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the urban big data lab

THE HONG KONG POLYTECHNIC UNIVERSITY 香港理工大學

JC STEM Lab of Earth Observations
The Hong Kong Polytechnic University

Research Centre for Artificial Intelligence in Geomatics
The Hong Kong Polytechnic University
地理空間智能研究中心

RILS 土地及空間研究院
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GRSS
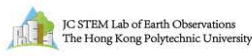
9&10 DEC 2023

Workshop on GeoAI and Big Data
for Urban, Environment, and
Sustainability cum

Research Centre for Artificial Intelligence in
Geomatics

Bridging the gap between point clouds for GeoAI:
Role of supervised, reinforced and unsupervised learning

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10 December 2023, Hong Kong, China

Introduction to HKU iLab – the urban big data lab

◈ https://ilab.hku.hk/

◈ 44 active members

◈ >25 alumni

My background

◈ Xue, Fan (Frank)

◈ Edu. background

- ▣ BEng in Automation
  - 2004
- ▣ MSc in Computer Science
  - 2007
- ▣ PhD(PolyU) in System Engineering
  - 2013
- ▣ PDF*/RAP/AP in Construction IT

◈ Research interests

- ▣ Urban sensing and computing
- ▣ As-built BIM and Digital Twin
- ▣ Automation/IT in construction
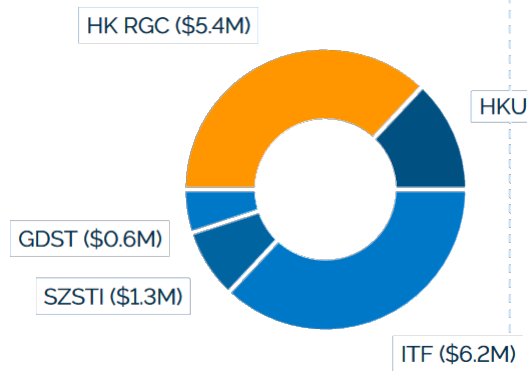- ▣ Operations research, ML
- ▣ Blockchain applications in construction

◈ Professional

- ▣ MACM, MHKGISA, MIEEE, SMCGS, MASC,
- ▣ Vice-Chair ACM-HK, Com. CGS-BIM, Com. ASC-Smart Construction

◈ 15M grants, 150 papers, 30 awards

HK RGC ($5.4M)
HKU
GDST ($0.6M)
SZSTI ($1.3M)
ITF ($6.2M)

INTRODUCTION TO POINT CLOUD AND GEOAI

1 GeoAI

◈ The world we live

    ◘ Needs in-depth knowledge

    ◘ For sustainable development

◈ GeoAI

    ◘ First coined at ACM SIGSPATIAL 2017

        ○ "AI for Geographic Knowledge Discovery" Workshop (6th GeoAI this year)

        ○ A.k.a. "Geospatial AI"

    ◘ Enriches a computer technology 'AI' with 'Geo' knowledge, to me

        ○ E.g., database → GIS, with geographical concepts and spatial laws

    ◘ Contributes to the SDGs, *hopefully* back to computer science, too

        ○ Like GIS → graph database,

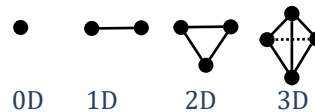   due to intensive geometric (e.g., intersection), topological (paths), metric operations (distance buffer)

1 3D point cloud

◈ 3D Point

 ▣ A location in space, 0D (no width, length, or thickness)

 ▣ Structured format: {x, y, z}, [R, G, B, Nx, Ny, Nz, Cls, Int., …]

◈ Cloud

 ▣ An unstructured collection [of water droplets or ice crystals]

 ▣ Dense when looking at a distance, sparse closely

◈ Urban point cloud

0D   1D   2D   3D

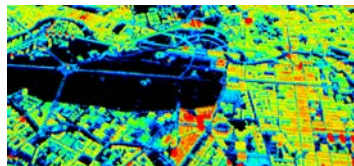A point cloud of HKU Campus (Source: Author, 2019)
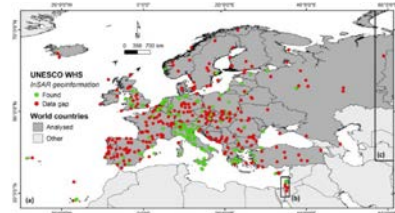

A close look of cloud at Mount Hua (Source: Author)

1 Sources and typical applications

◈ SAR
- ■ mm-accuracy
- ■ Coverage

◈ LiDAR
- ■ mm/cm/dm
- ■ No distortion
- ■ Intensity

◈ Photogrammetry
- ■ cm-accuracy
- ■ Colorful
- ■ Cheaper

◈ Use cases
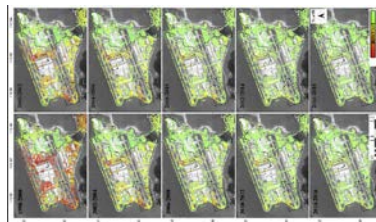
Ground settlement, UNESCO heritage sites (Wu et al. 2020a; Tapete & Cigna 2017))
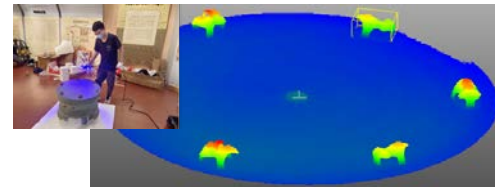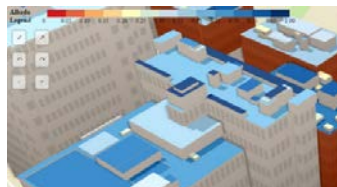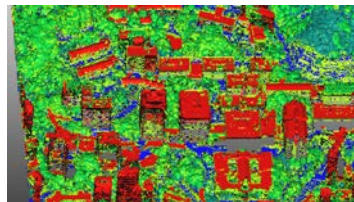
3D details (Xue et al. 2019b), indoor CFD simulation (Source: Xue 2023a)

Kowloon Wall City 3D model
(Source: patrick-@sketchfab.com)
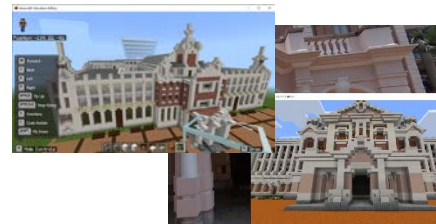
HKU @MineCraft (Source: Xue et al., 2023b)

1 Gap between the points for GeoAI

◈ Semantic gap [Point-level]

 ▣ No geo knowledge representation, e.g., class, materials, etc.

 ▣ "semantic labeling"

◈ Relational gap [Point patch-level]

 ▣ "unstructured [collection of] data"

 ▣ "object detection" as patch

 ▣ Patch to geo object

◈ Hierarchical gap [object level]

 ▣ Taxonomy and system of geo objects

◈ Other issues

 ▣ Spatial occlusion, clutters, uneven density, etc.
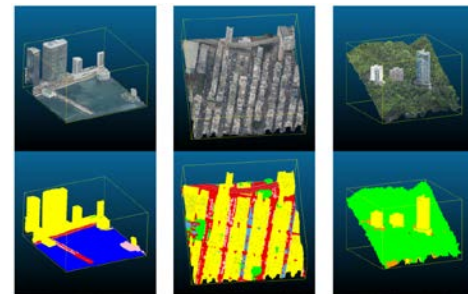
Semantic labels
(Li et al. 2023)

Heritage building 3D scan:
廣同會館 30 million points
(Source: OkayGIS, 2021)

Section 2
ML'S ROLE

2.1 Supervised Learning

◈ Supervised learning

  ▣ E.g., most deep learning

  ▣ Labels each point

  ▣ Fills the semantic gap

  ▣ Needs annotation data (🏷 🏷 🏷)

◈ HRHD-HK dataset

  ▣ Based on PlanD (2019) 3D model

  ▣ World only HRHD dataset, with sea & mount

  ▣ 7 semantic labels, 9.375 km2

  ▣ 273 million color points, in HKGS 1980

  ▣ Download https://doi.org/10.25442/hku.23701866.v1

Building ■ Vegetation ■ Road ■ Waterbody ■ Facility ■ Terrain ■ Vehicle
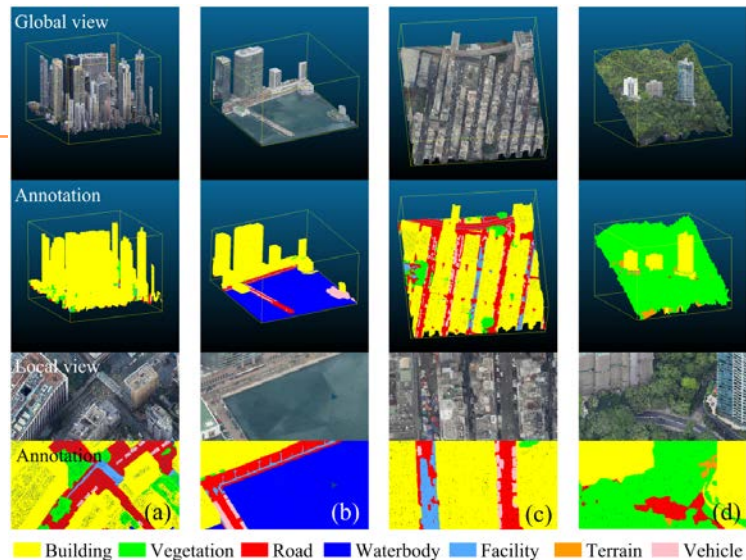
Group	DL method	Ref.	Overall metric (%)		
			OA	mAcc	mIoU
Voxel	SparseConvUnet	[11]	88.71	70.24	58.46
2D proj.	BEV-Seg3D-Net	[12]	89.18	73.25	61.14
Graph	SPGraph	[13]	85.32	58.53	49.86
Kernel	KPConv	[14]	91.23	71.53	63.81
MLP	PointNet	[15]	77.49	61.98	47.50
	PointNet++	[16]	79.85	66.95	52.52
	RandLA-Net	[17]	90.39	**78.81**	64.76
Trans.	StratifiedTransformer	[18]	**92.30**	76.99	**68.08**

(Li et al. 2023)

2.1 Further GeoAI

◈ Enhancing the AI with <u>Geospatial knowledge</u> (*a working paper*)

- ▣ + HK boundary, rough footprint, DTM, road network
- ▣ Improved deep learning on F_0

Legend: Building, Vegetation, Waterbody, Road, Facility, Terrain, Vehicle, Mask
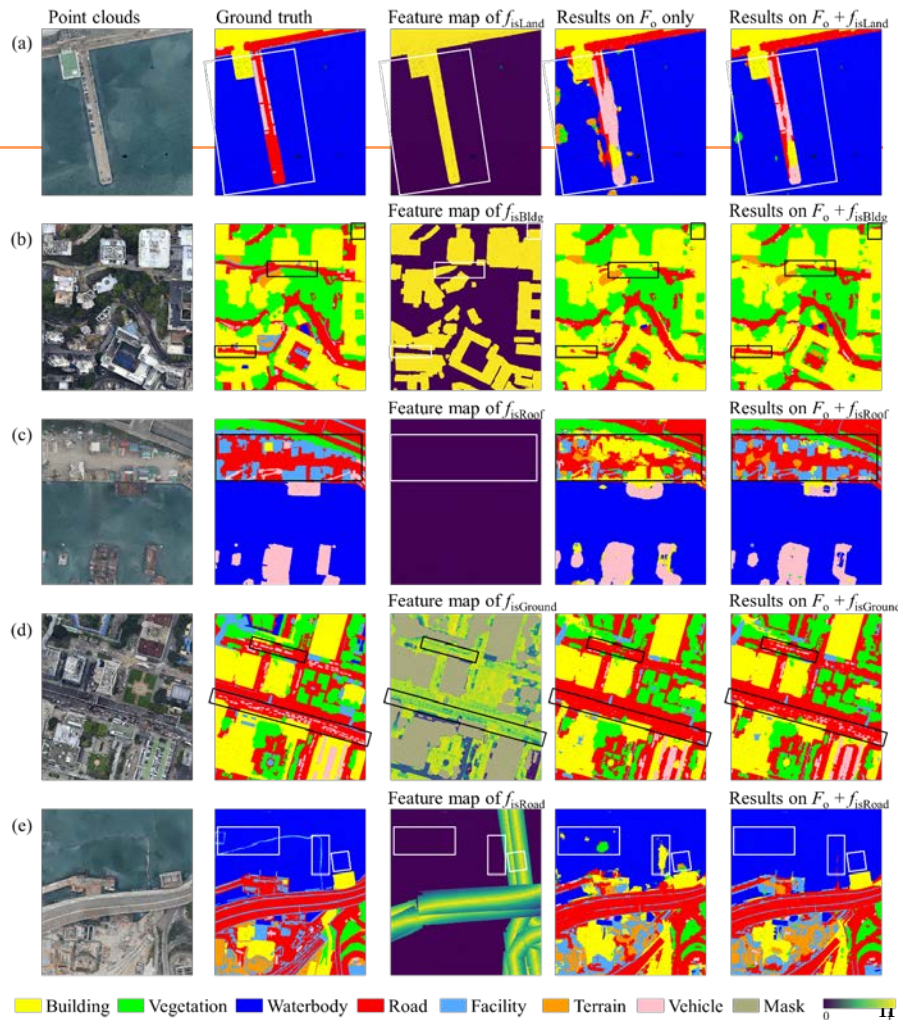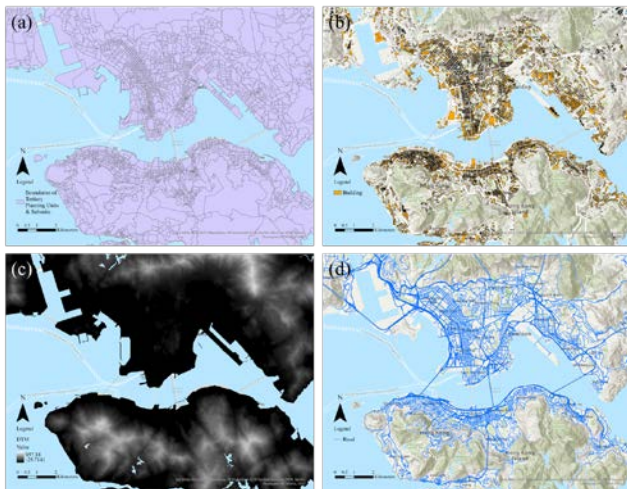
2.2 Reinforced learning

◈ Reinforced learning

- ☐ <u>Evolves</u> iteratively from <u>reward functions</u>
- ☐ Match points to similar 3D objects
- ☐ Partially fills the relational gap

Time = 6.44s (Manual > 300s)

RMSE = 3.87 cm
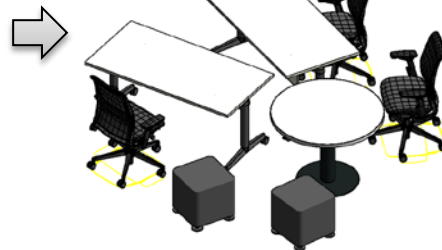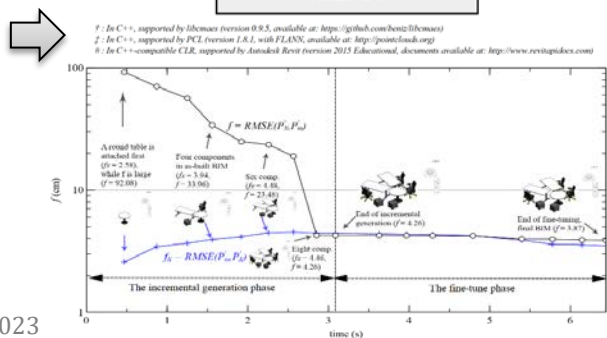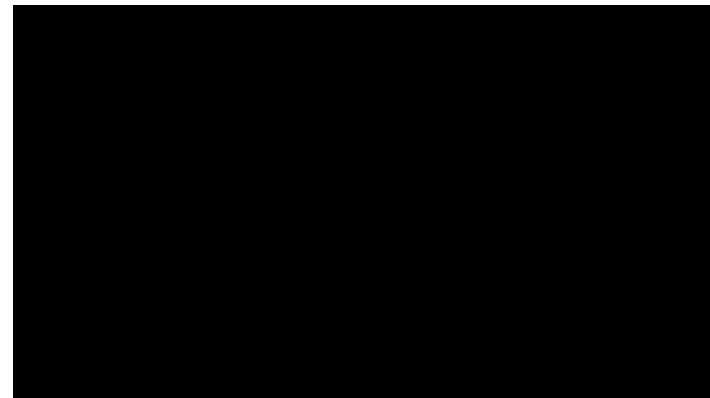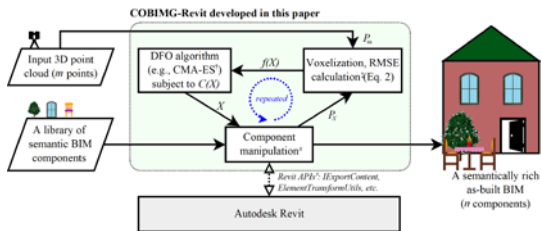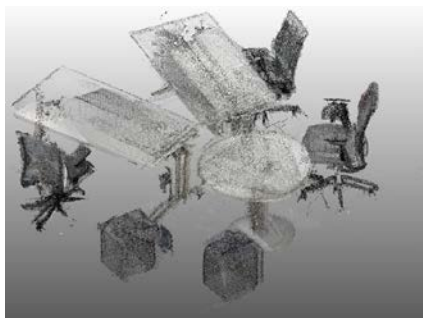
(Xue et al. 2019)

(a) A screenshot of the 3D view of the output as-built BIM

2.3 Unsupervised learning
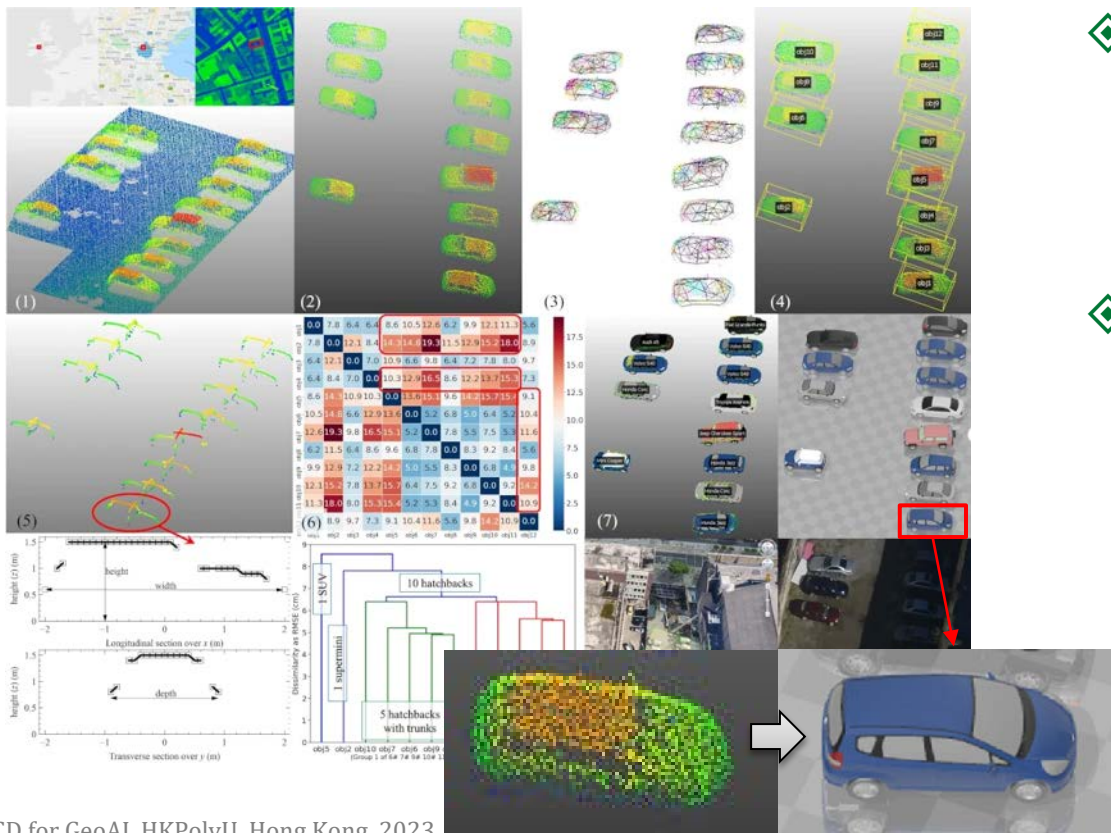
- ⬥ Unsupervised learning
  - ☒ <u>Groups</u> similar <u>by attributes</u>
  - ☒ A.k.a. clustering of objects
  - ☒ Fills the hierarchical gap
- ⬥ E.g., CIM (Xue et al. 2020)
  - ☒ Symmetry detection
    - ○ By reinforced learning
  - ☒ Cross-sections
    - ○ Longitudinal / transverse
  - ☒ Hierarchical clustering of patches using cross-sections
  - ☒ Clustering of 3D models onto patches for CIM

Xue: PCD for GeoAI. HKPolyU, Hong Kong. 2023

Section 3
SUMMARY

3 A recap

◈ GeoAI = Geo ✕ AI

    ▣ rather than Geo + AI, from my perspective

◈ Point cloud

    ▣ Indispensable data source, yet with many gaps

◈ Machine learning

    ▣ Supervised: fills semantic gap

        ○ Geo data helps AI in turn

    ▣ Reinforced: partially fills relational gap

        ○ Existing 3D models help AI

    ▣ Unsupervised: fills hierarchical gap

        ○ Design sections and models helps AI

◈ Possible future directions

    ▣ Time-dynamic spatiotemporal

    ▣ Geo-interpretable AI

    ▣ Geo-self-supervised AI

    ▣ Geo-probability in AI

Acknowledgement

◈ Presented work supported by

  ◘ HK RGC GRF/ECS (17201717, 17200218, 27200520)

  ◘ Guangdong S&T (2020B1212030009, 2023A1515010757)

  ◘ HK ITC (ITP/004/23LP)

◈ And an energetic team

◈ Students' works involved or cited

  ◘ Maosu Li

  ◘ Yijie Wu

  ◘ Siyuan Meng

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Thank you!

Q&A