



THE UNIVERSITY OF HONG KONG 香港大學
faculty of architecture 建築學院



iLab | @HKURBANlab
the urban big data lab

Computational Streetscapes

Big data, deep learning, and vector model

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Outline



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Background & motivation

.....●



Computational streetscapes

.....●



Discussion

.....●

Section 1

BACKGROUND & MOTIVATION



1.1 Background



◆ Streetscape

- Is a narrow and linear urban space lined up by buildings, used for circulation and other activities (Rapoport, 1987)

◆ Elements of streetscape

- Road, sidewalk and amenities, landscaping, street furniture, connections, background buildings
- Pedestrians, vehicles, animals, vegetation

◆ Computational streetscape

- A topic under urban informatics/computing
- Less laborious, more objective than manual audits

◆ For smart applications in many disciplines

- Landscape, planning, architecture, psychology
- Construction, conservation, logistics, robotics
- Business planning, valuation and taxation, etc.



Typical Hong Kong street scenes,
 (a) Hill Road near HKU West Gate
 (b) Hillier Street at Sheung Wan
 (source: Diamfleoss; DDMLL
 @Wikipedia CC BY-SA)



1.2 Upstream urban data



- ◆ Accurate, (near) real time, big data of streets
- ◆ Through many devices
 - ▣ Underground: Optical fiber network
 - ▣ Ground: AR phone, Internet of things, mobile scanner
 - ▣ Low-altitude: Drone, helicopter, plane (camera, laser, radar)
 - ▣ High-altitude: Satellite (camera, radar)
- ◆ In multi-dimension data
 - ▣ 0D points: Crowd-sourced location, wind, traffic congestion
 - ▣ 1D linear features: Vibration, deformation
 - ▣ 2D images: Aerial photo, satellite photo, heat map
 - ▣ 3D point clouds: Geometry, deformation
 - ▣ n D over time
- ◆ Some data associated with meanings
 - ▣ Tagged / annotated dataset



Google street view car
(photo: Wikipedia)



train/val – fine annotation – 3475 images



train – coarse annotation – 20 000 images

Tagged CityScapes dataset
(Cordts et al. 2017)



1.2 Downstream applications

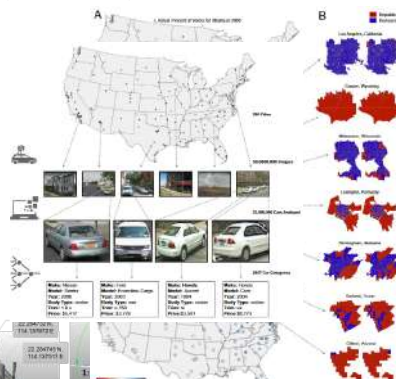


◇ For

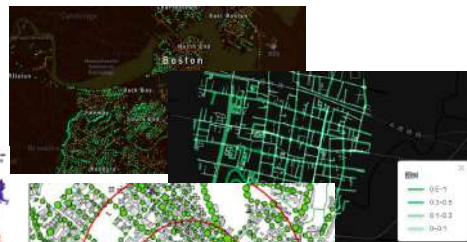
- ▣ Urban objects: forestry, shade, density, ...
- ▣ Users: walk, cycling, safety, comfort, election

◇ On top of, e.g.,

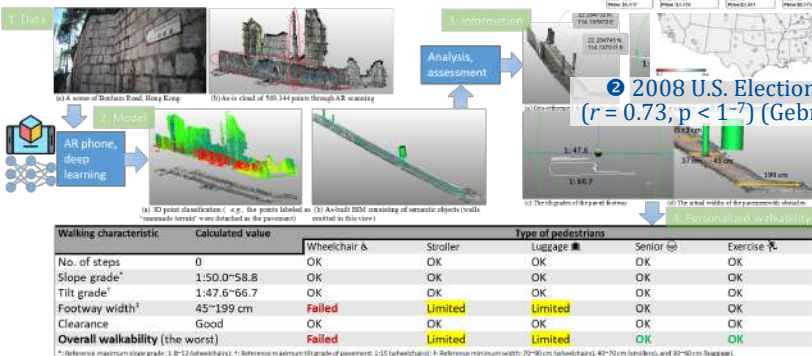
- ▣ ① Green view index
- ▣ ② Street car models
- ▣ ③ As-build 3D modeling
- ▣ ④ “Black-box” DL models



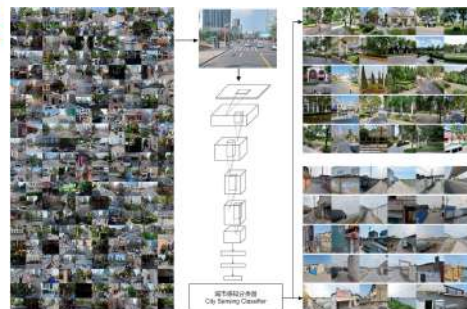
② 2008 U.S. Election prediction ($r = 0.73$, $p < 1^{-7}$) (Gebru et al. 2018)



① Green view indices for urban forestry & cycling (MIT 2017; Long & Liu 2017; Lu et al. 2019)



③ Personalized walkability assessment (sidewalk) near HKU (Xue et al. 2018)



④ Prediction (1-10 points) of safety & comfort street scenes in Shanghai (Liu et al. 2018)



1.2 Vector model & applications



◇ Vector algebra

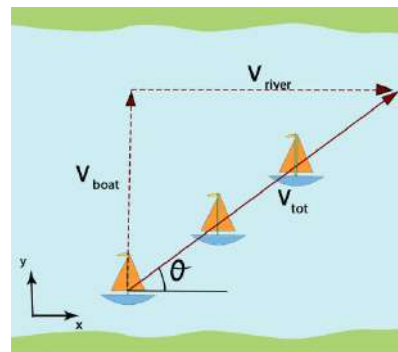
- ▣ $V_{\text{tot}} = V_{\text{boat}} + V_{\text{river}}$
- ▣ $V_{\text{river}} = V_{\text{tot}} - V_{\text{boat}}$
- ▣ $\cos \theta$: Closeness between V_{river} and V_{tot}

◇ Vector models (vector space models)

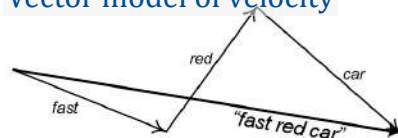
- ▣ In math and physics
- ▣ In natural language processing (Mikov et al. 2013)
 - “Einstein – scientist + painter” = Picasso

◇ Vector model about street elements ...

- ▣ *Hill Road* and *Hillier Street* sound very similar
 - But *how much* do they look alike?
- ▣ Can we *compute* a street as a vector of elements?
 - Vector operators $+$, $-$, $\times$, $\cos \theta$, *corr*
- ▣ What applications can be benefited?
 - How?



Vector model of velocity



Vector model of words



Vector model of streetscape? 7



1.3 Opportunity



◆ Gaps

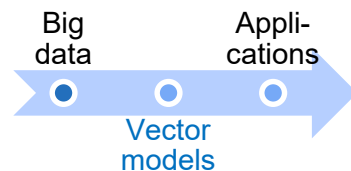
- ▣ Hard-coded processing / method
- ▣ Ad-hoc applications
- ▣ No reusing of valuable urban information

◆ Opportunity for a midstream study on

- ▣ A vector model of streetscape
- ▣ General math-like operations
- ▣ Multi-purpose usages / use cases

◆ Urban Big Data Platform (UBDP), HKU

- ▣ Multi-source big data
 - Including streetscapes
- ▣ Multi-scale urban information
 - Point, line, and area
- ▣ Supported by HKU Platform Technology Fund (\$915,870)
 - 2018—2020. PC: Prof. Webster



**AN URBAN BIG DATA
PLATFORM FOR
SMARTER HONG KONG:
INTEGRATE TO INSPIRE**
Key research topics

This project aims to develop an urban big data platform for Hong Kong's smart city ambitions. The platform serves as a vital midstream infrastructure of smart city, which feeds the upstream theories and data to the downstream applications.

UBDP introduction page
<http://fac.arch.hku.hk/ubdp>

The background of the slide is a photograph of a large, classical-style building with a prominent clock tower on the right side. The building features a long colonnade of columns. In the foreground, there are lush green palm trees and other tropical vegetation. The overall scene is brightly lit, suggesting a sunny day.

Section 2

COMPUTATIONAL STREETSCAPES



2 Method



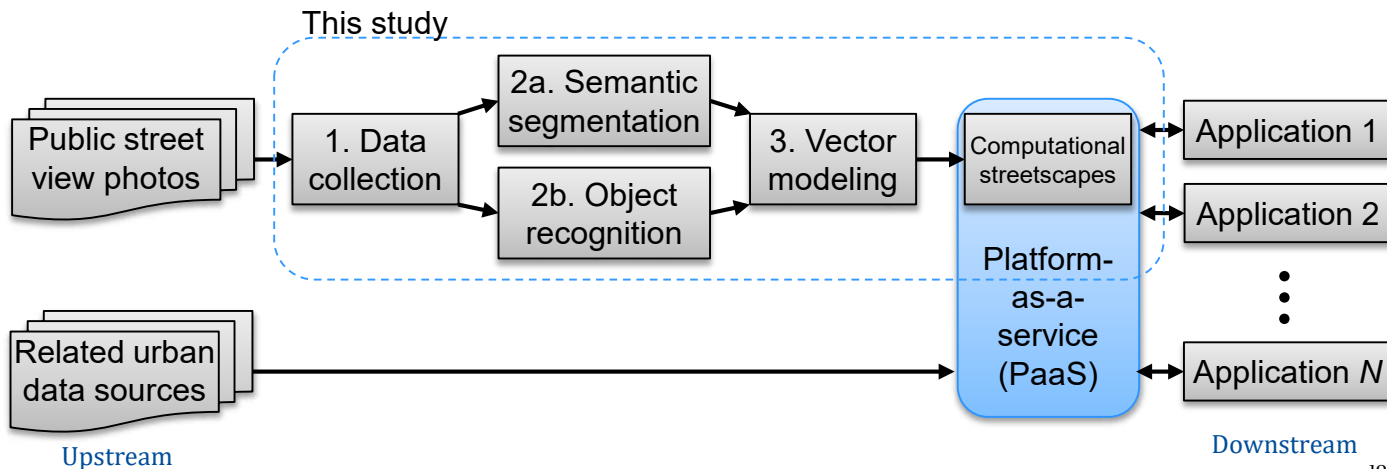
◆ Theoretical stance



- ▣ A midstream approach, distributed via Platform-as-a-Service (PaaS)

◆ 3 steps to channel upstream data to downstream

- ▣ Step 1: Data collection
- ▣ Step 2: Information extraction: (a) Semantic segmentation + (b) object recognition
- ▣ Step 3: Vector modeling





2.1 Step 1: Street data collection

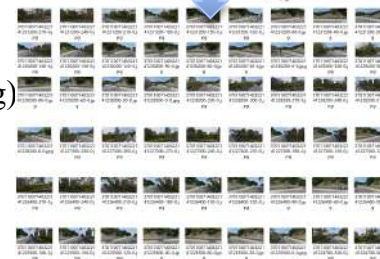


◆ Partner: Tencent Street View

- ▣ 2D images; Source: *NavInfo*
- ▣ Datum: GCS-02, not WGS-84

◆ The Hong Kong Island

- ▣ 78.6 km² Area
 - Both *high* and *low* density areas
- ▣ 3,625 road segments (473.35 km) with street views
 - Extracted from *OpenStreetMap* database
 - No data of steps / corridors / foot bridge / private road ...
- ▣ 42,683 panorama coordinates
 - Resolution: 8.58m between two points
 - Some shared at segment connections
- ▣ ~500,000 street photos (12 shots per point, every 30° heading)
 - 48 GB, Downloaded in ~10 days
 - Deep learning processing in 22 days
 - ~670,000 including connections, tunnels, ...



Data collection



2.2 Step 2a: Elements from semantic segmentation



◇ Semantic segmentation

- ▣ DL model: *DeepLab* v3 CNN (trained on *cityscape*)

◇ Area by counting pixels

- ▣ Construction: Building, infrastructure, wall
 - E.g., 45% + 0% + 2% = 47%
- ▣ Sidewalk: Walking path, guardrail
- ▣ Greenery: Vegetation
- ▣ Other: Sky, street signs, etc.

◇ Lines by counting vertical image slices

- ▣ Sidewalk, guardrail, unguarded sidewalk

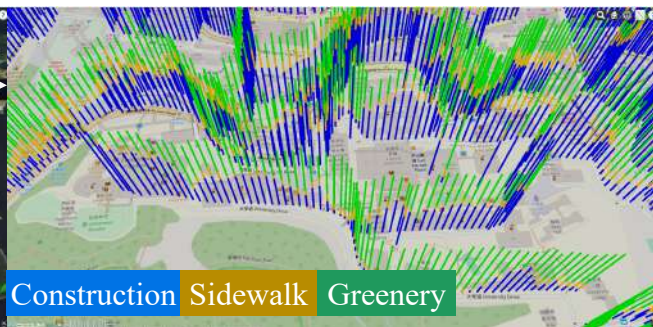




2.2 Results of Step 2a

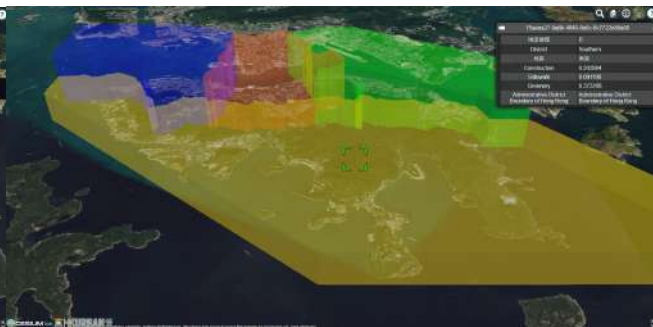
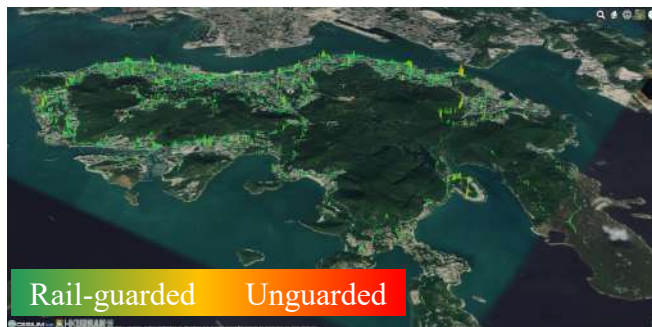


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(a) Green view is high except for the high-density areas

(b) Visual fields around HKU Main Campus



(c) Level of sidewalk railing is satisfactory in general

(d) Average percentages of elements in the four districts



2.2 Step 2b: Elements from object recognition



◆ Object recognition

- ▣ DL model: *Luminoth* v0.2.4 RNN (trained on COCO)

◆ Counting objects

- ▣ Vehicles: Cars, buses, trucks, motorcycles, bicycles
- ▣ Personal: Persons, backpacks, handbags
- ▣ Street furniture: Traffic signs, traffic lights, bench, fire hydrants, ...
- ▣ City animals: Cats, dogs, birds

◆ Actions of people

- ▣ Walking / standing: On a sidewalk, behind a guardrail (using segmentation results)
- ▣ Road crossing: On a roadway, in front of a vehicle

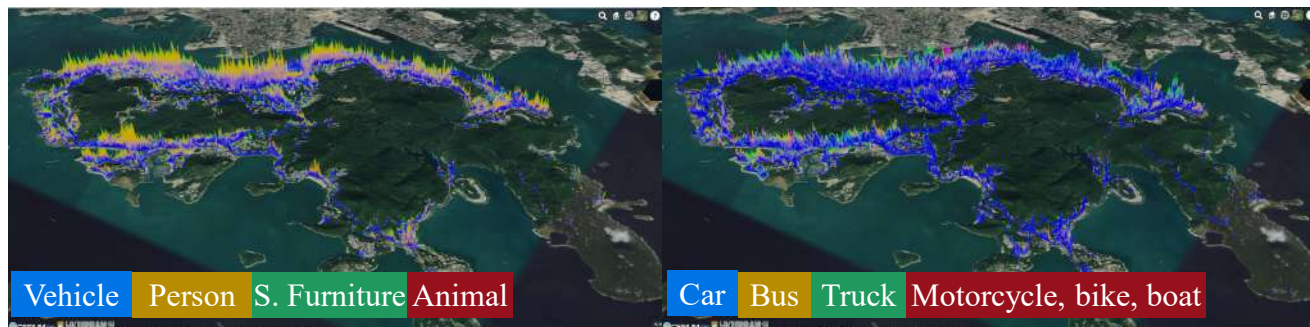




2.2 Results of Step 2b

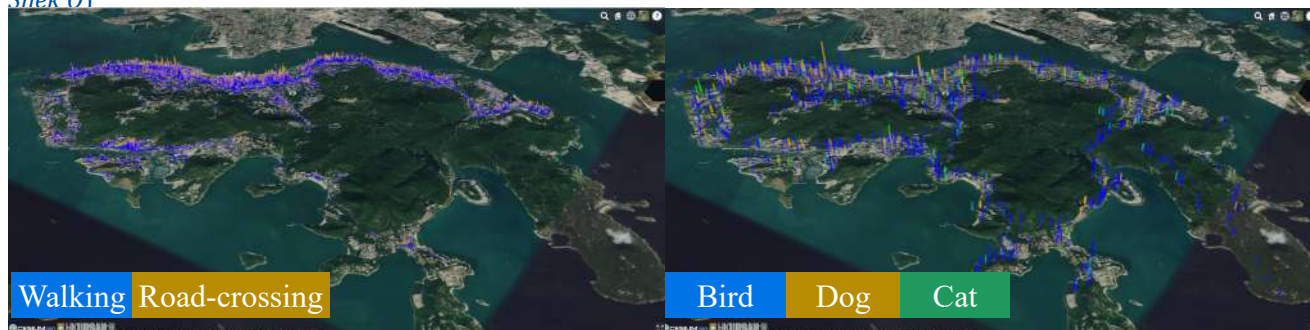


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(a) More vehicles and persons in high-density areas; Street furniture and animals relatively even (except for *Shek O*)

(b) More buses in residential areas; trucks on major roads



(c) More people walking in high-density (less greenery) areas

(d) Dogs/cats found in residential areas; more birds in low-density areas

>>[DEMO LINK](#)<<



2.3 6D vector modeling

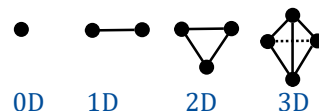


◇ Vectorization of 6 major street elements

- ▣ Construction, sidewalk, greenery, vehicles, persons, street furniture
- ▣ Balanced and normalized for each explicit dimension

◇ Hong Kong Island Datasets

- ▣ 0D “point” data table (panorama coordinates) Better for elements/behavior analyses
 - 42,683 vectors
- ▣ 1D “street” data table (roads)
 - 784 vectors
- ▣ 2D “District” data table (election district)
 - 4 vectors



Better for calculus

◇ Vector calculus

- ▣ Norm ($||$), addition (+), subtraction ($-$)
- ▣ Multiplication ($\times$), division ($/$), dot product ($\cdot$)
- ▣ Cosine similarity ($\cos$), correlation (ρ)
- ▣ Gradient (∇), Laplacian (Δ)



2.4 Use case 1: Logarithmic usage of street



◆ Number of street users at a point obeys logarithmic distribution

▣ Vehicles seen

- Volume: Blue,
~322,000
- Max: ~55

▣ Pedestrians seen

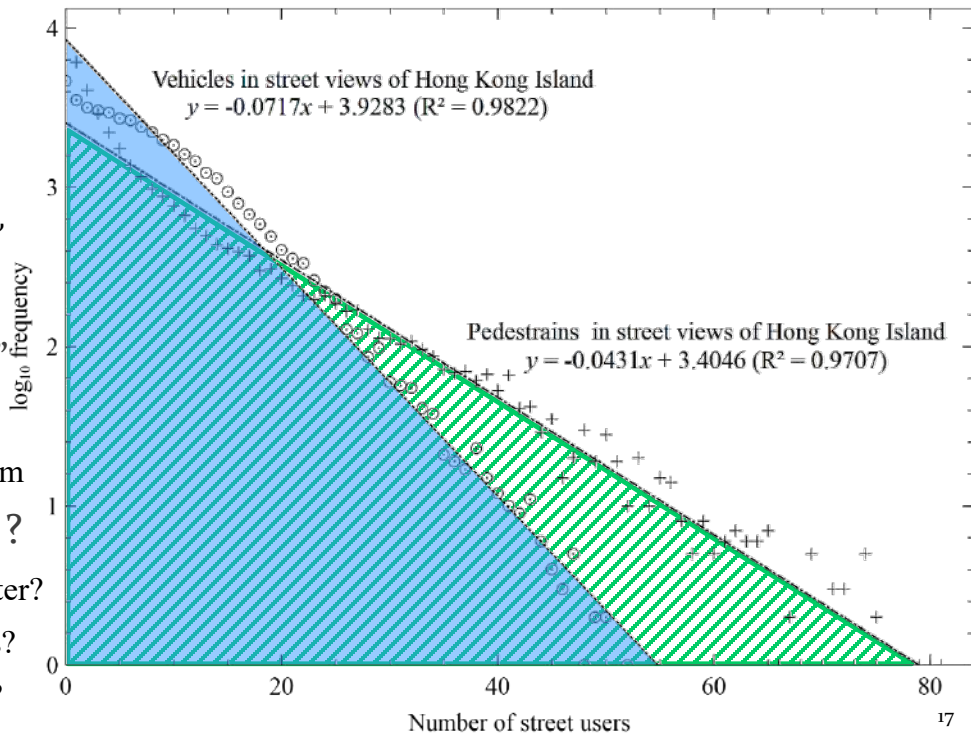
- Volume: Green,
~237,000
- Max: ~80

◆ Average “density”

▣ $237,000 / 473.35$
= 500.7 pedestrians/km

◆ Unique behavior ?

- ▣ People always cluster?
- ▣ Urban health issues?
- ▣ Similar elsewhere ?





2.4 Use case 2: Streetscape algebra



◇ Similarity between *Hill Road* and *Hillier Street*

▣ Cosine similarity: $\cos \theta = \mathbf{A} \cdot \mathbf{B} / |\mathbf{A}| \times |\mathbf{B}| = 0.7673$

▣ 76.73%

◇ “*Queen’s Road West – Central Western District* *+ South District* = _____?”

▣ $\mathbf{C} - \mathbf{D} + \mathbf{E} = [-0.02706, -0.01939, 0.014958, -0.05959, 0.043838, 0.010644]^T$

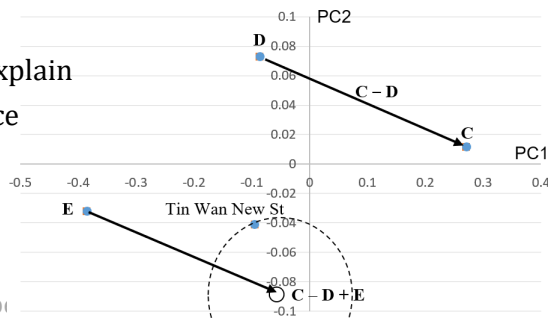
▣ The closest street in South District is

- Tin Wan New Street (distance = 0.1209)

▣ “*Queen’s Road W to Central & Western District* is roughly equivalent to Tin Wan New Street to *South District*.”

▣ As illustrated

- PC1 & 2 explain 65% variance



Vectors of Hill Rd (A) and Hillier St (B)

Dimension	Hill Rd (A)	Hillier St (B)
Construction	0.186837	0.305023
Sidewalk	0.011774	-0.148464
Greenery	-0.09866	-0.210708
Vehicles	-0.09689	0.049695
Persons	0.034738	0.157678
S. Furniture	0.052523	0.116280

Vectors of Queen’s Rd W (C), Central Western (D), and South (E)

Dimension	Queen’s Rd W (C)	Central & Western (D)	South (E)
Construction	0.195057	-0.07714	-0.29926
Sidewalk	-0.07509	-0.03884	0.016865
Greenery	-0.16886	0.070689	0.254503
Vehicles	0.011577	-0.02056	-0.09173
Persons	0.103898	-0.04118	-0.10124
S. Furniture	0.052947	-0.01499	-0.0573

Closest street vectors to $\mathbf{C} - \mathbf{D} + \mathbf{E}$

Rank	Street name (South District)	dist
1	Tin Wan New Street	0.120894
2	South Horizon Drive	0.122902
3	Lee Hing Street	0.143904
4	Yi Nam Road	0.145450
5	Aberdeen Main Road	0.163997
6	Kwun Hoi Path	0.189905
7	Wah Fu Road	0.207953



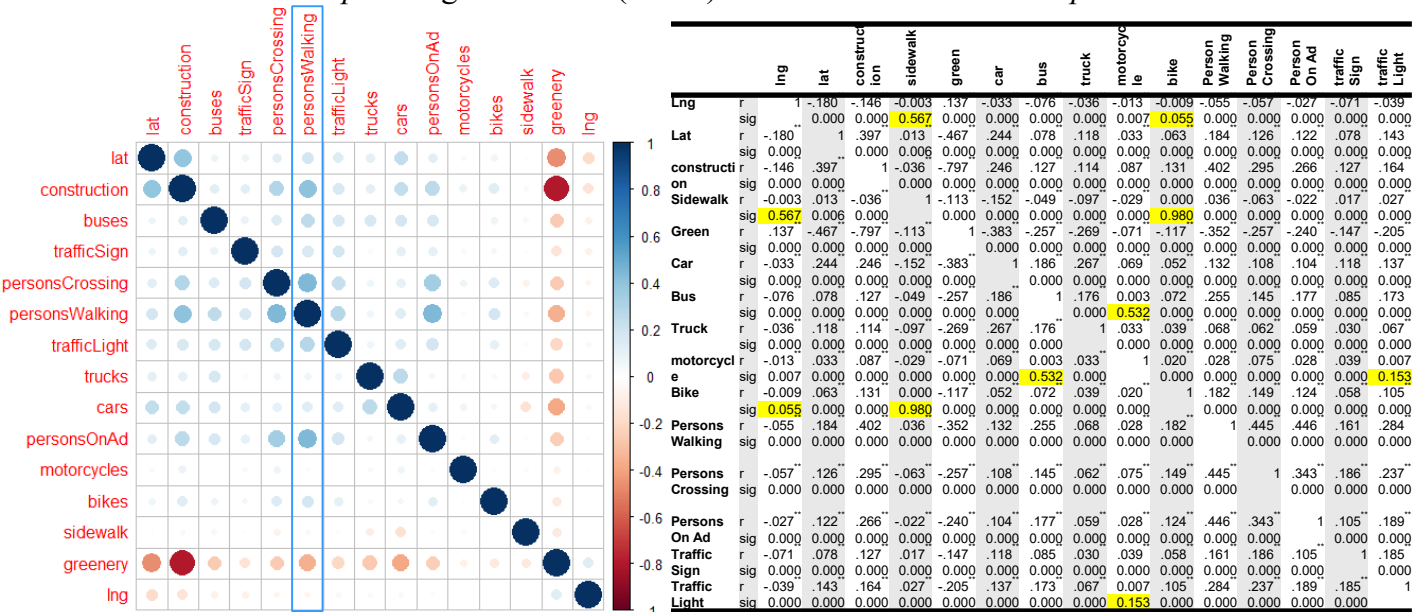
2.4 Use case 3: Street element clustering



Clusters based on Pearson's correlation



- “Nature” {longitude, greenery}, {sidewalk}, and “town” {others}
- Walking in HK Island: Positive r to building, road-crossing, & ad.; Negative to green
- Beware of p for big data: Most (>95%) bivariate correlations had $p < 0.00001$



The background of the slide is a photograph of a large, ornate building with a clock tower, likely a university or government building. The building is light-colored with many windows and columns. In the foreground, there are lush green palm trees and other tropical vegetation. The sky is a clear, pale blue.

Section 3

DISCUSSION



3.1 A wrap-up



◆ Work done

- ▣ 3 steps for computational streetscapes
 - Big data collection, RNN and CNN processing, and vector modeling
- ▣ 3 use cases of computational streetscapes
 - Logarithmic use behavior, street algebra, Street element clustering

◆ Pros

- ▣ Big data, objective and low-cost
- ▣ Automatic processing
- ▣ Mathematical modeling and calculus
- ▣ Multiple potential applications

◆ Cons

- ▣ Limited by explicit, major street elements
 - Orthogonal decomposition
- ▣ Some DL results are erroneous
 - Small elements, e.g., fire hydrants
- ▣ GCJ-02 obstruction to WGS-84



3.2 In a life-cycle view



◆ Streetscape

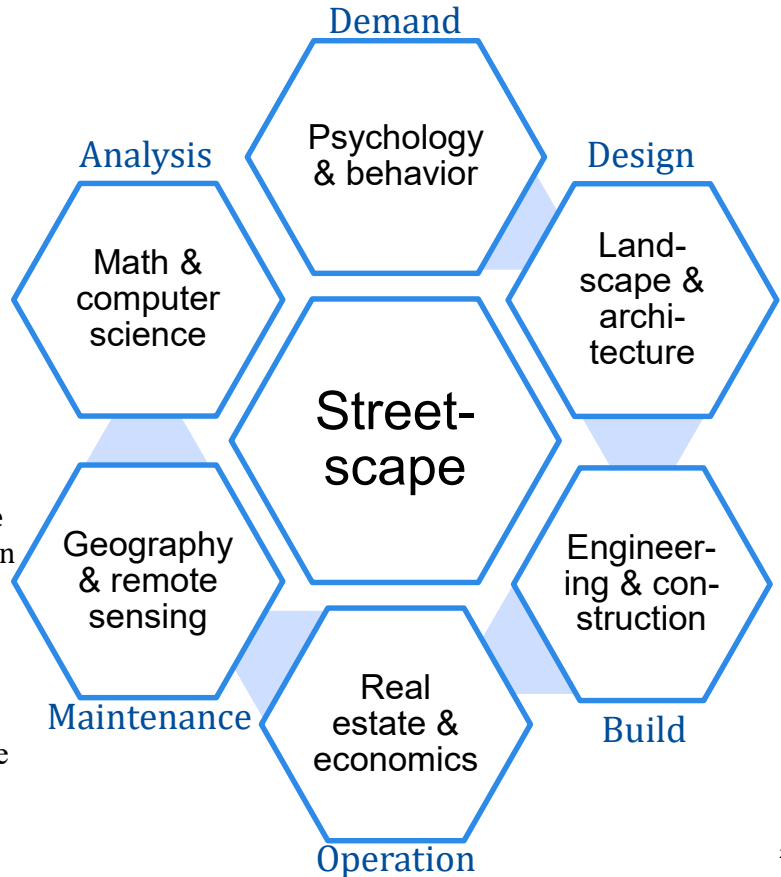
- ▣ Small but influential
- ▣ Has a typical product life cycle

◆ Many disciplines needed

- ▣ 10+
- ▣ Each focuses certain phases
- ▣ Calling for cross-disciplinary collaboration
 - E.g., explaining the log distribution, comparing the demand and supply of green on streets

◆ Linking related big data

- ▣ 3D: Aerial LiDAR, ...
- ▣ Buildings: Ownership and price
- ▣ Demography: Age distribution, education, income, ...





3.3 Future work



◆ Future work

- ▣ Minor elements
- ▣ Implicit vector space
 - Fully independent dimensions
- ▣ Integrating multi-source urban big data
- ▣ Kowloon and New Territories

◆ Collaboration opportunities

- ▣ ITF Midstream Research, RGC Research Impact Fund, RGC Collaborative Research Fund
- ▣ Based on the “Urban Big Data Platform: Integrate to inspire” project
- ▣ Contact: Prof. Chris Webster

◆ Acknowledgements

- ▣ The work was supported by HKU Platform Technology Fund (PTF)
 - In partial by RGC (17200218), SPPR (S2018.A8.010.18S), NSSFC (17ZDA062)
- ▣ Street view data granted by partner Tencent (Guangzhou)





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THANK YOU !