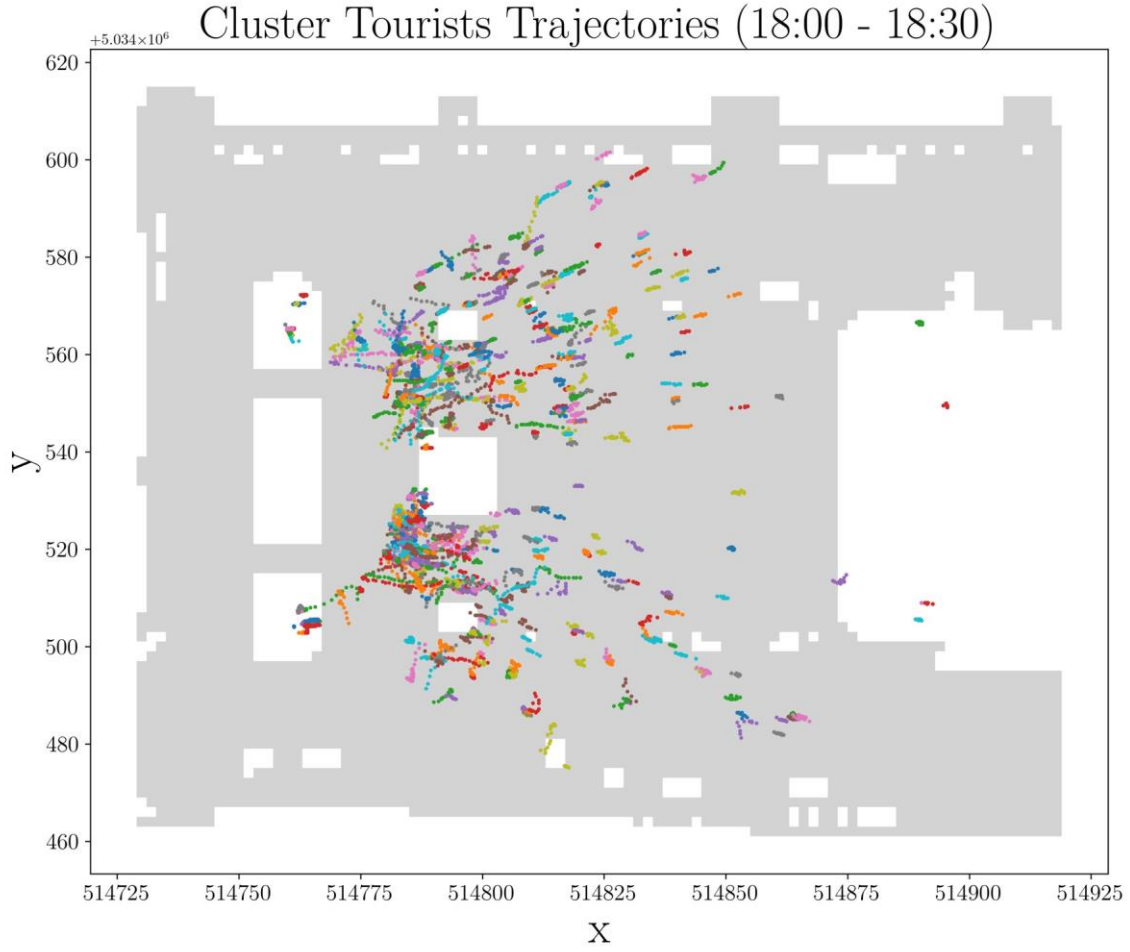


Commuters and Tourists

K-Means (k = 2)

Distance, Duration, Speed, Direction

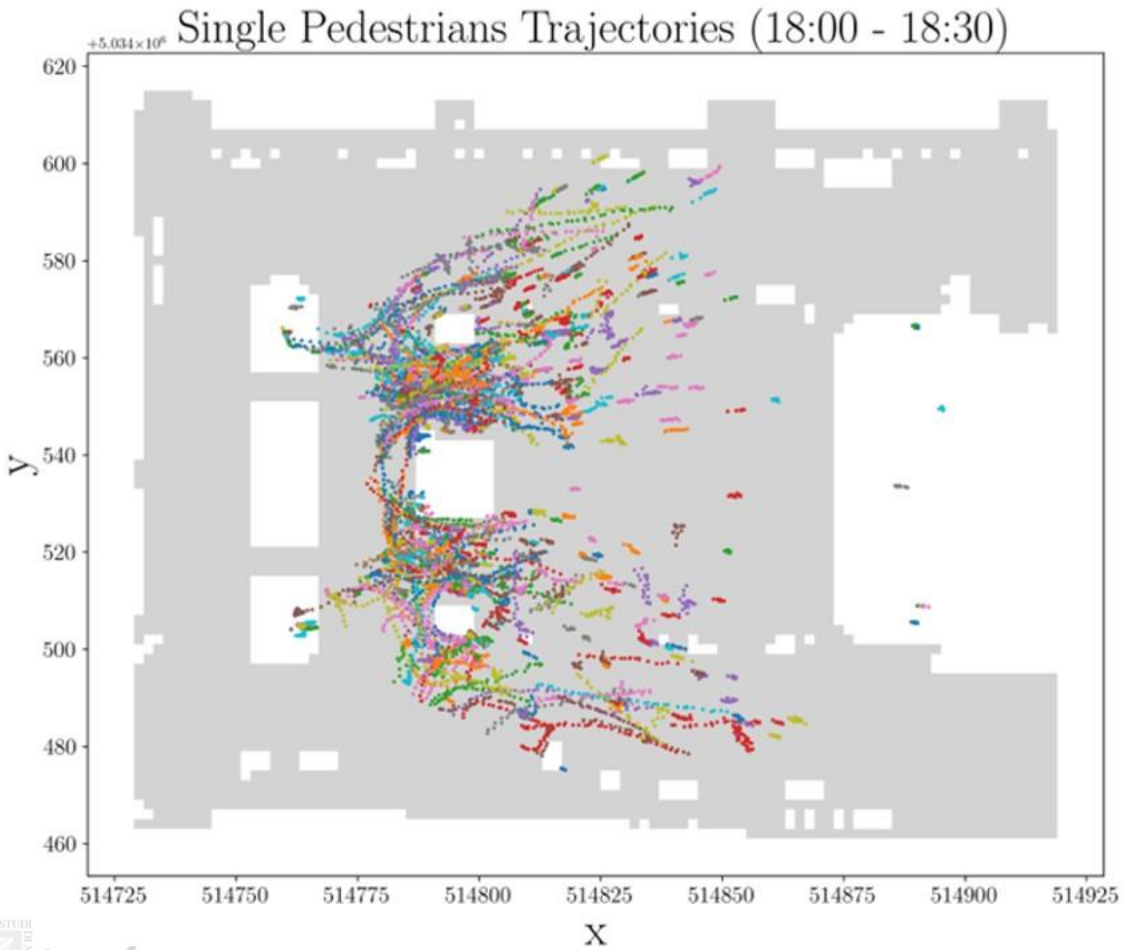


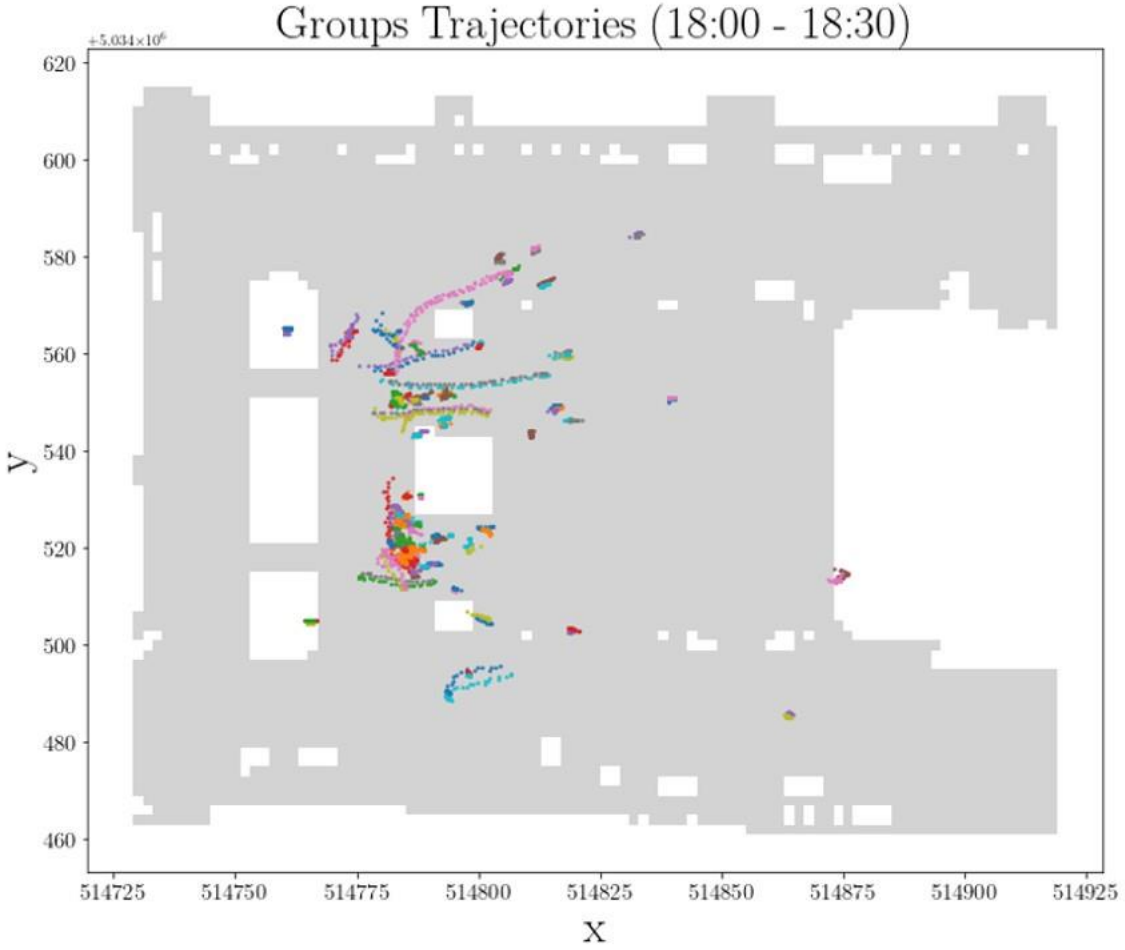


Single Pedestrians and Groups

Proxemic (1.5 m)

Close start/end points (4 m)





4 - Conclusions and Future Work

Conclusions

- Promising role of computer vision techniques in urban analysis
- Usefulness of object detection model training in achieving greater accuracy
- Difficulty in scenarios with crowded areas and small-size pedestrians
- Metrics more suitable for transport engineering

Future Work

- Definition of new metrics
- Object tracking model training
- Use of pedestrian micro-simulations
- Manual annotation of the available dataset

References

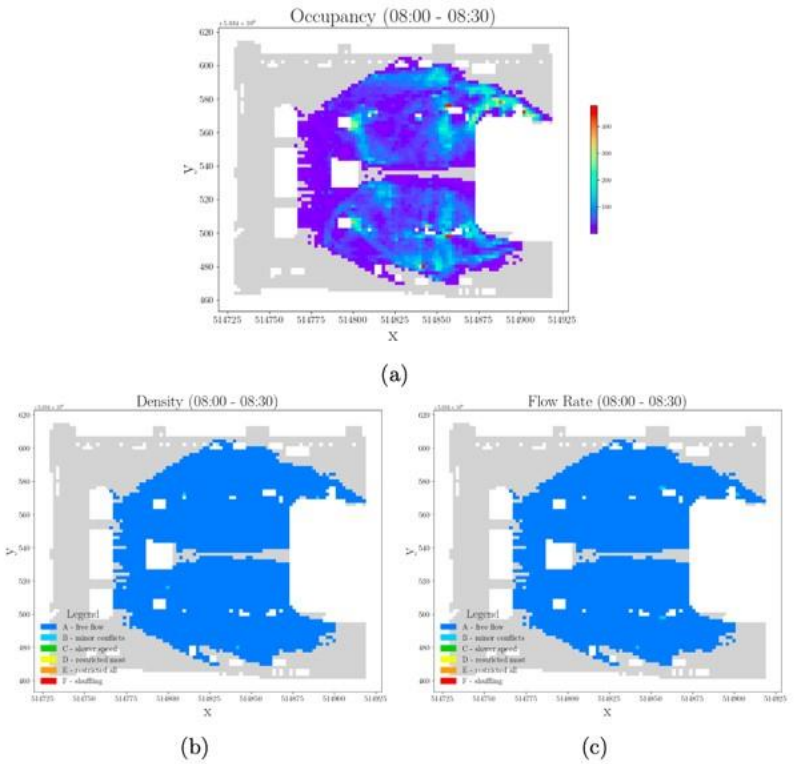
- Ceccarelli, G., Messa, F., Gorrini, A., Presicce, D., and Choubassi, R. (2023a). Deep learning video analytics for the assessment of street experiments: The case of bologna. *Journal of Urban Mobility*. Submitted.
- City of Montreal (2020). Images annotées - caméras de circulation. https://donnees.montreal.ca/ville-de-montreal/ images-annotees-cameras-circulation.
- Crociani, L., Gorrini, A., Feliciani, C., Vizzari, G., Nishinari, K., and Bandini, S. (2019). Micro and macro pedestrian dynamics in counterflow: The impact of social group. In *Traffic and Granular Flow'17 12*, pages 151–158. Springer.
- Foth, M., Choi, J. H.-j., and Satchell, C. (2011). Urban informatics. In *Proceedings of the ACM 2011 conference on Computer supported cooperative work*, pages 1–8
- Fruin, J. J. (1971). *Pedestrian planning and design*. Metropolitan Association of Urban Designers and Environmental Planners.
- Gorrini, A., Vizzari, G., and Bandini, S. (2016). Age and group-driven pedestrian behaviour: from observations to simulations. *Collective Dynamics*, 1:1–16.
- Messa, F., Ceccarelli, G., Gorrini, A., Presicce, D., Choubassi, and Choubassi (2022). Deep learning video analytics to assess vga measures and proxemic behaviour in public spaces. In *13th International Space Syntax Symposium (13SSS), 22-24 June 2022, Bergen (Norway),* pages 1–22

Thank you for your attention.

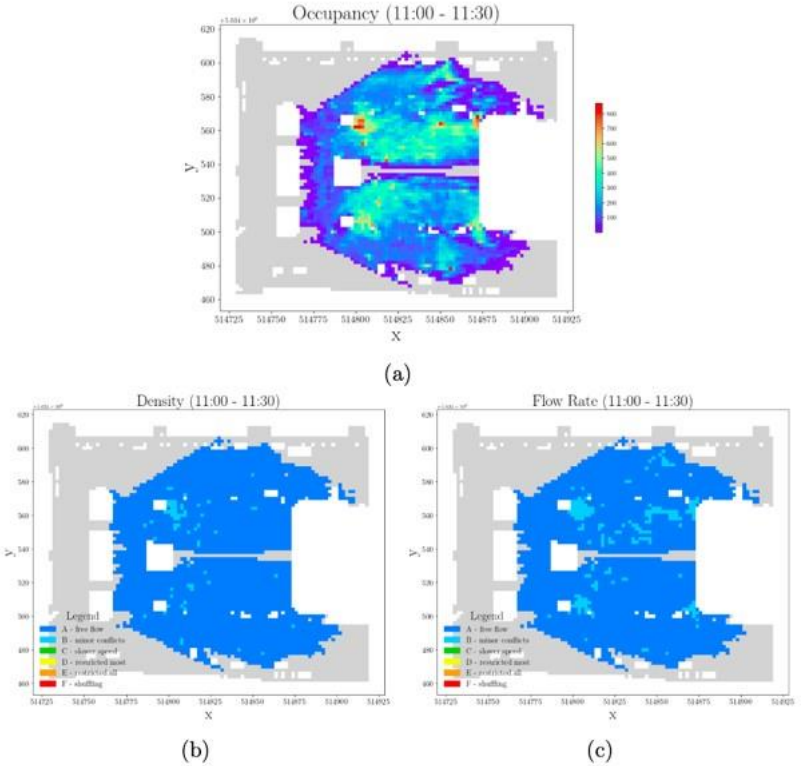
Annex – Standard Metrics

Time Slot	Occupancy $[ped/cell]$	Density $[ped/m^2]$	Flow Rate $[ped/min/m]$
08:00 - 08:30	57.725 ± 52.355	0.007 ± 0.008	0.948 ± 0.861
11:00 - 11:30	185.599 ± 136.160	0.023 ± 0.021	3.058 ± 2.252
12:45 - 13:15	228.648 ± 154.555	0.029 ± 0.025	3.653 ± 2.472
15:00 - 15:30	223.052 ± 153.374	0.026 ± 0.022	3.669 ± 2.531
18:00 - 18:30	241.459 ± 166.982	0.027 ± 0.025	3.971 ± 2.754
Total	180.495 ± 120.534	0.021 ± 0.017	2.949 ± 1.973

Occupancy, Density, Flow Rate



(a) Occupancy, (b) Density, (c) Flow Rate for 08:00 – 08:30 time slot

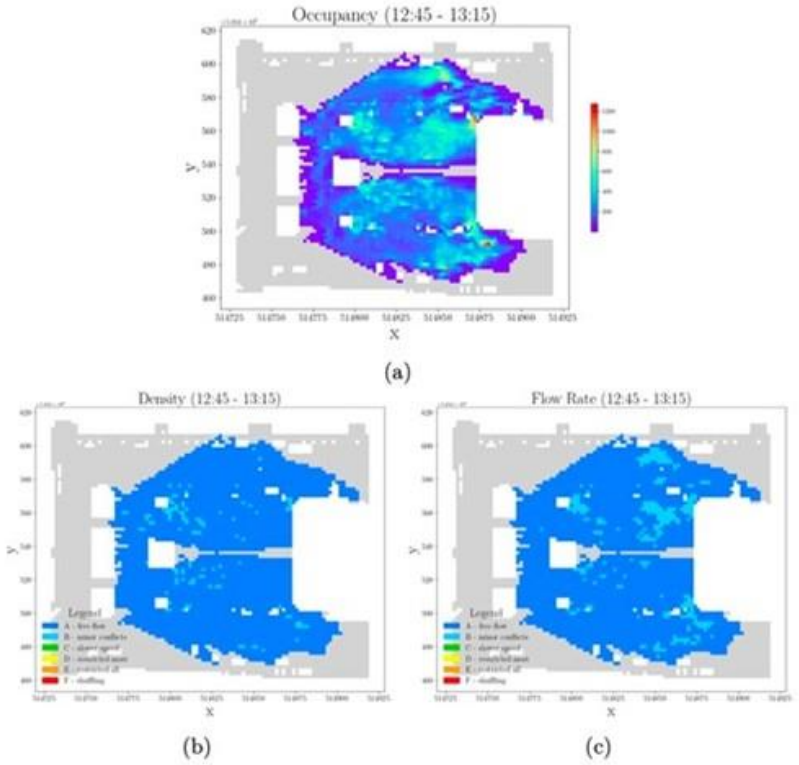


(a) Occupancy, (b) Density, (c) Flow Rate for 11:00 – 11:30 time slot

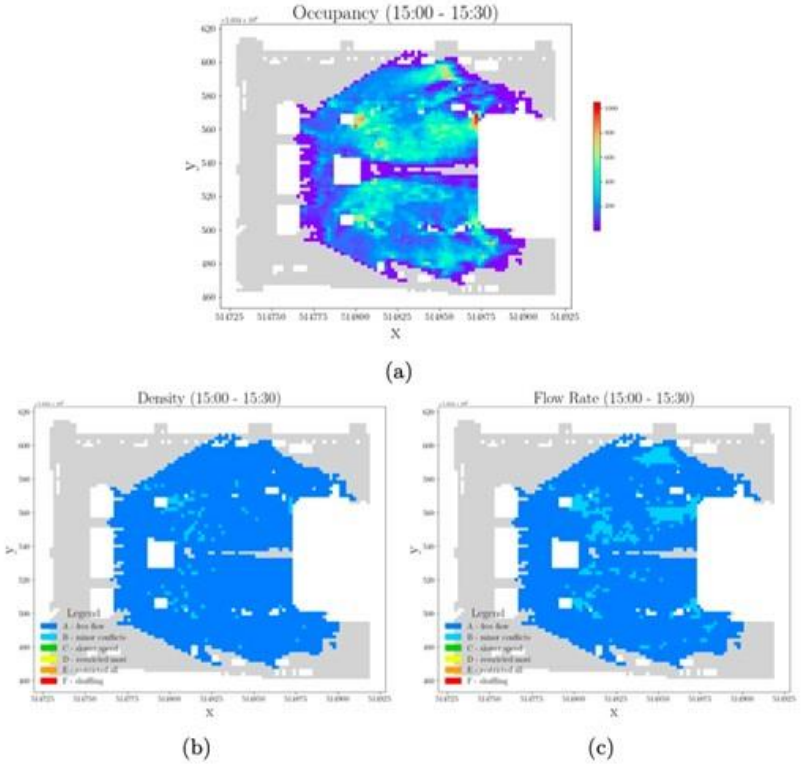
Annex – Standard Metrics

Time Slot	Occupancy $[ped/cell]$	Density $[ped/m^2]$	Flow Rate $[ped/min/m]$
08:00 - 08:30	57.725 ± 52.355	0.007 ± 0.008	0.948 ± 0.861
11:00 - 11:30	185.599 ± 136.160	0.023 ± 0.021	3.058 ± 2.252
12:45 - 13:15	228.648 ± 154.555	0.029 ± 0.025	3.653 ± 2.472
15:00 - 15:30	223.052 ± 153.374	0.026 ± 0.022	3.669 ± 2.531
18:00 - 18:30	241.459 ± 166.982	0.027 ± 0.025	3.971 ± 2.754
Total	180.495 ± 120.534	0.021 ± 0.017	2.949 ± 1.973

Occupancy, Density, Flow Rate



(a) Occupancy, (b) Density, (c) Flow Rate for 12:45 – 13:15 time slot

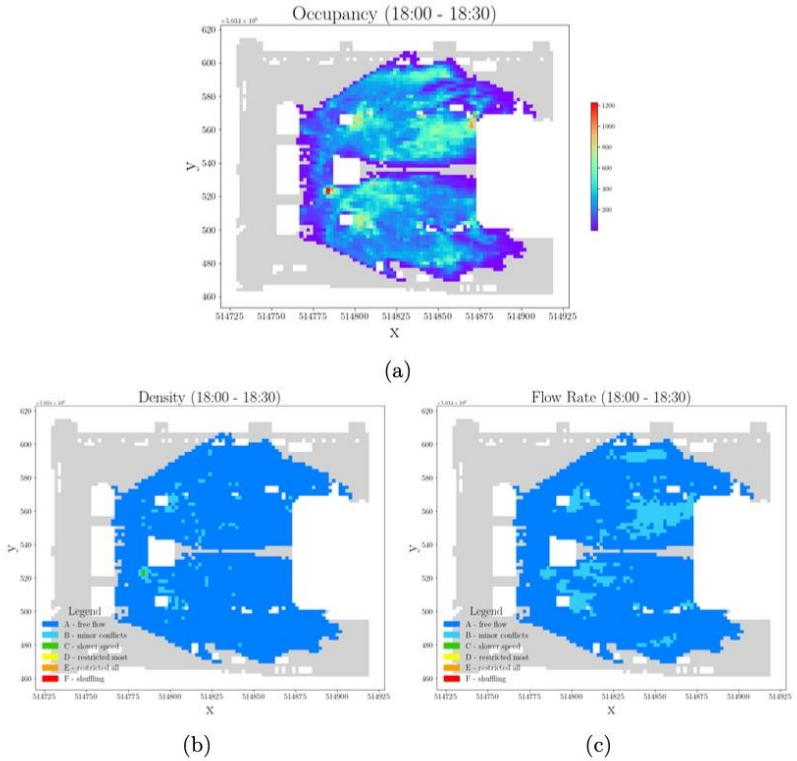


(a) Occupancy, (b) Density, (c) Flow Rate for 15:00 – 15:30 time slot

Annex – Standard Metrics

Time Slot	Occupancy $[ped/cell]$	Density $[ped/m^2]$	Flow Rate $[ped/min/m]$
08:00 - 08:30	57.725 ± 52.355	0.007 ± 0.008	0.948 ± 0.861
11:00 - 11:30	185.599 ± 136.160	0.023 ± 0.021	3.058 ± 2.252
12:45 - 13:15	228.648 ± 154.555	0.029 ± 0.025	3.653 ± 2.472
15:00 - 15:30	223.052 ± 153.374	0.026 ± 0.022	3.669 ± 2.531
18:00 - 18:30	241.459 ± 166.982	0.027 ± 0.025	3.971 ± 2.754
Total	180.495 ± 120.534	0.021 ± 0.017	2.949 ± 1.973

Occupancy, Density, Flow Rate



(a)

(b)

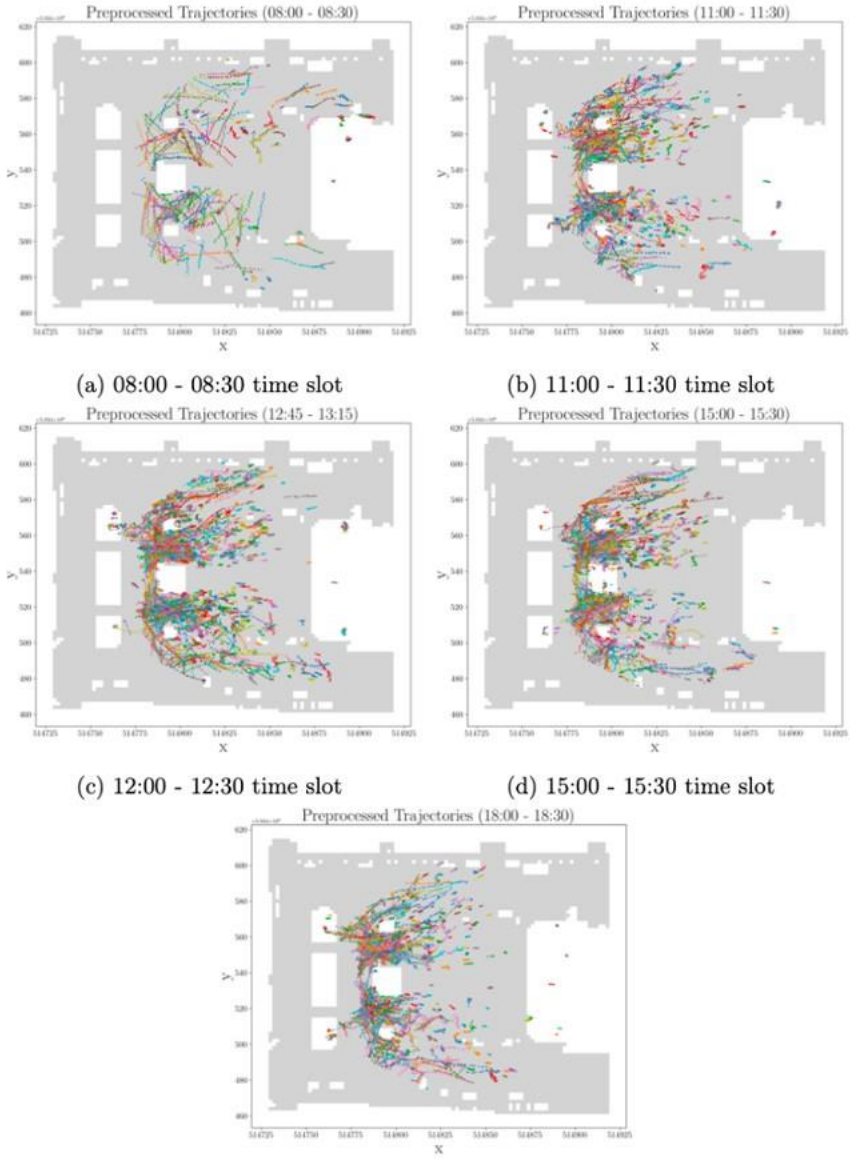
(c)

(a) Occupancy, (b) Density, (c) Flow Rate for 18:00 – 18:30 time slot

Annex – Trajectory Data Mining

Time Slot	Count	Avg. Distance $[m]$	Avg. Duration $[s]$	Avg. Speed $[m/s]$	Avg. Direction $[°]$
08:00 - 08:30	255	18.087 ± 10.472	31.751 ± 15.226	0.610 ± 0.377	120.422 ± 57.002
11:00 - 11:30	922	13.236 ± 8.332	32.150 ± 18.740	0.436 ± 0.274	113.616 ± 46.916
12:45 - 13:15	1,274	13.589 ± 8.259	31.147 ± 14.354	0.450 ± 0.271	116.79 ± 47.385
15:00 - 15:30	970	13.653 ± 8.852	30.046 ± 13.367	0.468 ± 0.296	121.909 ± 53.729
18:00 - 18:30	905	12.523 ± 8.525	31.235 ± 16.279	0.418 ± 0.281	116.899 ± 47.671

Trajectories summary statistics



(a) 08:00 - 08:30 time slot

(b) 11:00 - 11:30 time slot

(c) 12:00 - 12:30 time slot

(d) 15:00 - 15:30 time slot

(e) 18:00 - 18:30 time slot

Preprocessed trajectories

Annex – Trajectory Data Mining

Time Slot	Avg. Distance [m]		Avg. Duration [s]	
	Commuters	*Tourists*	*Commuters*	*Tourists*
08:00 - 08:30	26.956 ± 7.269	10.802 ± 6.209	28.012 ± 9.149	34.822 ± 18.274
11:00 - 11:30	23.007 ± 7.233	9.125 ± 4.424	31.869 ± 16.742	32.268 ± 19.530
12:45 - 13:15	22.902 ± 7.210	9.778 ± 4.984	28.895 ± 10.607	32.069 ± 15.541
15:00 - 15:30	24.488 ± 7.990	9.727 ± 5.068	27.430 ± 8.129	30.994 ± 14.705
18:00 - 18:30	23.630 ± 7.689	8.717 ± 4.534	29.745 ± 14.101	31.746 ± 16.941

Time Slot	Avg. Speed [m/s]		Avg. Direction [°]	
	Commuters	*Tourists*	*Commuters*	*Tourists*
08:00 - 08:30	0.960 ± 0.240	0.322 ± 0.166	156.568 ± 61.191	90.731 ± 29.962
11:00 - 11:30	0.763 ± 0.240	0.298 ± 0.136	149.558 ± 57.163	98.497 ± 31.363
12:45 - 13:15	0.792 ± 0.204	0.310 ± 0.138	155.572 ± 59.831	100.910 ± 28.875
15:00 - 15:30	0.872 ± 0.203	0.322 ± 0.155	177.725 ± 61.486	101.684 ± 32.058
18:00 - 18:30	0.814 ± 0.220	0.282 ± 0.131	162.510 ± 59.800	101.267 ± 29.524

Clustering results

Time Slot	Avg. Distance [m]		Avg. Duration [s]	
	Single pedestrians	*Groups*	*Single pedestrians*	*Groups*
08:00 - 08:30	19.323 ± 10.478	9.156 ± 4.320	31.645 ± 15.501	32.516 ± 13.269
11:00 - 11:30	14.060 ± 8.664	10.123 ± 6.006	30.829 ± 15.044	37.142 ± 28.192
12:45 - 13:15	14.229 ± 8.408	10.928 ± 7.022	30.034 ± 13.468	35.777 ± 16.822
15:00 - 15:30	14.344 ± 9.137	10.208 ± 6.234	29.559 ± 13.348	32.479 ± 13.237
18:00 - 18:30	12.981 ± 8.698	10.343 ± 7.287	30.589 ± 14.630	34.316 ± 22.345

Time Slot	Avg. Speed [m/s]		Avg. Direction [°]	
	Single pedestrians	*Groups*	*Single pedestrians*	*Groups*
08:00 - 08:30	0.655 ± 0.378	0.280 ± 0.109	124.298 ± 58.713	92.416 ± 31.037
11:00 - 11:30	0.471 ± 0.285	0.301 ± 0.171	116.754 ± 49.238	101.763 ± 34.457
12:45 - 13:15	0.483 ± 0.276	0.310 ± 0.195	120.643 ± 48.918	100.746 ± 36.307
15:00 - 15:30	0.496 ± 0.301	0.329 ± 0.226	125.572 ± 55.086	103.640 ± 41.973
18:00 - 18:30	0.440 ± 0.290	0.309 ± 0.203	119.304 ± 49.783	105.444 ± 33.791

Groups detection results

Time Slot	Avg. Distance	Avg. Duration	Avg. Speed	Avg. Direction
	Commuters vs Tourists	*Commuters vs Tourists*	*Commuters vs Tourists*	*Commuters vs Tourists*
	t-test	*t-test*	*t-test*	*t-test*
08:00 - 08:30	p value<.001	p value<.001	p value<.001	p value<.001
11:00 - 11:30	p value<.001	-	p value<.001	p value<.001
12:45 - 13:15	p value<.001	p value<.001	p value<.001	p value<.001
15:00 - 15:30	p value<.001	p value<.001	p value<.001	p value<.001
18:00 - 18:30	p value<.001	-	p value<.001	p value<.001

Commuters vs. Tourists: independent-samples two-tails t-test

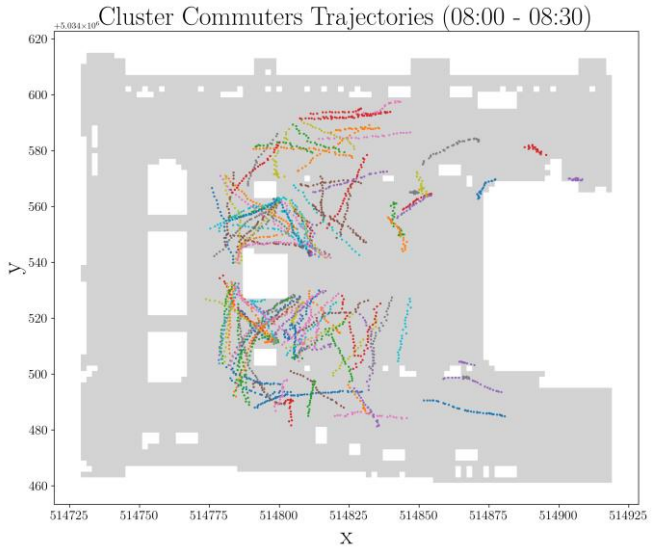
Time Slot	Avg. Distance	Avg. Duration	Avg. Speed	Avg. Direction
	Single pedestrians vs Groups	*Single pedestrians vs Groups*	*Single pedestrians vs Groups*	*Single pedestrians vs Groups*
	t-test	*t-test*	*t-test*	*t-test*
08:00 - 08:30	p value<.001	-	p value<.001	p value<.005
11:00 - 11:30	p value<.001	p value<.001	p value<.001	p value<.001
12:45 - 13:15	p value<.001	p value<.001	p value<.001	p value<.001
15:00 - 15:30	p value<.001	p value<.005	p value<.001	p value<.001
18:00 - 18:30	p value<.001	p value<.005	p value<.001	p value<.001

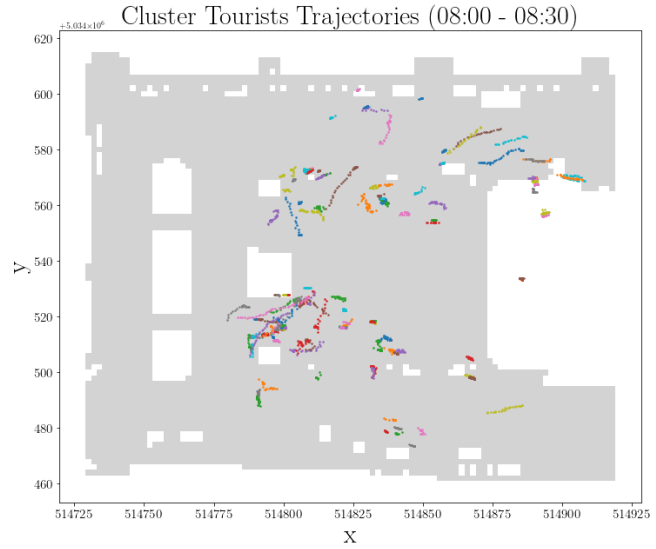
Single pedestrian vs. Groups: independent-samples two-tails t-test

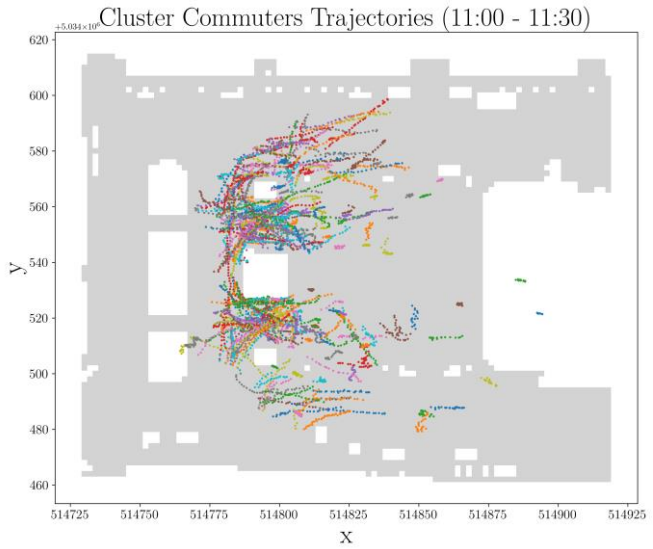
Time slot	Total points	Total trajectories	Detected commuters	Detected tourists	Detected single pedestrians	Detected groups
08:00 - 08:30	7,966	255	115	140	224	14
11:00 - 11:30	29,151	922	273	649	729	91
12:45 - 13:15	39,058	1,274	370	904	1,027	113
15:00 - 15:30	28,719	970	258	712	808	76
18:00 - 18:30	27,826	905	231	674	748	72

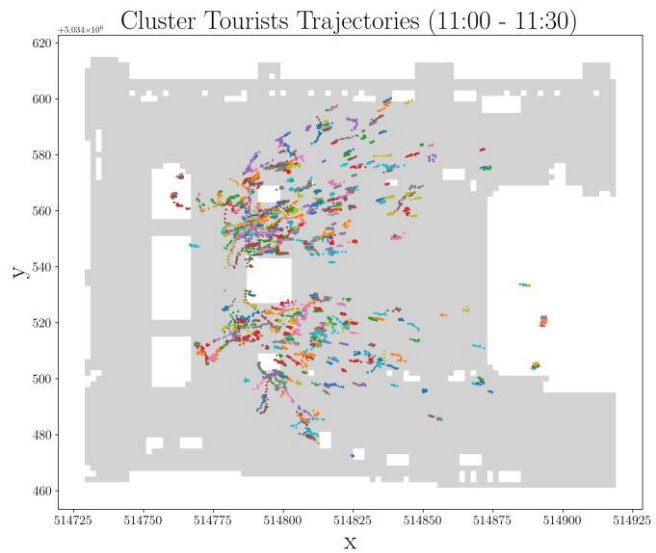
Clustering and Groups detection results

Annex – Trajectory Data Mining

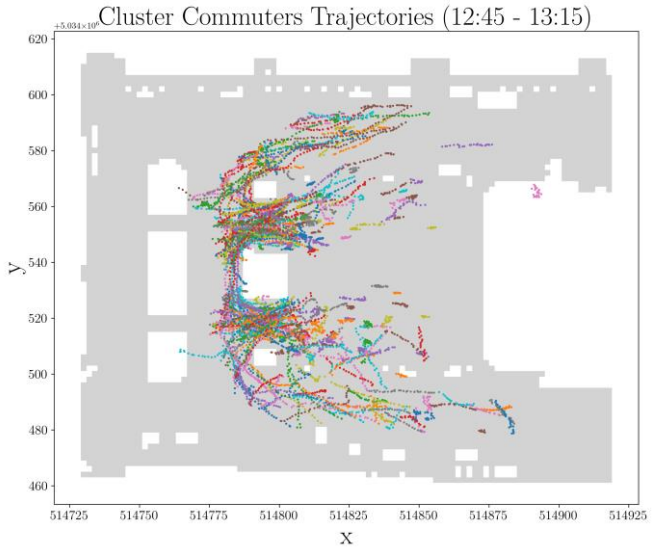


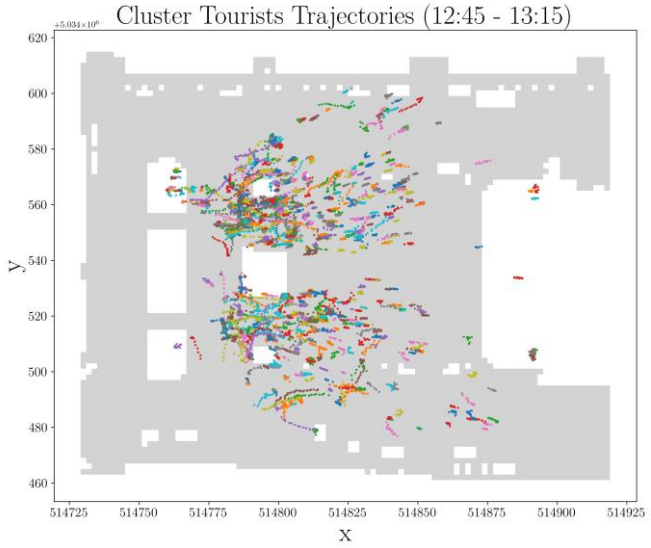


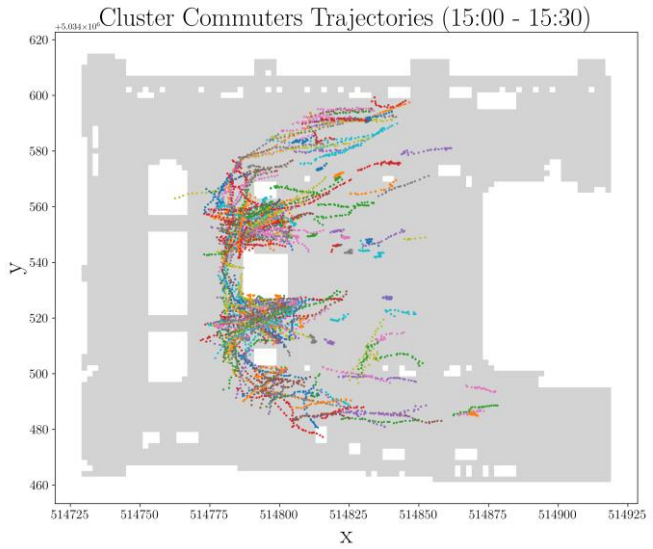


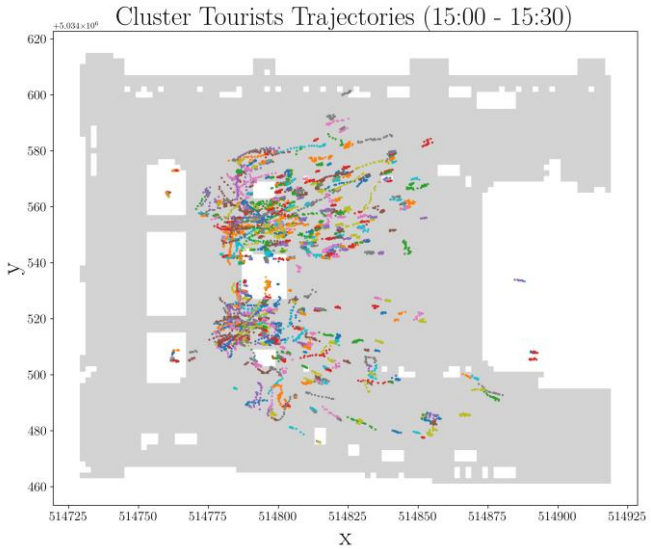


Annex – Trajectory Data Mining

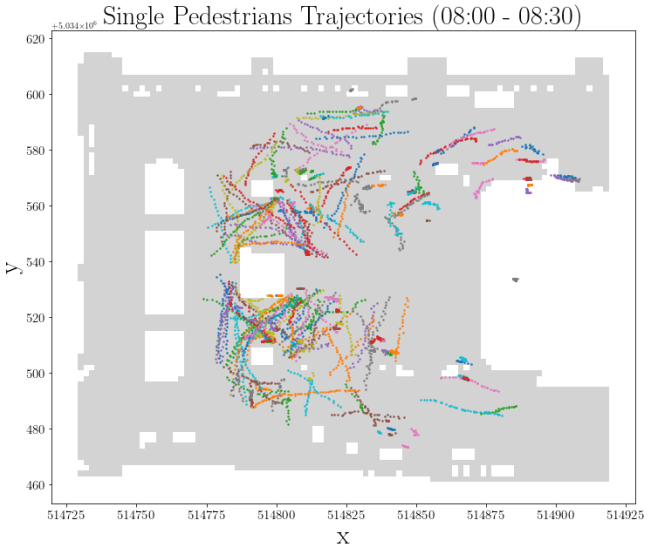


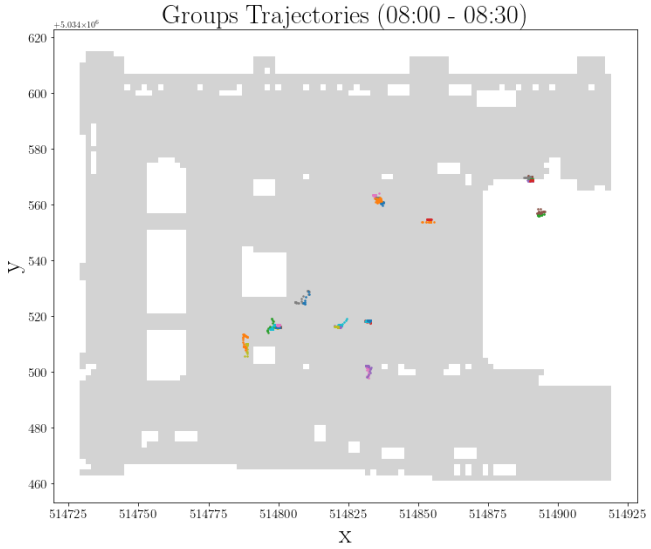


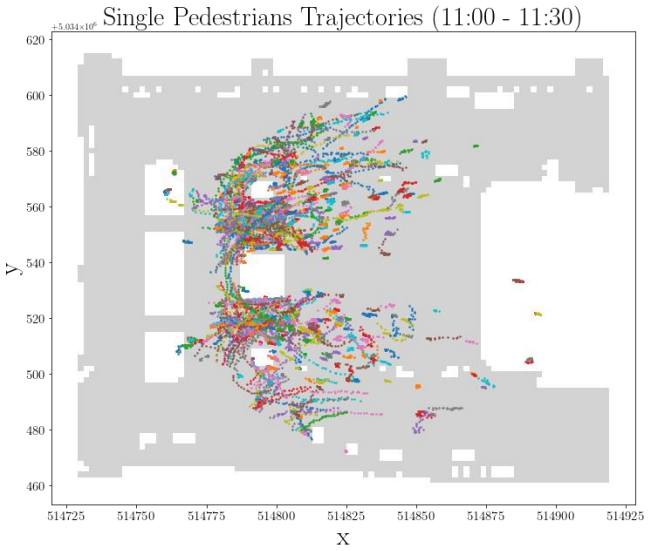


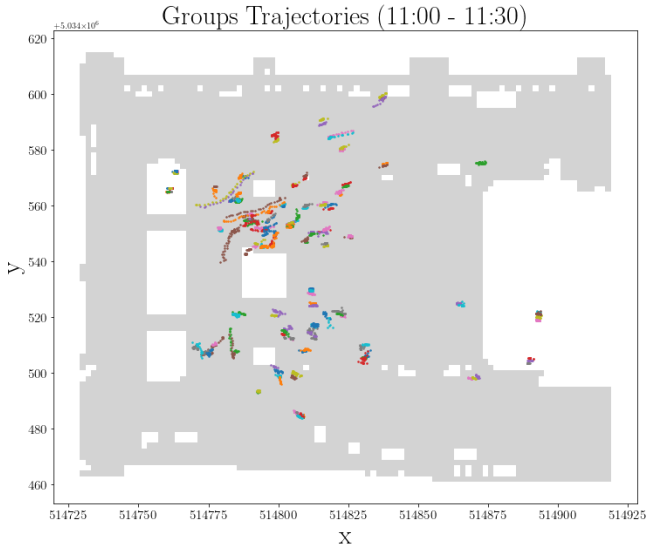


Annex – Trajectory Data Mining

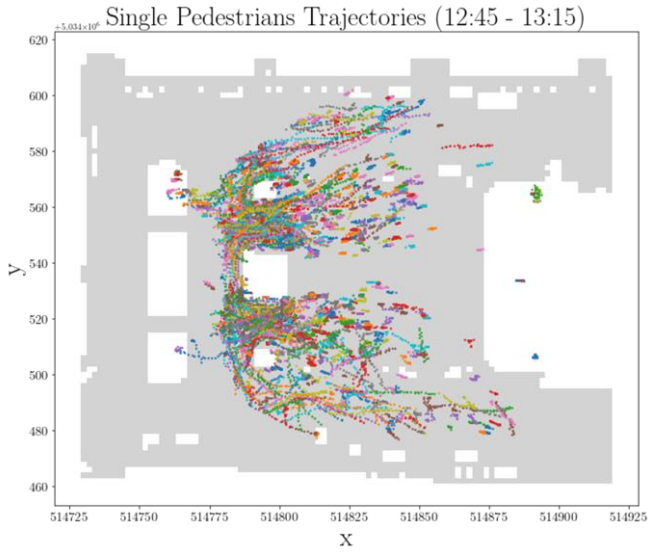


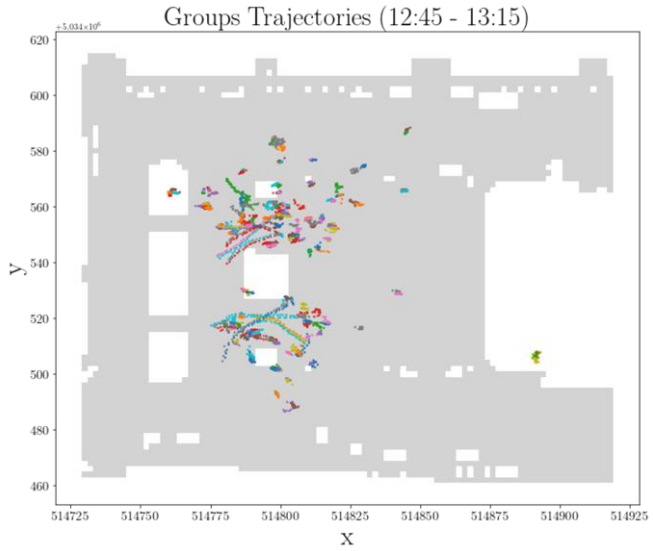


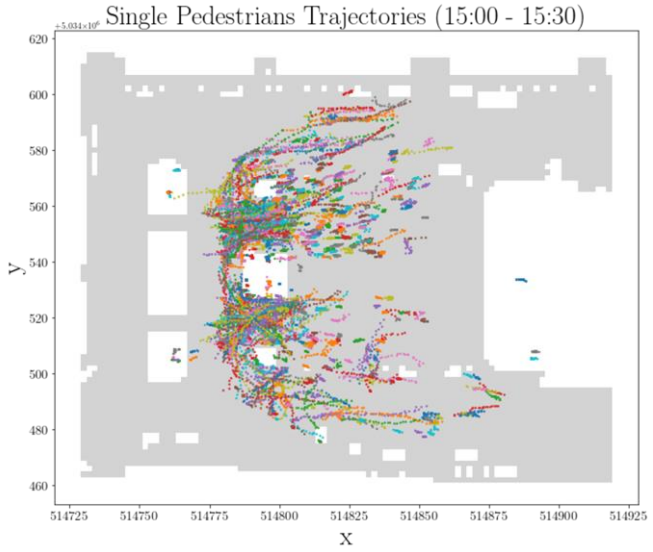


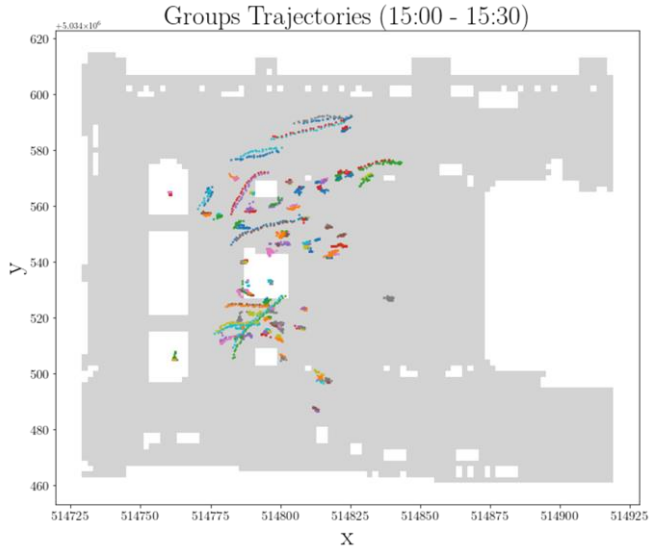


Annex – Trajectory Data Mining

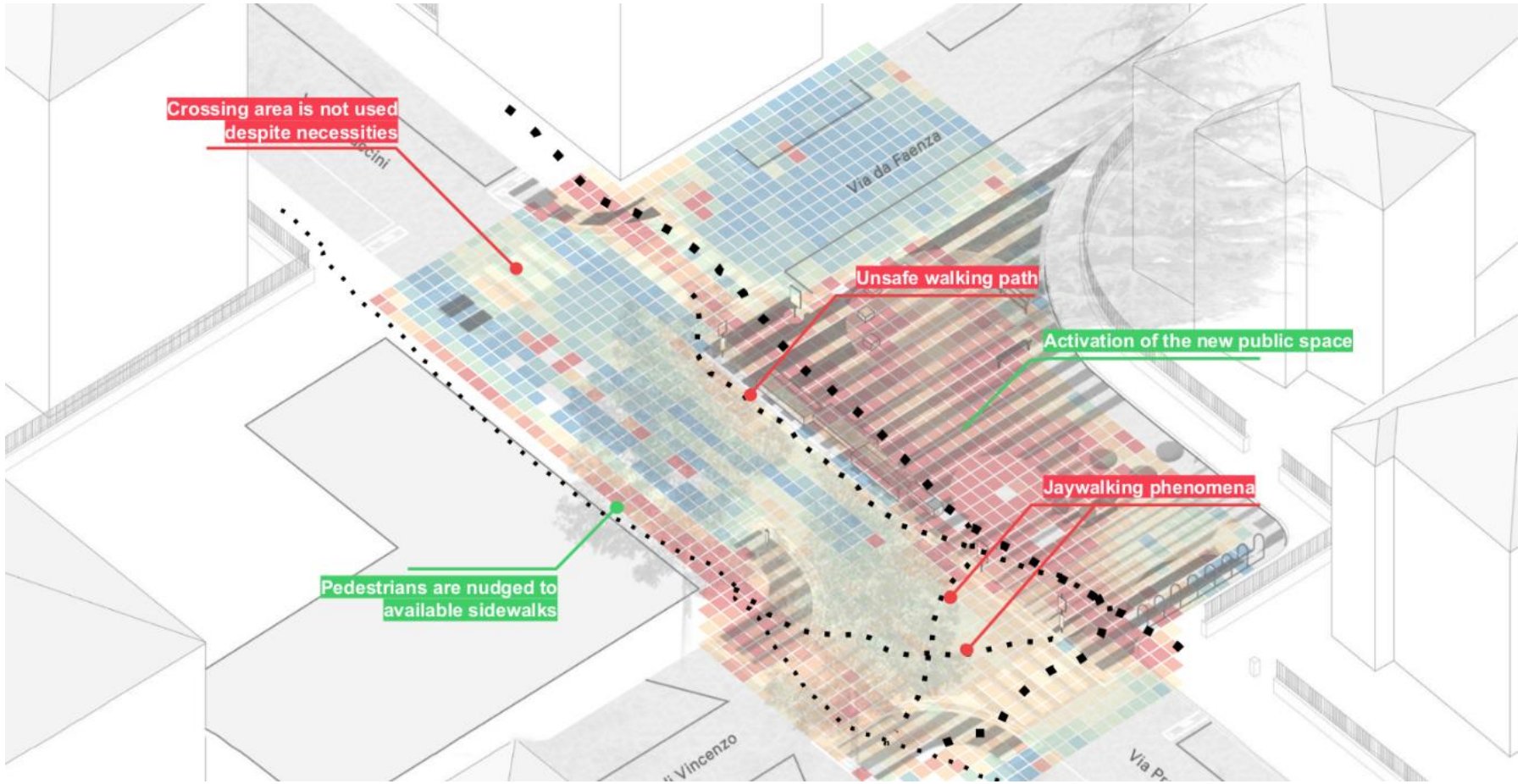








Walkability for Children in Bologna: An Urban Informatics Approach



https://transformtransport.org/research/livable-streets/walkability-for-children-in-bologna-gis-and-space-syntax-applications/