The complex interrelation of walking and thermal stress: Surprising results from large-scale pedestrian monitoring of a main street using machine vision

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BDAR Big Data in Architectural Research Lab

Daytime heat stress avoidance directly depends on shade provision

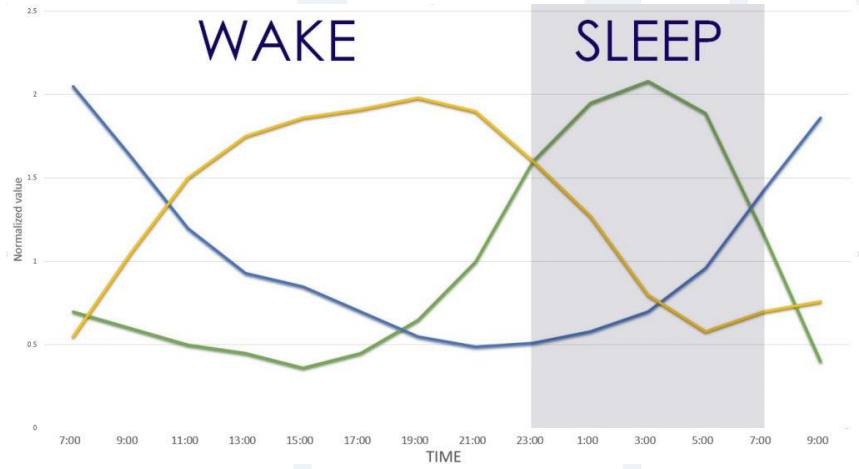
How does heat stress affect pedestrian flow volumes?

Kaplan Street, Tel Aviv

Circadian Rhythms of Streets

Circadian rhythms are the recurring physical, mental, and behavioural changes an organism experiences over a 24-hour cycle.

This study examines whether we can apply the concept of "circadian rhythms" to the changing volumes of street pedestrians, and if so, how pedestrian circadian rhythms are affected by climatic conditions.



Research questions

1. Can a circadian rhythm of a street be defined by the volume of pedestrian movement?

Image source: https://www.telegraph.co.uk/

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1. Can a circadian rhythm of a street be defined by the volume of pedestrian movement?
2. Can a link be drawn between the circadian rhythm of a street and changing seasonal conditions?

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Research questions

1. Can a circadian rhythm of a street be defined by the volume of pedestrian movement?
2. Can a link be drawn between the circadian rhythm of a street and changing seasonal conditions?
3. Is the ratio of male-to-female pedestrians in the street subject to temporal changes?

Image source: https://www.telegraph.co.uk/

Pedestrian counting methods

Manual Counting:

- On-site
- Video samples

Focuses on pedestrian flow volumes during peak time and avoids irregular events.

Manual counts are sample-based and, therefore, limited in the picture they draw.

Image source: Ali Express

Image source: https://altatherapies.com/

Sporadic manual counts are not well-suited to define the circadian rhythm of a street and its irregularities throughout the year

Pedestrian counting methods

Video stream: Machine Vision counts. The data can be verified, and existing CCTV infrastructure can be used.

Sensors: Limited verification process. Requires investment in dedicated infrastructure.

Bluetooth/Cellular: Does not count people who do not engage with BT technology. Difficult to distinguish between pedestrians and other forms of movement.

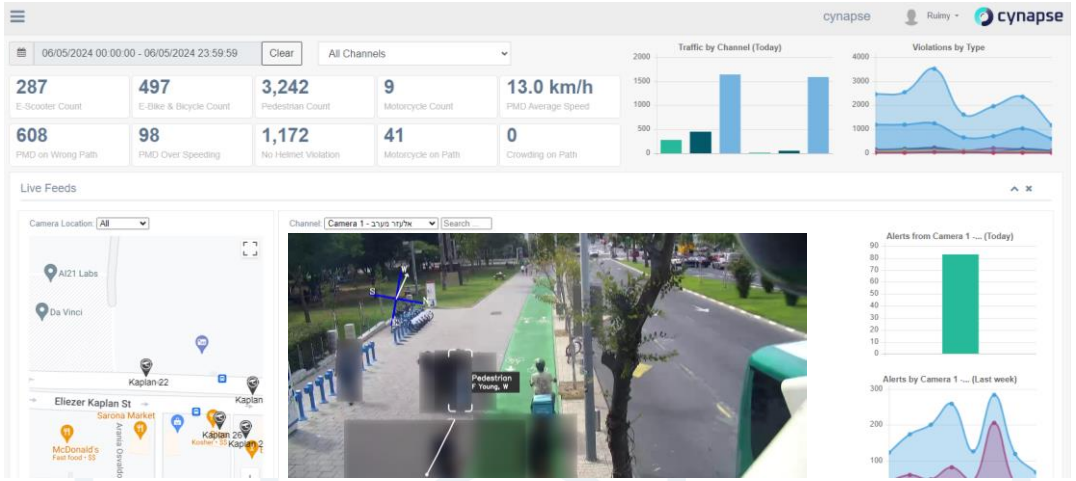


Image source: Cynapse

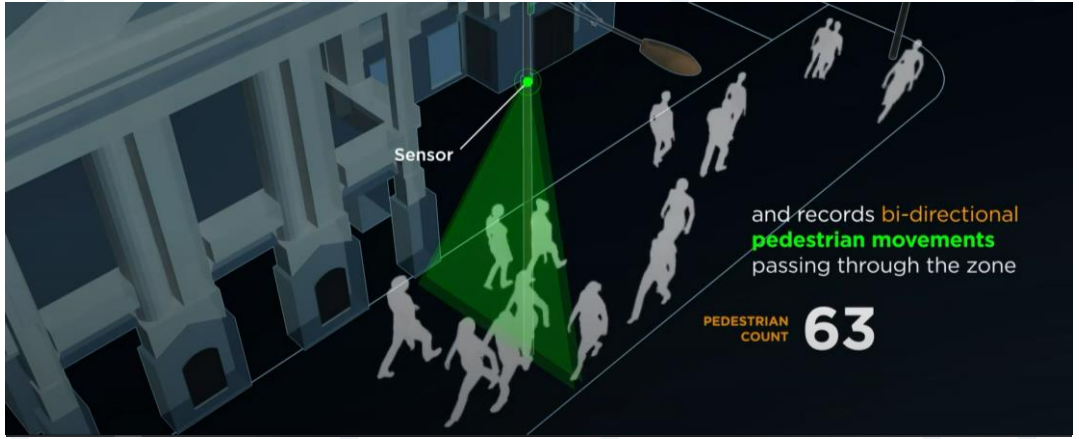
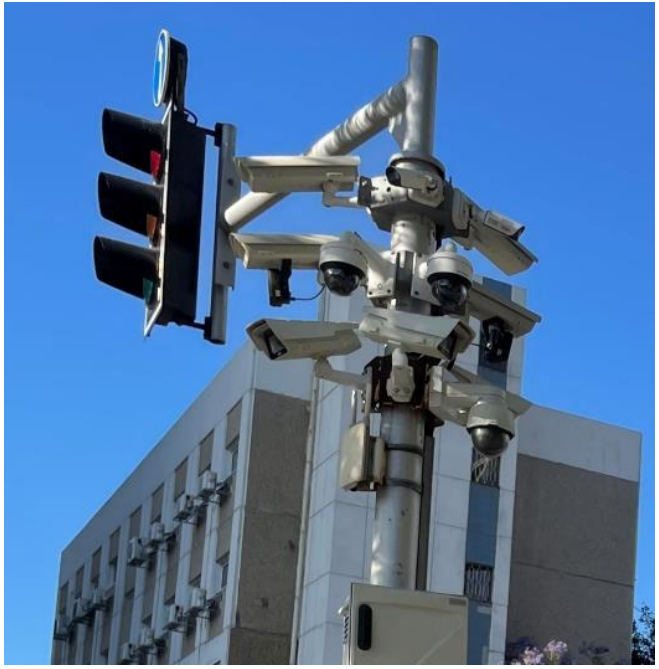
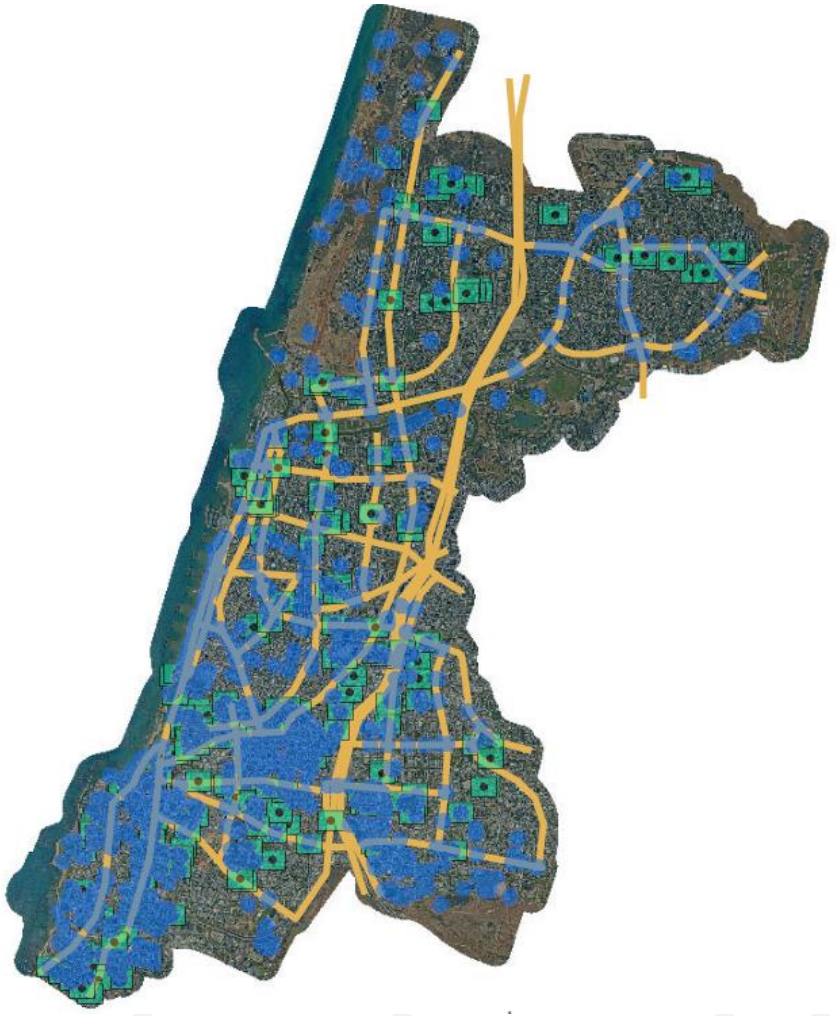


Image source: City of Melbourne Pedestrian Counting System

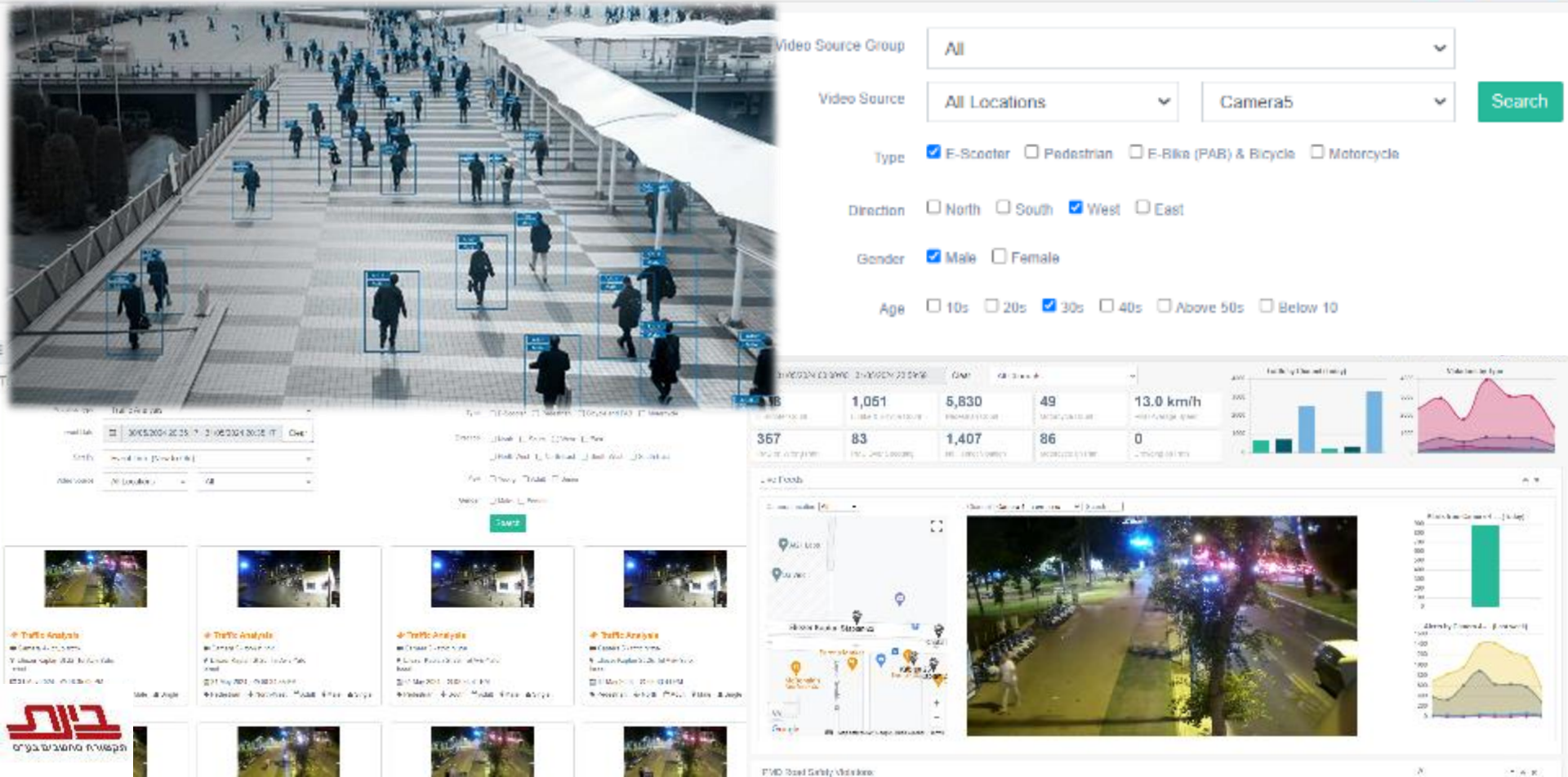
Data collection potential using CCTV cameras

Tel Aviv-Yafo alone has 1,200 security cameras.
Additional cameras for other purposes total 4,500 CCTV city cameras.

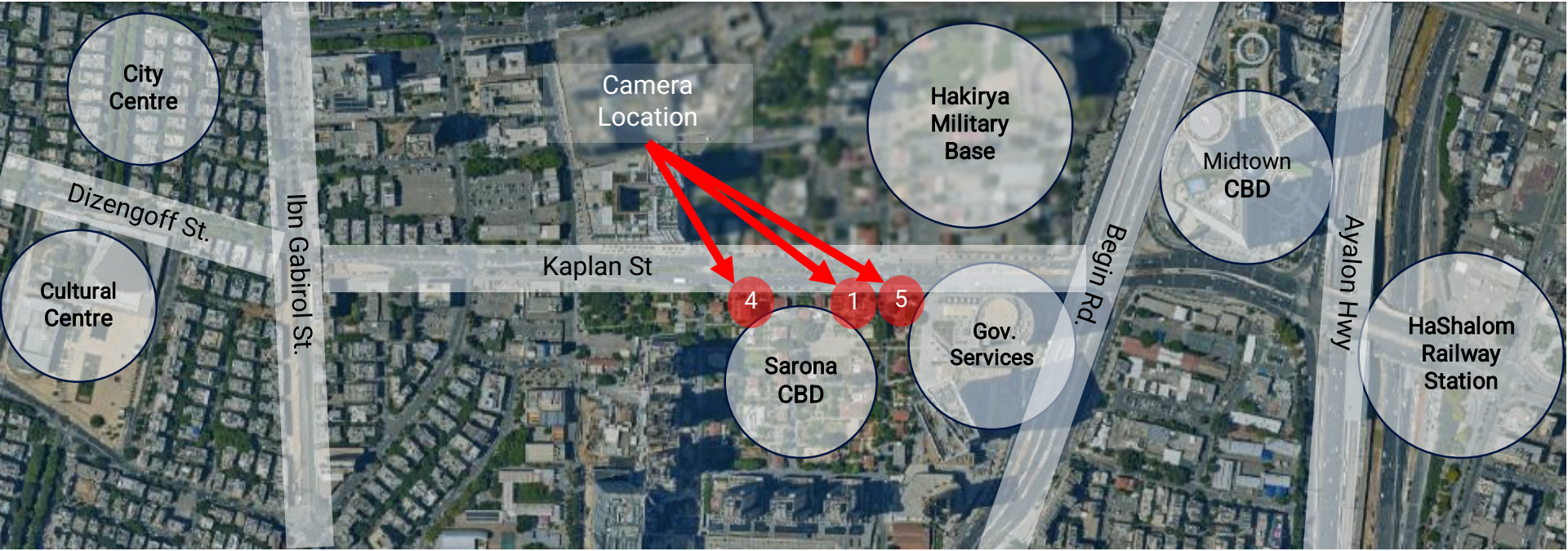




Pedestrian counting: Vision AI



Case study: Kaplan Street, Tel Aviv-Yafo



Main street and thoroughfare street, CBD area, HaKirya military base, essential public services, residential, leisure

Case study: Kaplan Street, Tel Aviv-Yafo

Kaplan Street and its surroundings, shad map of Tel Aviv-Yafo (detai
Severe lack of shade

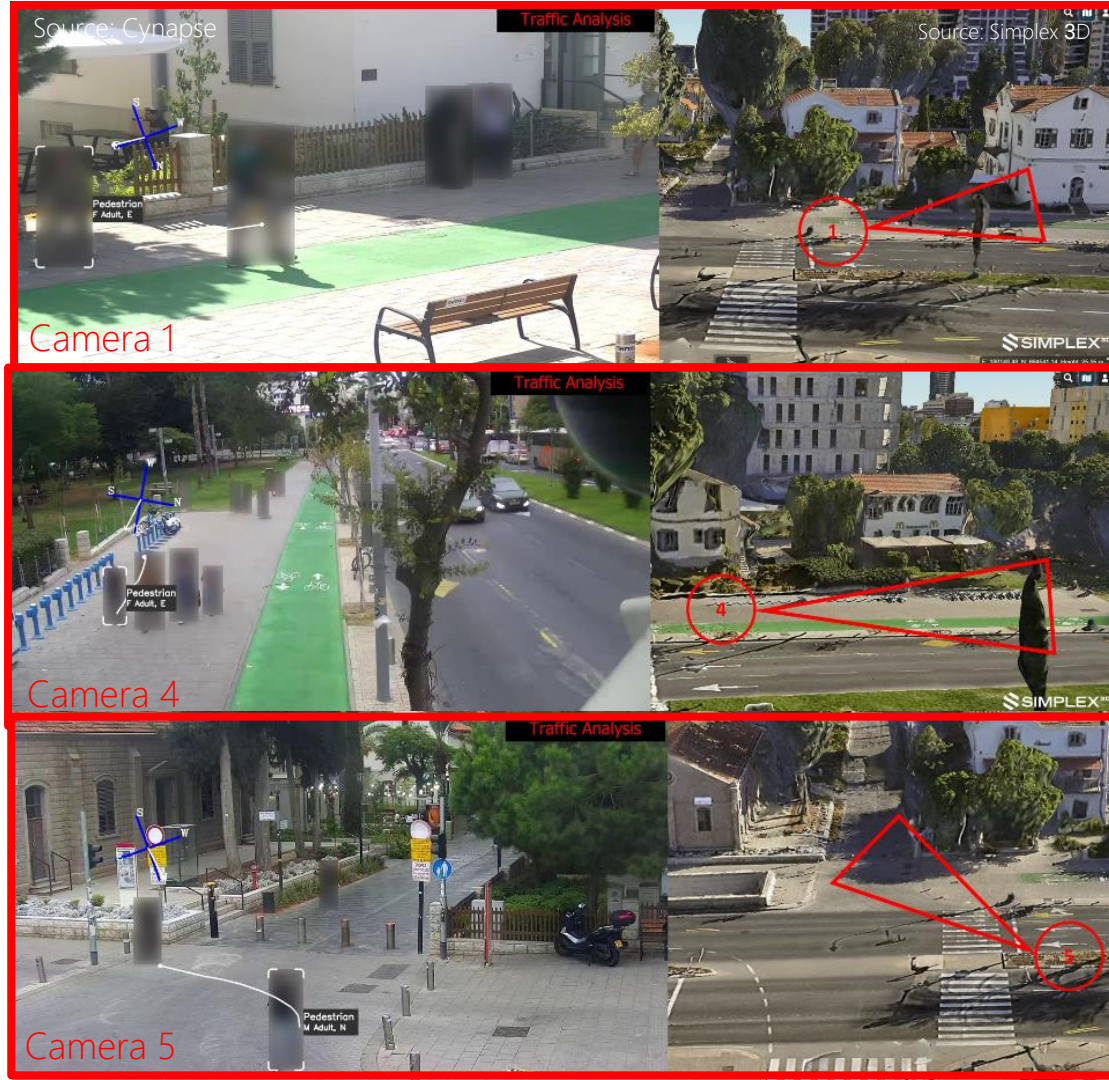
Case study: Kaplan Street, Tel Aviv-Yafo

Monitoring period: August 2022 till October 2023

Number of pedestrian counts on each camera:
Camera 1 - 2,489,263
Camera 4 - 2,007,337
Camera 5 - 3,710,909
A total of 8,207,509 pedestrians

The difference in pedestrian counts between cameras 1 and 4 suggests that physical and functional differences along a single street may impact pedestrian counts.

Camera 5 was located at a T junction and recorded two perpendicular movements, not only on Kaplan Street. Therefore, it was excluded from further analysis.



Case study: Kaplan Street, Tel Aviv-Yafo

Orthophotos showing the area covered by both cameras and the lack of shading on the sidewalk at different times on 6 August

Camera 1

Camera 4

8:00

10:00

12:00

14:00

16:00

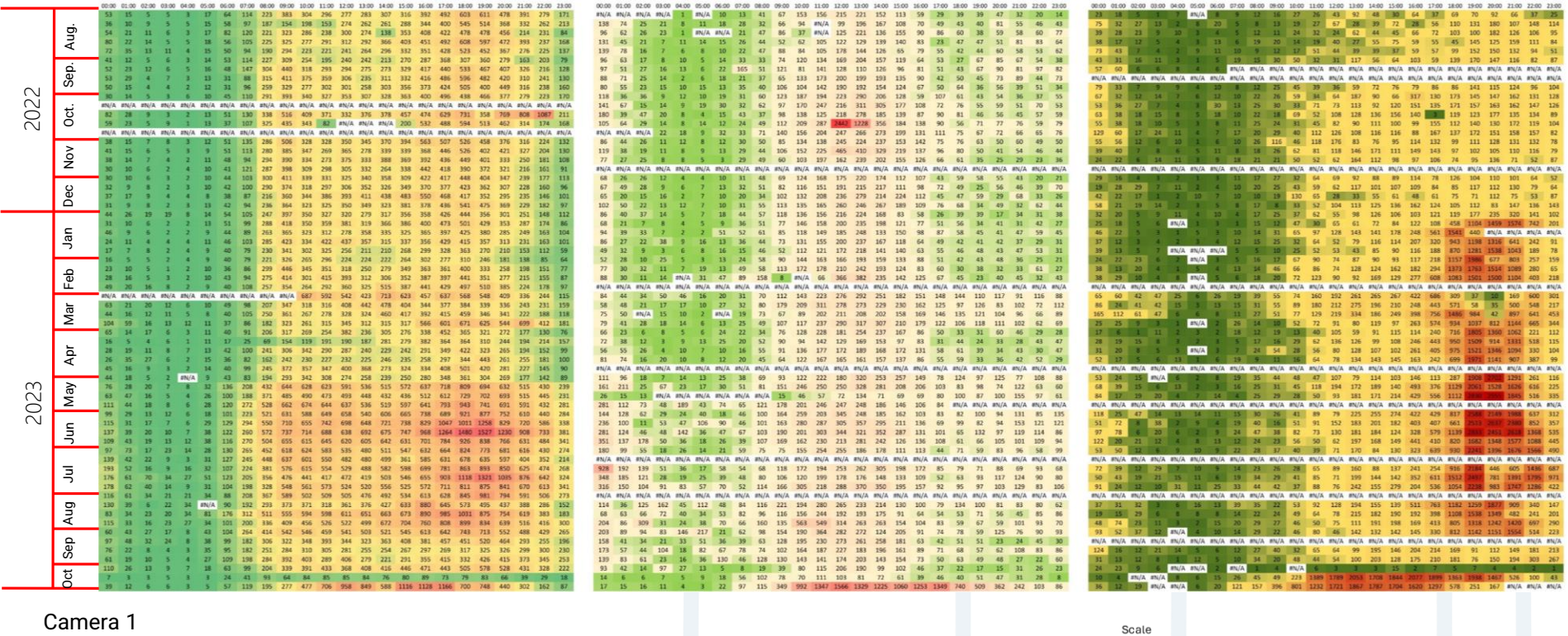
Pedestrian detection validation process

Camera 01			Accuracy
Date	Time	Day	Count
10/11/2022	17:00:03-17:09:59	Tuesday	99%
29/12/2022	18:00:38-18:09:59	Thursday	99%
04/01/2023	09:52:07-10:17:56	Thursday	92%
07/02/2023	09:00:14-09:29:59	Saturday	100%
15/03/2023	11:00:13-11:09:10	Friday	100%
02/04/2023	11:50:05-11:59:58	Tuesday	100%
23/05/2023	14:50:00-14:58:47	Thursday	83%
08/06/2023	17:01:00-17:10:00	Saturday	87%
20/07/2023	21:00:03-21:07:04	Thursday	96%
21/08/2023	15:00:12-15:09:58	Sunday	98%
06/09/2023	15:01:12-15:09:53	Wednesday	91%
02/10/2023	14:00:13-14:20:00	Monday	88%
Total accuracy			94%

Camera 04			Accuracy
Date	Time	Day	Count
10/11/2022	17:00:02-17:09:52	Tuesday	100%
12/11/2022	13:00:07-13:09:57	Saturday	100%
21/11/2022	14:00:54-14:10:00	Sunday	100%
29/12/2022	18:00:41-18:09:56	Thursday	100%
04/01/2023	09:57:02-10:31:53	Thursday	99%
07/02/2023	09:00:03-09:29:17	Saturday	100%
15/03/2023	11:00:203-11:09:09	Friday	100%
02/04/2023	11:50:10-12:00:00	Tuesday	100%
23/05/2023	14:50:03-14:59:55	Thursday	100%
08/06/2023	17:01:00-17:10:00	Saturday	100%
20/07/2023	21:00:02-21:06:37	Thursday	93%
21/08/2023	15:00:12-15:09:58	Sunday	97%
06/09/2023	15:01:57-15:09:53	Wednesday	94%
02/10/2023	14:00:13-14:19:58	Monday	99%
Total Accuracy			99%

Results: Weekly overview (weekdays, Fridays, Saturdays)

Distinctive seasonal difference, noticeable mainly on weekdays



Results: Monthly averages (weekdays)

Seasonal differences were more pronounced on Camera 1 than on Camera 4.

Both cameras recorded higher pedestrian volumes in the hot season, including during the daytime when heat stress is at its highest level.

Year	Month	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
2022	August	66	23	11	7	4	17	61	107	212	312	269	254	286	280	296	353	402	464	570	546	435	341	243	150
2022	September	49	20	7	6	3	14	43	114	274	372	302	272	275	250	267	320	371	425	487	424	365	265	225	122
2022	October	53	22	7	3	3	13	49	124	324	460	368	277	326	355	378	380	461	538	559	464	457	363	341	166
2022	November	40	16	10	6	4	12	48	112	280	419	347	294	376	330	349	368	441	455	535	456	387	299	199	120
2022	December	33	11	8	3	3	10	42	96	259	376	331	335	345	364	362	380	430	424	457	398	330	233	166	102
2023	January	35	13	9	4	5	11	48	97	266	392	333	354	342	316	320	342	362	420	436	368	301	242	154	94
2023	February	24	10	6	2	2	9	41	89	257	382	303	336	309	264	269	314	344	348	392	331	255	179	133	77
2023	March	64	30	16	13	7	10	40	97	217	340	302	343	389	370	496	423	451	487	517	456	406	380	253	143
2023	April	36	23	17	7	3	14	38	86	194	273	273	258	276	231	249	247	289	336	380	369	260	215	163	99
2023	May	66	32	14	6	6	24	94	180	372	519	531	516	525	455	420	457	508	597	696	633	553	429	339	191
2023	June	119	37	18	10	8	31	118	265	541	686	651	678	650	624	659	694	804	944	1049	1081	880	715	558	342
2023	July	159	61	30	18	14	34	121	236	410	599	583	545	519	479	533	525	631	745	871	891	777	611	472	271
2023	August	113	44	26	20	25	45	101	212	374	472	497	513	514	518	583	640	766	783	857	830	704	575	450	258
2023	September	73	33	20	13	6	37	102	207	322	390	407	373	398	352	359	395	425	460	487	514	448	366	333	237
2023	October	51	17	10	9	4	13	53	95	208	298	358	386	435	418	325	460	522	518	590	556	505	378	236	122

Camera 1

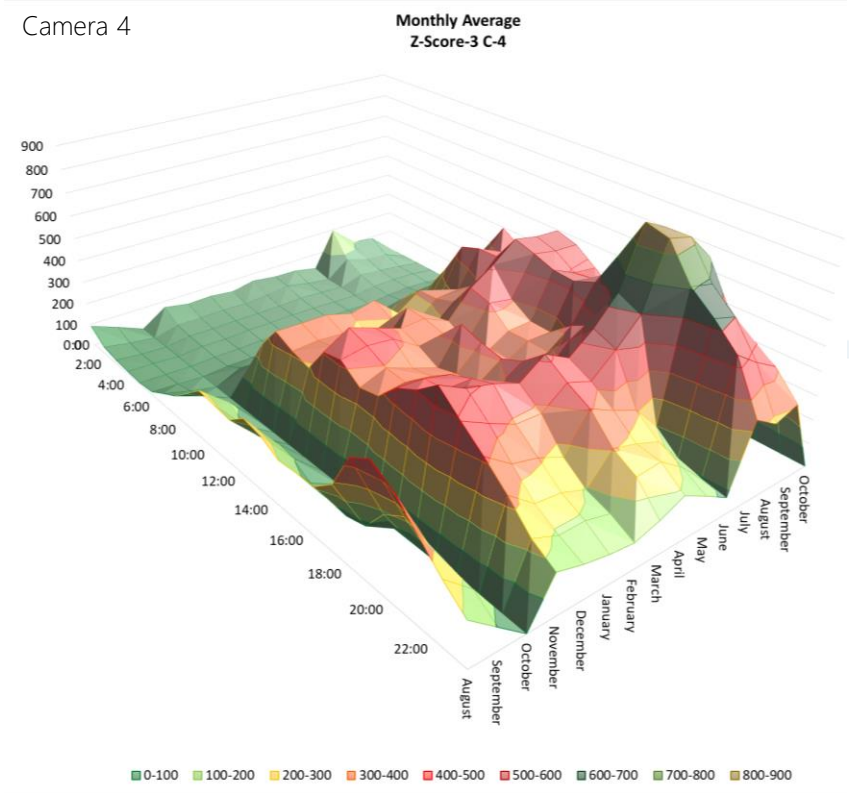
Year	Month	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
2022	August	90	34	18	11	6	15	57	97	158	225	214	204	264	247	203	212	217	287	447	499	447	356	263	187
2022	September	47	14	6	8	3	7	25	53	96	128	78	84	115	106	58	50	43	67	179	234	206	142	163	93
2022	October	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2022	November	71	26	15	10	4	9	48	114	258	353	315	292	404	421	358	376	458	501	570	491	416	332	234	175
2022	December	51	24	13	6	5	8	42	100	231	350	321	340	465	437	396	387	451	459	513	435	339	247	189	144
2023	January	55	26	15	13	6	10	50	102	232	348	312	330	425	425	353	369	424	457	488	385	312	236	189	123
2023	February	43	23	14	11	5	10	39	80	211	317	266	290	385	355	312	335	338	380	447	381	264	194	161	111
2023	March	64	30	16	13	7	10	40	97	217	340	302	392	389	370	453	423	404	442	517	456	406	307	253	143
2023	April	50	43	19	11	7	18	44	80	177	245	243	264	341	295	291	295	317	357	461	418	354	276	262	188
2023	May	48	21	14	7	6	18	57	108	238	313	317	346	447	424	348	351	352	450	537	502	310	237	189	132
2023	June	27	8	7	4	2	17	51	73	164	263	325	384	513	405	352	350	421	466	640	597	198	119	92	73
2023	July	194	82	37	17	12	25	116	188	307	445	474	477	590	565	534	528	564	715	874	849	709	632	540	338
2023	August	104	51	27	18	16	34	101	171	273	352	389	455	569	545	491	501	573	699	823	824	684	601	470	277
2023	September	90	41	15	14	10	27	89	182	340	468	417	459	564	539	476	412	410	483	742	716	544	473	412	310
2023	October	53	24	12	10	5	10	52	95	182	233	328	481	606	423	388	402	401	572	713	597	394	239	181	128

Camera 4

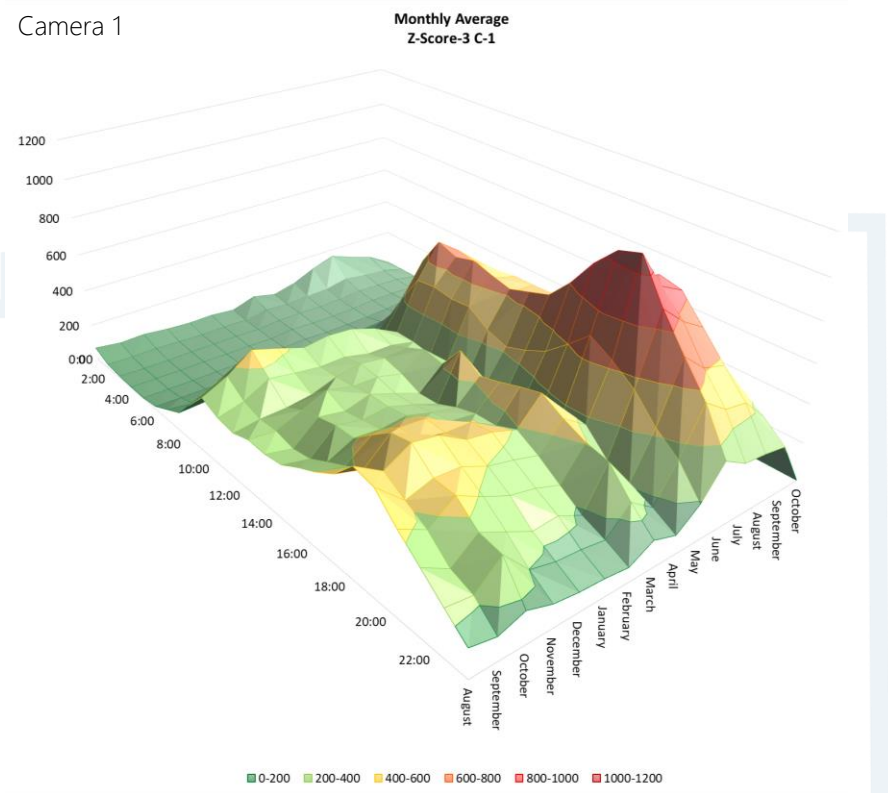
Results: Monthly averages (weekdays)

Distinct seasonal changes, different on each camera

Camera 4



Camera 1

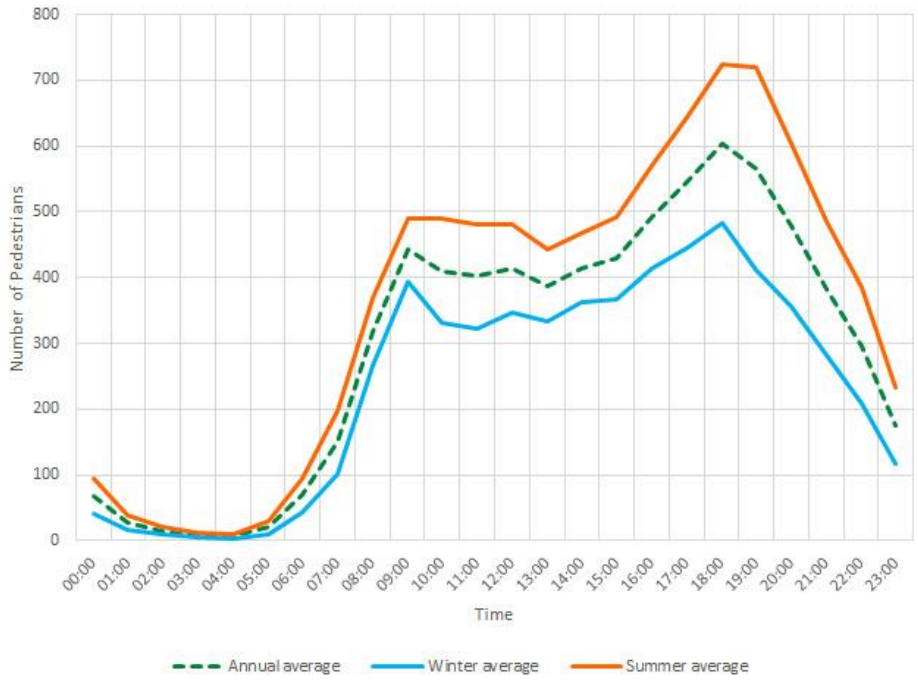


Results: Hourly averages (weekdays)

- Throughout the whole period (1.10.2022-30.9.2023)
- Average during the cold period (1.10.2022-31.3.2023)
- Average during the hot period (1.4.2023-30.9.2023)

Circadian rhythms are evident.

Different pedestrian flow volumes and their daily patterns are seen on each camera.

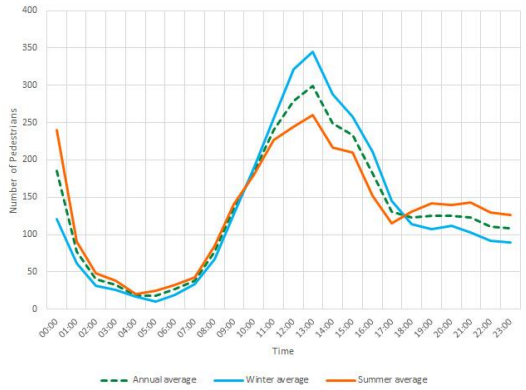


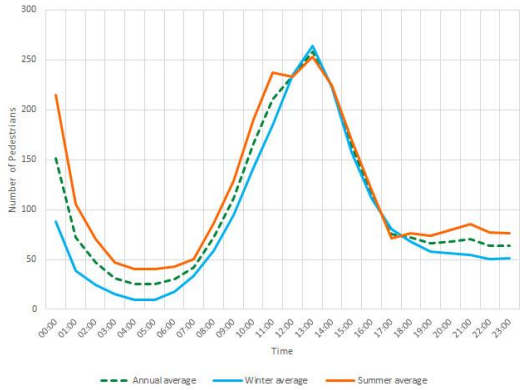
Results: Hourly averages (Fridays and Saturdays)

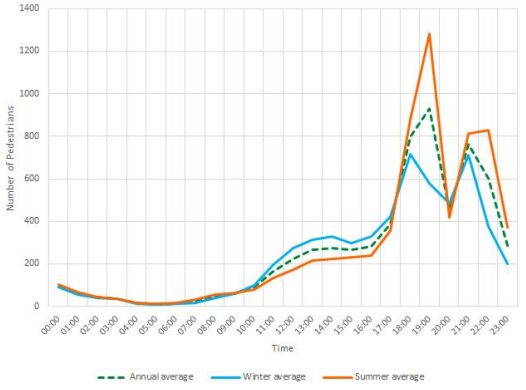
- Throughout the whole period (1.10.2022-30.9.2023)
- Average during the cold period (1.10.2022-31.3.2023)
- Average during the hot period (1.4.2023-30.9.2023)

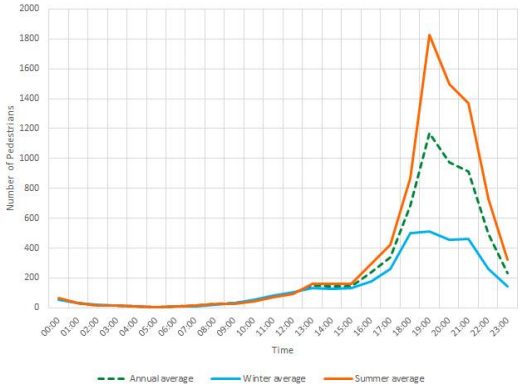
Circadian rhythms are evident.
Different pedestrian flow volumes and their daily patterns are seen on each camera.

The results on Saturdays were significantly influenced by massive demonstrations that took place each Saturday night in 2023.



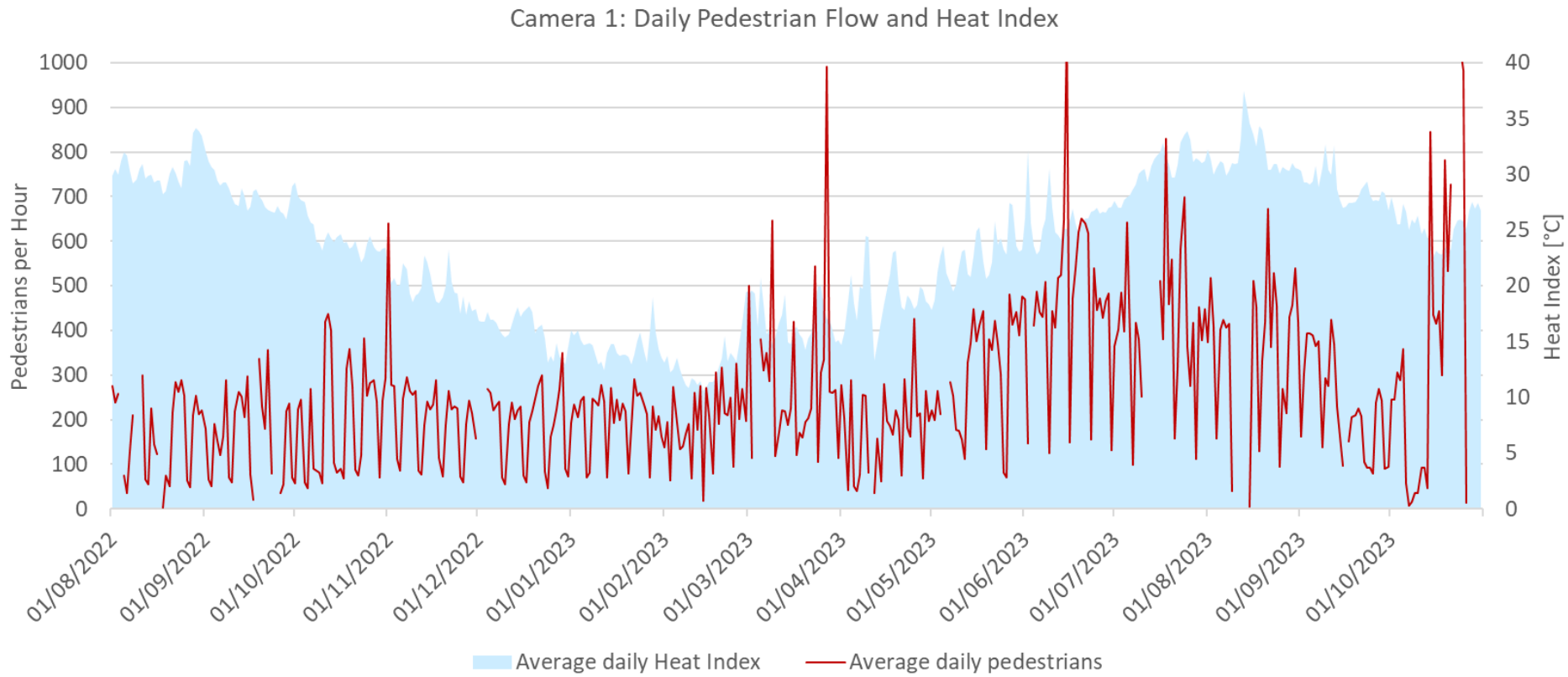






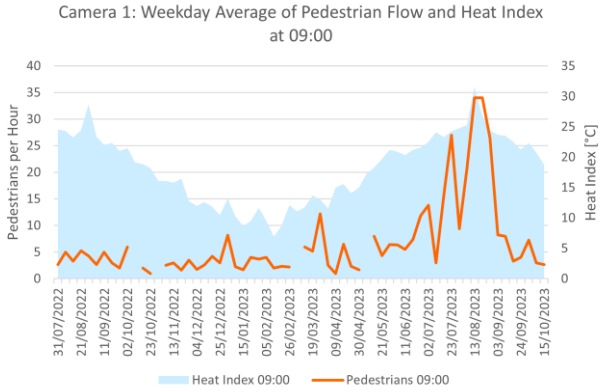
Results: Average hourly heat stress index and average hourly pedestrian count per day

The volume of pedestrians rises during the high heat stress period till mid-July.

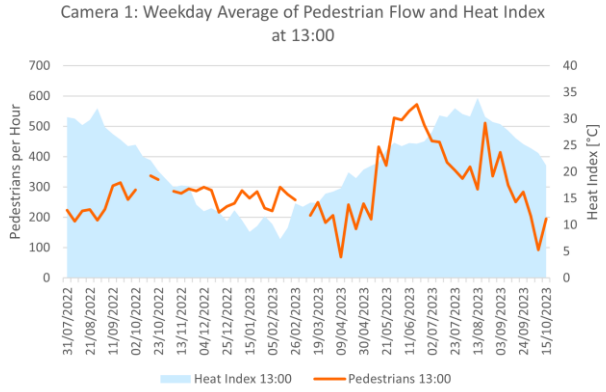


Results: Average hourly heat index and pedestrian count at different hours for the entire period

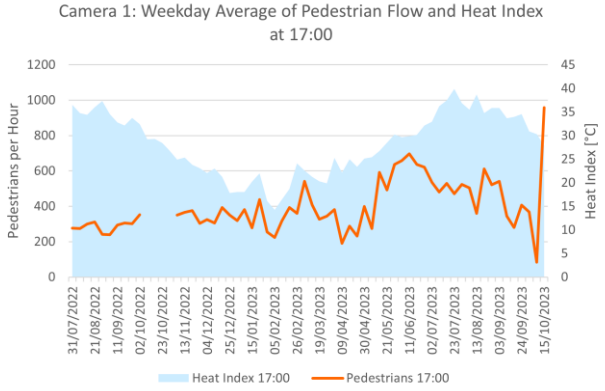
A rise in pedestrian volume occurs in tandem with the rise in heat stress.



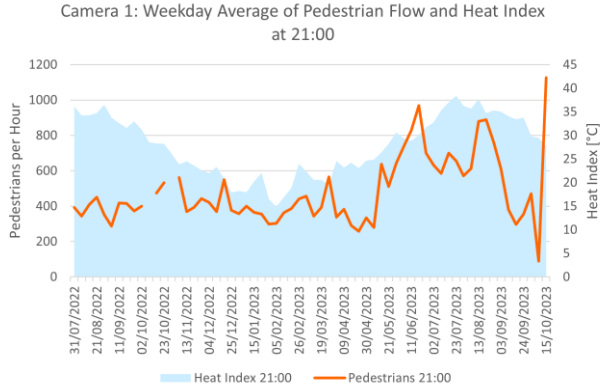
9:00



13:00



17:00



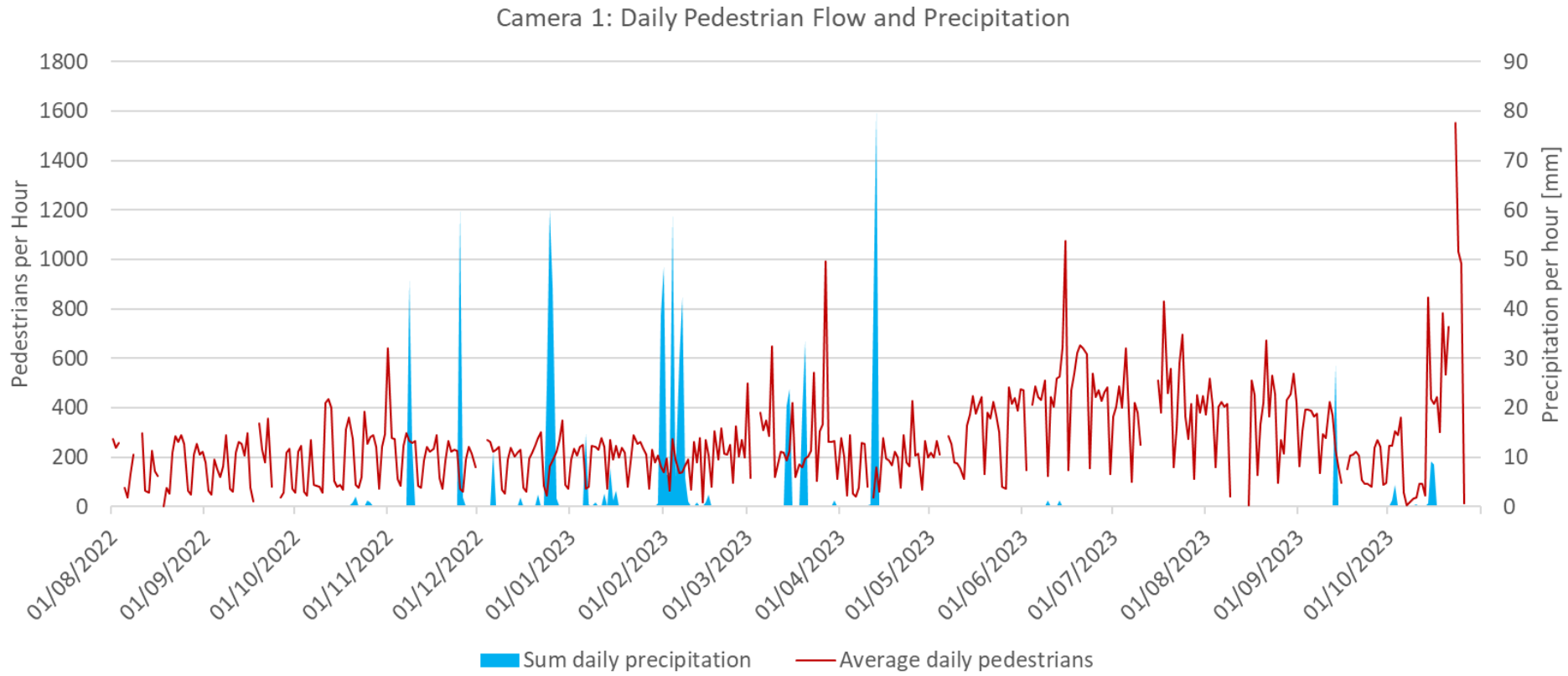
21:00

Heat Index

Pedestrians

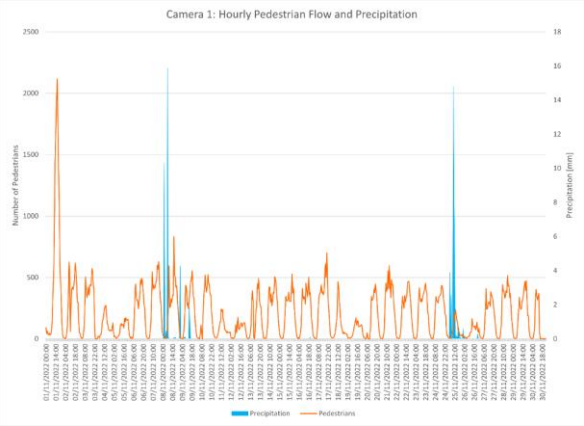
Results: Daily precipitation and average hourly pedestrian count

No significant relation was detected.

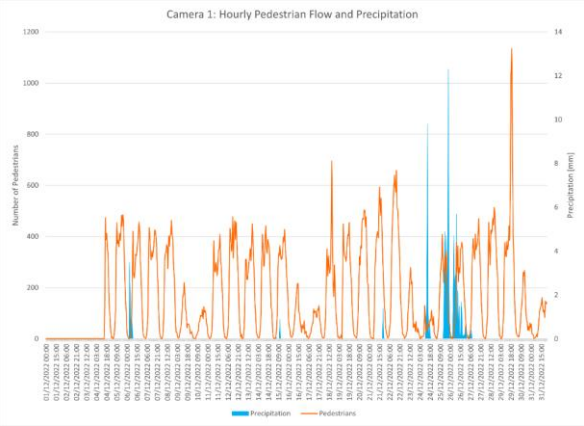


Results: Average hourly precipitation and pedestrian counts

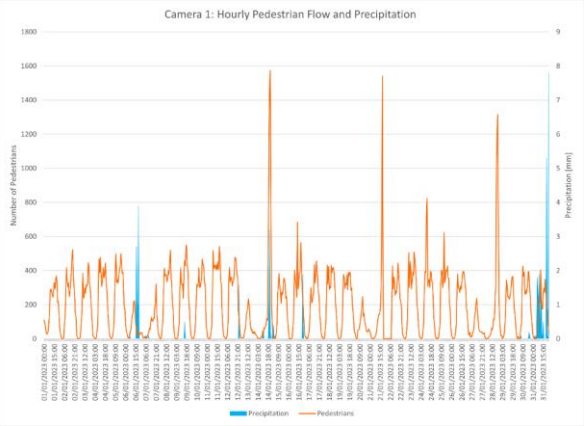
No strong correlation was detected between heavy rains and a decrease in pedestrian counts.



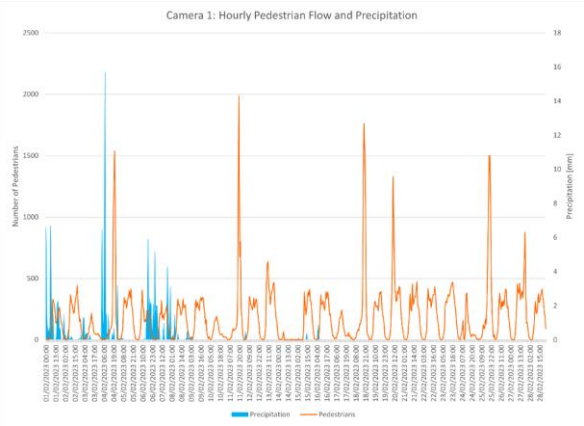
November 2022



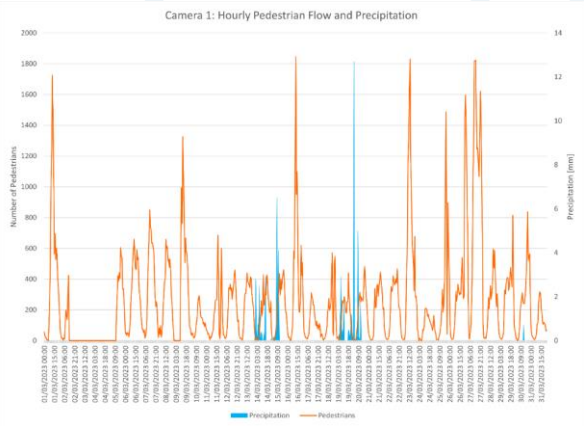
December 2022



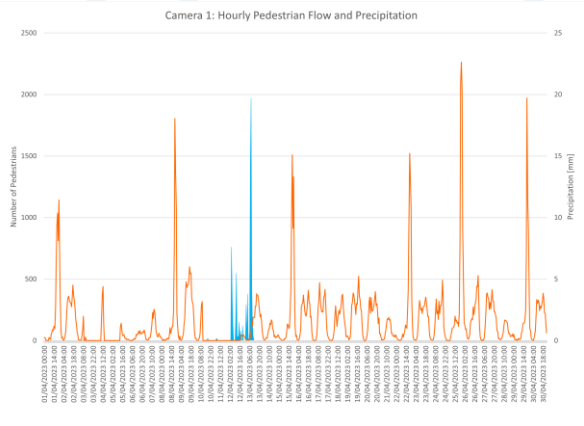
January 2023



February 2023



March 2023



April 2023

Precipitation Pedestrians

Results: Male-female average monthly ratio per hour (percentage of males)

Can we rely on VAI gender detection?

Male

Female

Year	Month	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
2022	August	63%	70%	67%	62%	67%	60%	67%	59%	54%	52%	54%	54%	60%	58%	54%	55%	54%	54%	54%	56%	60%	60%	59%	64%
2022	September	67%	72%	75%	75%	66%	46%	64%	53%	53%	55%	57%	55%	62%	64%	56%	56%	58%	57%	56%	62%	64%	57%	64%	65%
2022	October	73%	78%	69%	62%	72%	54%	71%	62%	53%	55%	57%	60%	63%	60%	53%	54%	54%	57%	61%	66%	64%	65%	64%	69%
2022	November	74%	69%	79%	69%	67%	56%	73%	61%	61%	58%	60%	61%	62%	60%	58%	55%	55%	65%	67%	67%	67%	68%	67%	67%
2022	December	75%	77%	79%	69%	61%	60%	72%	63%	61%	60%	61%	60%	62%	60%	58%	57%	55%	63%	65%	66%	68%	66%	70%	73%
2023	January	74%	69%	72%	75%	61%	43%	76%	67%	61%	61%	62%	62%	64%	65%	62%	59%	55%	63%	68%	68%	71%	71%	71%	75%
2023	February	68%	64%	65%	79%	53%	48%	74%	67%	66%	63%	64%	64%	66%	64%	63%	61%	59%	61%	67%	67%	68%	68%	68%	72%
2023	March	61%	64%	53%	49%	62%	56%	65%	61%	59%	59%	54%	53%	53%	58%	54%	53%	52%	52%	55%	57%	59%	60%	61%	61%
2023	April	74%	72%	81%	54%	67%	61%	69%	63%	60%	58%	60%	57%	62%	57%	55%	54%	55%	56%	58%	57%	60%	60%	61%	62%
2023	May	62%	69%	70%	56%	45%	65%	63%	58%	54%	54%	54%	53%	55%	52%	50%	50%	50%	54%	52%	51%	49%	49%	49%	49%
2023	June	47%	53%	52%	56%	57%	68%	66%	58%	55%	54%	53%	54%	52%	51%	49%	49%	50%	52%	49%	49%	41%	37%	38%	39%
2023	July	53%	55%	62%	68%	72%	63%	69%	60%	59%	57%	56%	57%	56%	56%	50%	52%	53%	58%	55%	56%	44%	43%	42%	45%
2023	August	50%	54%	52%	55%	60%	67%	60%	58%	57%	53%	57%	55%	51%	48%	53%	50%	53%	59%	54%	44%	44%	40%	43%	44%
2023	September	56%	48%	48%	48%	62%	51%	69%	58%	60%	58%	57%	55%	57%	56%	48%	47%	54%	55%	55%	49%	41%	46%	41%	41%
2023	October	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Camera 1

Year	Month	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
2022	August	65%	68%	59%	55%	52%	58%	50%	44%	43%	36%	33%	35%	41%	40%	36%	31%	27%	31%	36%	47%	63%	62%	65%	65%
2022	September	49%	44%	71%	55%	10%	70%	51%	35%	33%	26%	30%	20%	28%	31%	28%	18%	18%	30%	38%	46%	46%	39%	49%	50%
2022	October	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2022	November	67%	64%	70%	72%	63%	64%	61%	53%	43%	43%	50%	52%	51%	52%	51%	46%	47%	57%	58%	61%	63%	64%	64%	64%
2022	December	65%	63%	59%	56%	65%	56%	66%	53%	49%	53%	55%	51%	51%	55%	51%	48%	45%	55%	57%	59%	60%	61%	62%	67%
2023	January	62%	55%	54%	64%	71%	60%	63%	53%	47%	51%	55%	56%	55%	57%	53%	48%	45%	55%	61%	63%	63%	64%	64%	66%
2023	February	64%	64%	62%	55%	76%	64%	58%	48%	47%	51%	52%	51%	53%	55%	50%	50%	47%	49%	61%	63%	64%	63%	66%	67%
2023	March	58%	60%	55%	55%	63%	60%	55%	52%	47%	47%	47%	49%	54%	54%	50%	50%	48%	45%	53%	54%	57%	59%	58%	58%
2023	April	63%	57%	55%	75%	72%	59%	56%	49%	42%	41%	42%	44%	49%	48%	44%	42%	46%	44%	49%	46%	56%	58%	59%	57%
2023	May	57%	54%	55%	58%	47%	39%	42%	34%	28%	24%	24%	23%	28%	32%	29%	29%	30%	32%	32%	31%	52%	55%	58%	54%
2023	June	27%	18%	33%	0%	0%	4%	12%	13%	16%	13%	11%	10%	12%	13%	8%	8%	9%	8%	14%	11%	26%	29%	30%	29%
2023	July	62%	62%	68%	67%	80%	58%	55%	46%	44%	46%	45%	46%	51%	53%	49%	50%	53%	50%	52%	50%	54%	57%	55%	59%
2023	August	65%	62%	62%	68%	66%	59%	51%	48%	45%	45%	47%	51%	52%	51%	48%	49%	49%	49%	49%	51%	55%	54%	57%	61%
2023	September	63%	67%	64%	68%	73%	65%	55%	43%	44%	47%	49%	51%	57%	54%	48%	47%	49%	51%	49%	52%	56%	56%	57%	61%
2023	October	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Camera 4

Kaplan Street, Tel Aviv-Yafo

Source: Simplex 3D

Conclusions

- Different daily street circadian rhythms can be detected by measuring pedestrian flow volume on weekdays, Fridays, and Saturdays.
- The considerably higher pedestrian flow volumes recorded during the hot summer indicate the strong attraction of the street and underscore the need for climatic protection from heat using shading elements.
- Precipitation events did not seem to affect pedestrian flow volumes on the street.
- Different pedestrian flow patterns were detected at different locations along the same footpath.
- High-resolution pedestrian count over long stretches of time can reveal a complex picture and sometimes unpredictable pedestrian behaviour on different days and seasons.
- CCTV has a high potential to capture pedestrian flow patterns that are hard to detect using other pedestrian count methods.