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

iLab @ HKURBAN 城
the urban big data lab

2022 Leica Geosystems Seminar

"Are you ready for an autonomous future?"

Digital Twinning buildings and cities with 3D point clouds: A semantics perspective

Fan "Frank" Xue

PhD, MACM, SMCGS, MIEEE, MHKGISA

Dept. of Real Estate and Construction

University of Hong Kong

25 Nov 2022

0 HKU iLab: The urban big data hub

- HKUrbanLan—iLab
  - Director: Prof. Wilson Lu Deputy director: Dr. Frank Xue
  - Urban big data hub at Faculty of Architecture, HKU
  - multi-dimensional and multi-disciplinary *urban big data* collection, storage, analysis, and presentation to inform decision-making in urban development
  - Focusing on Information Technology (IT)
    - BIM, GIS, GNSS, *Urban Remote Sensing,* IoT
    - Blockchain (BC/DLT)

https://frankxue.com

https://ilab.hku.hk

iLabHKU

Lab workshop

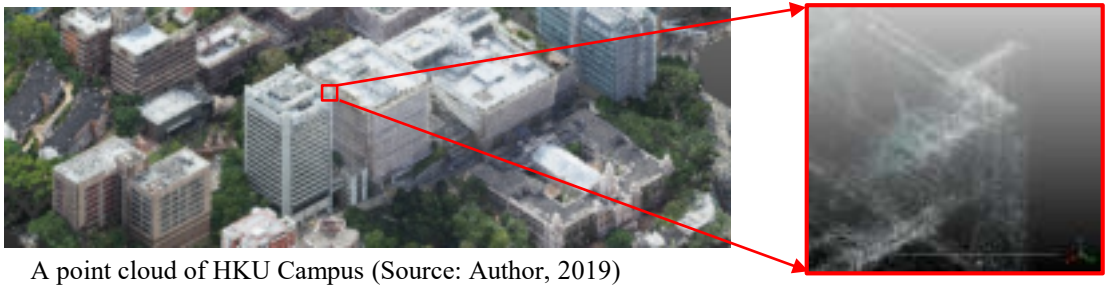
iLab | @ HKURBANlab the urban big data lab

Section 1

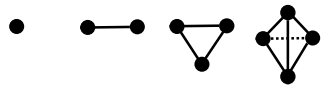
INTRODUCTION

1.1 Urban point cloud

- Point 點
  - A location in space, 0D (no width, length, or thickness)
  - Structured format: {x, y, z}, [R, G, B, Nx, Ny, Nz, Cls, Int., …]
- Cloud 雲
  - An unstructured collection [of water droplets or ice crystals]
  - Dense when looking at a distance, sparse closely
- Urban point cloud 城市點雲



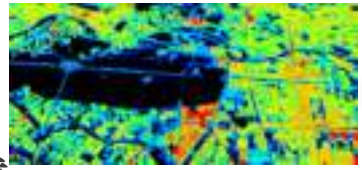
A point cloud of HKU Campus (Source: Author, 2019)

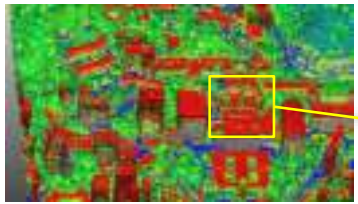


A close look of cloud at Mount Hua (Source: Author)

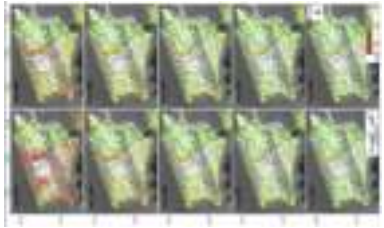
1.1 Sources and applications

- SAR 合成孔徑雷達
  - mm-accuracy
  - Coverage
- LiDAR 激光雷達
  - mm/cm/dm
  - No distortion
  - Intensity
- Photogrammetry 攝影測量
  - cm-accuracy
  - Colorful
  - Cheaper

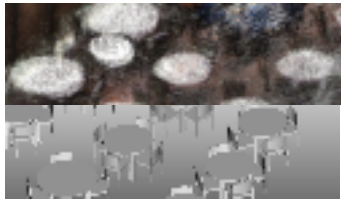




- Use cases



Ground settlement, building deformation (Wu et al. 2020a; 2020b)



Roof albedo (Xue et al. 2019f), indoor CFD simulation (Source: Author, 2022)

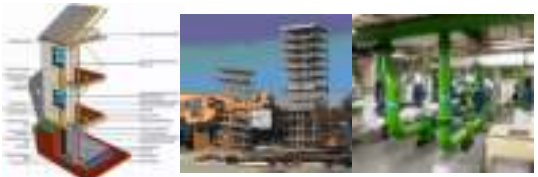
Kowloon Wall City 3D model (Source: patrick-@sketchfab.com)

HKU @MineCraft (Source: Author, 2021)

1.2 Digital Twin

- DT 數字孿生 (數位雙生)
  - "a virtual representation of a physical object or system
    - across its lifecycle, using real-time data
    - to enable understanding, learning, and reasoning."
  - -- UK National Infrastructure Commission (2017)
- DTing buildings/city is a systems/semantics approach
  - Building systems
    - Structure, envelope, services
  - City systems:
    - Transportation, space, green-blue infrastructure, etc.
  - Required semantics: Class, symmetry, object, relationship, etc.
- Challenge: Semantics in unstructured urban points

Scope of digital twinning
(Xue et al. 2020)



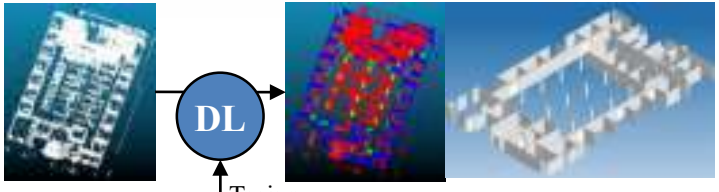
Building systems
(L to R: envelope, structure, services)
(Sources: Wikipedia.org, wbdg.org)

Section 2

DETECTING SEMANTICS IN URBAN POINT CLOUDS

2.1 Classification of urban points

- Supervised Deep learning
  - Adds a ‘label’ to each point
    - “Wall”, “columns”, “tree”…
  - Point-level semantics
- High-rise high-density dataset
  - 150 tiles of HKI and KLN
    - From LandsD/PlanD’s city model
  - Sampled and annotated for city objects
  - To be open-sourced soon

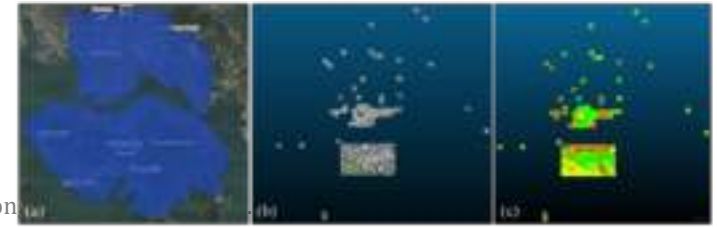


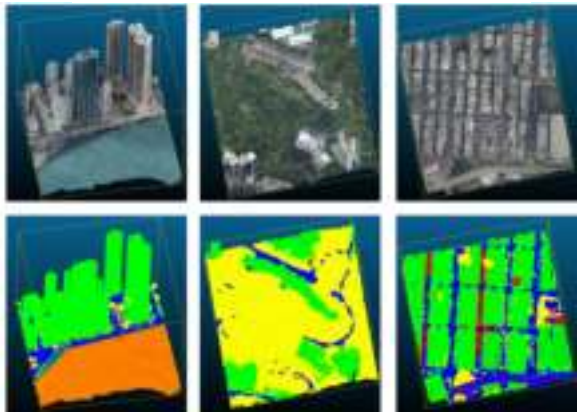
Trains

FLKPP (Wu et al, 2022)
(2nd place of Scan2BIM Challenge, CVPR2022)

Supports

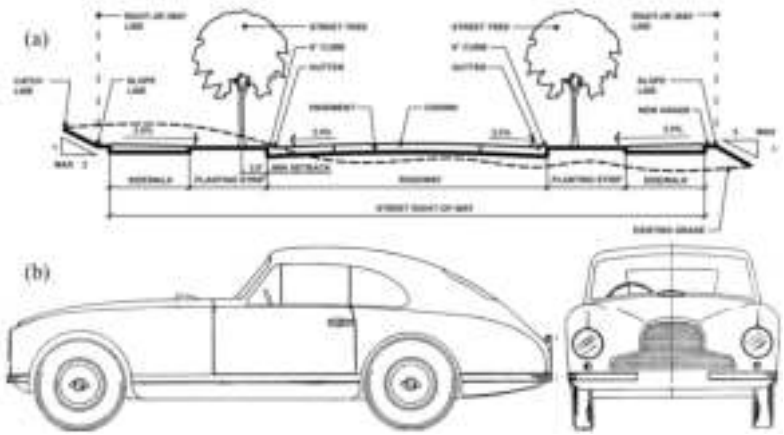
An HRHD urban dataset (on-going)





2.2 Symmetry and similarity

- Symmetry **對稱**
  - $\text{Reflect}_x(C) \approx C$ 鏡面對稱
- Similarity **相似**
  - $\text{AffineTrans}_x(C_1) \approx C_2$ 仿形變換
- Guided by design/engineering laws



(Xue et al, 2019d)

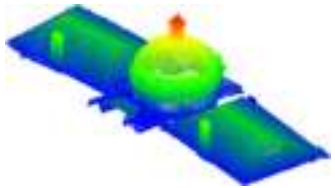
2.2 Symmetry in points: Methods and data

Symmetry detection

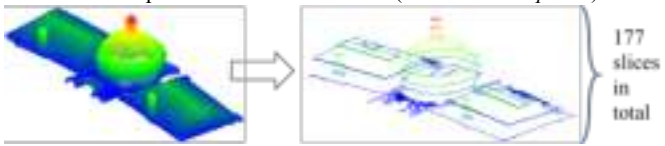
Category	Accuracy (less geometric error)	Efficiency (Using less time)	Types of symmetries
Pairwise voting-clustering	+	−	All (++)
Heuristic feature matching	−	++	Limited by the features (−)
Our parameter optimization	++	+	All (++)

(a) The Hung Hing Ying Building at HKU main campus

(b) 250 aerial photos taken with a UAV (model: *DJI Inspire 1*)



(c) A dense cloud of 1,413,211 points of the building rooftop

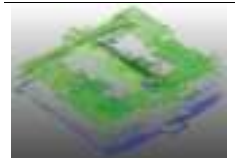


(d) The slices for fast verifying reflections on rooftop in the pilot case

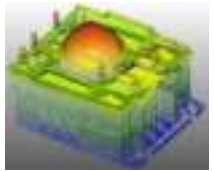
(e) The formulated problem

$$\min f(x) = f_{\mathcal{C}}(x) + 10\mathcal{A}(x)$$
$$= \frac{1}{n}\Sigma_{i=1}^{177}|\mathcal{C}_i| \cdot MNND_{\mathcal{C}i}(x) + 10\,[\,\mathcal{A}_g(x) + \mathcal{A}_t(x)\,]$$
$$\text{s.t. } x = (\rho, \varphi),\ \rho \in \mathbb{R}^+ \cup \{0\},\ \varphi \in (-\pi, \pi].$$

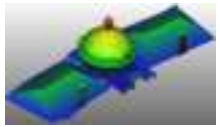
Test data



Main Building, University of Hong Kong* (29,756; 86.56%)

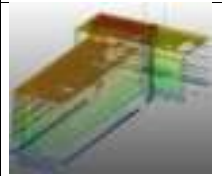


Dublin City Hall† (459,386; 86.14%)

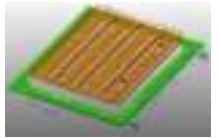


Hung Hing Ying Building, University of Hong Kong‡ (1,413,211; 96.04%)

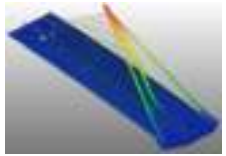
One George's Quay Plaza, Dublin† (1,170,122; 95.50%)



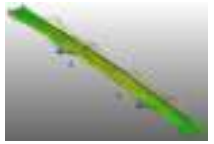
47-51 O'Connell Street Upper, Dublin† (395,818; 97.18%)



Western District Fruits Wholesale Market, Hong Kong (44,699; 96.97%)



Samuel Beckett Bridge, Dublin† (570,338; 97.52%)

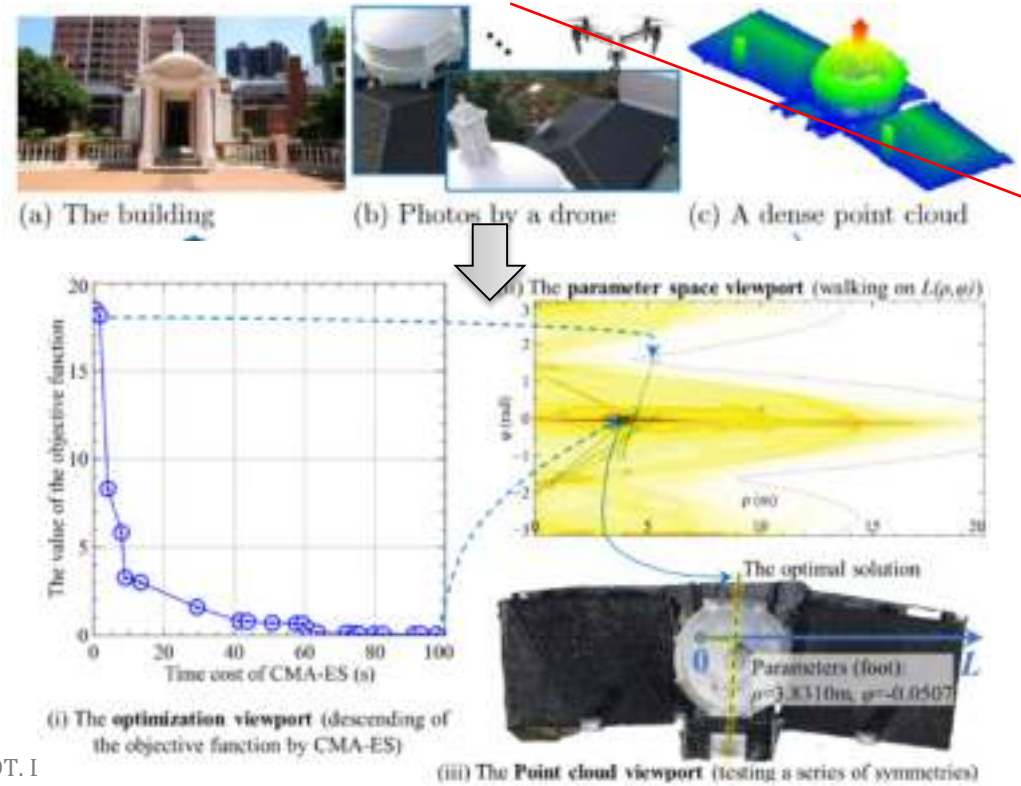


Seán O'Casey Bridge, Dublin† (223,213; 99.55%)

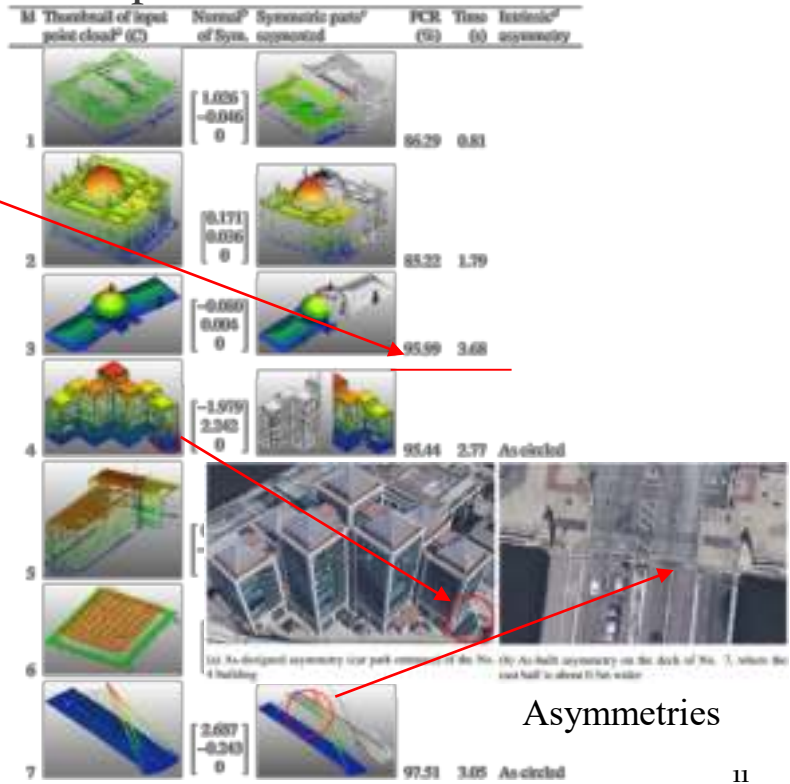
Two piers at Victoria Harbor, Hong Kong* (12,631; 94.84%)

2.2 Symmetry detection: Results

- PCR = 93.7%, Time = 98.6s (Xue et al. 2019d)

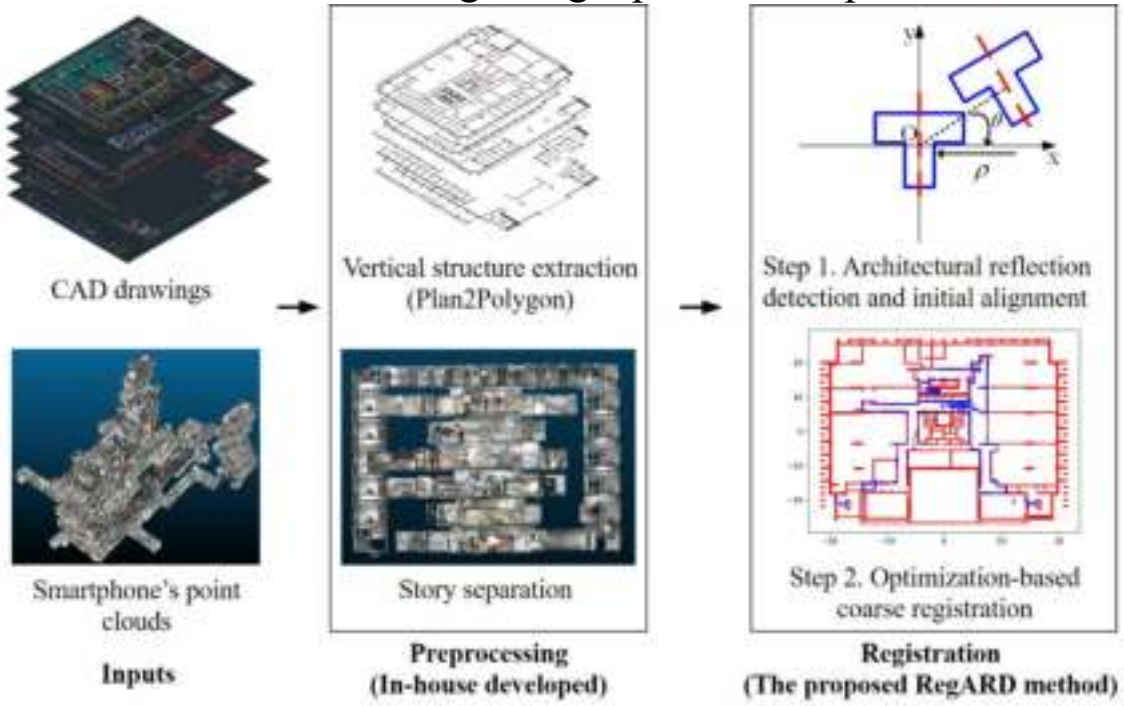


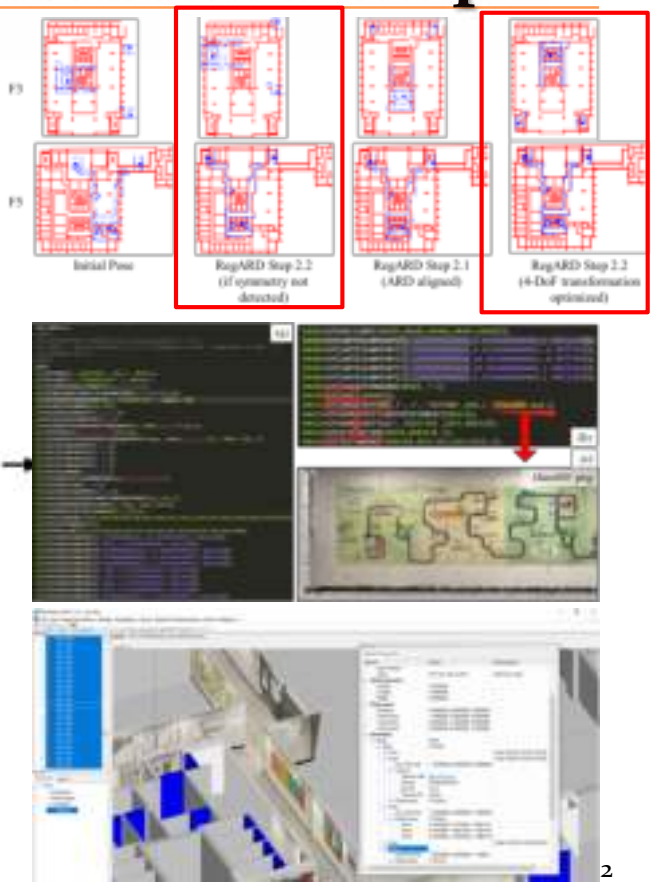
- Updated in (Xue et al. 2019a)



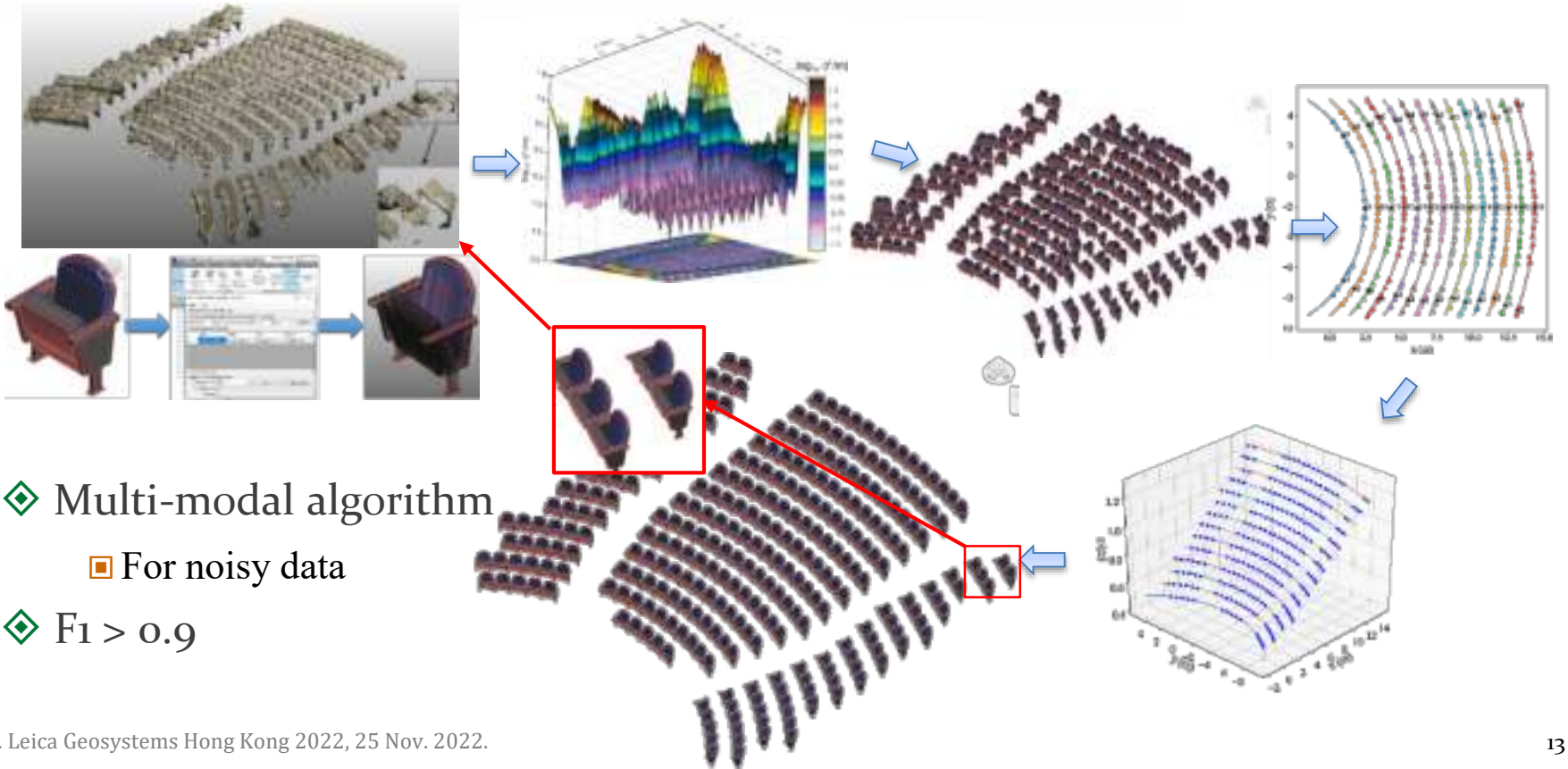
2.2.1 Case 1: Symmetry-guided BIM texture map

- Wu et al. (2021)
  - Merit Award, Hong Kong OpenBIM / OpenGIS Award





2.2.2 Case 2: Sim-guided many chairs (Xue et al. 2019c)

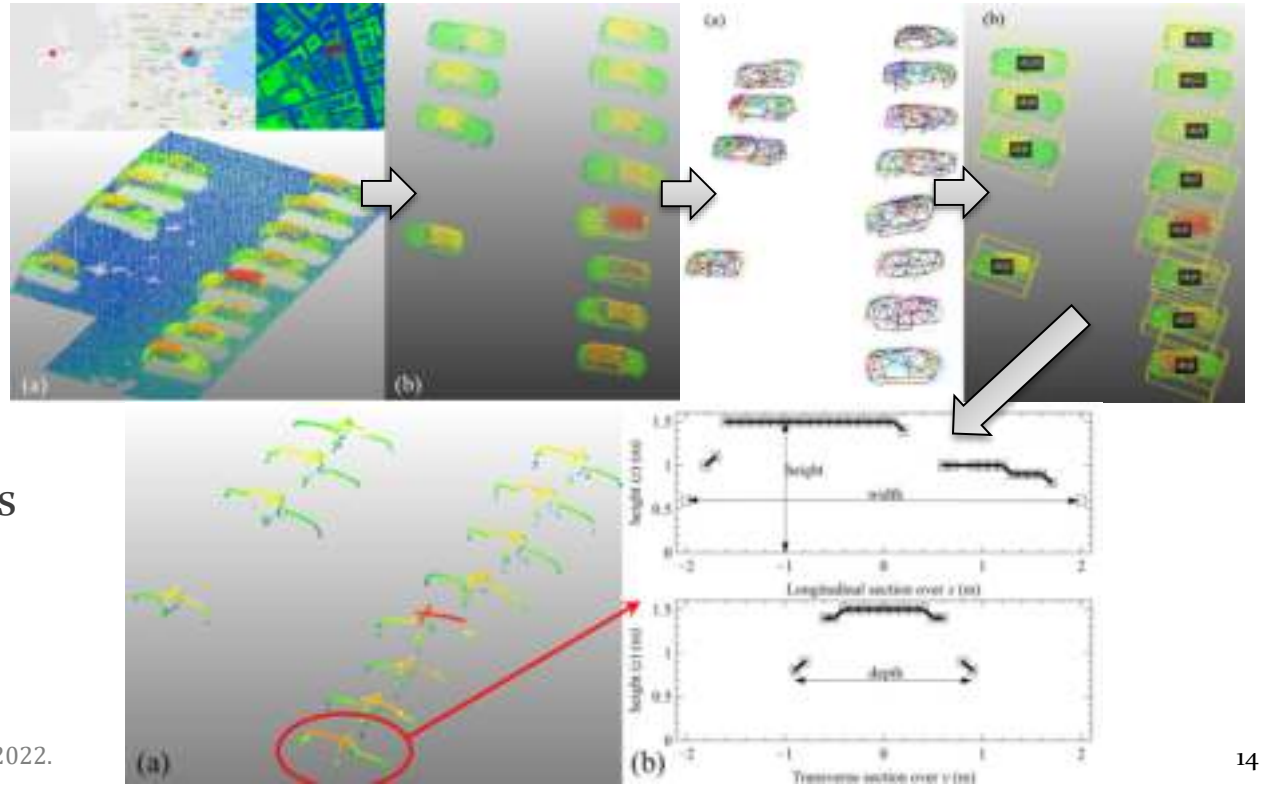


- Multi-modal algorithm
  - For noisy data
- F1 > 0.9

2.3 Cross-section clustering for object types

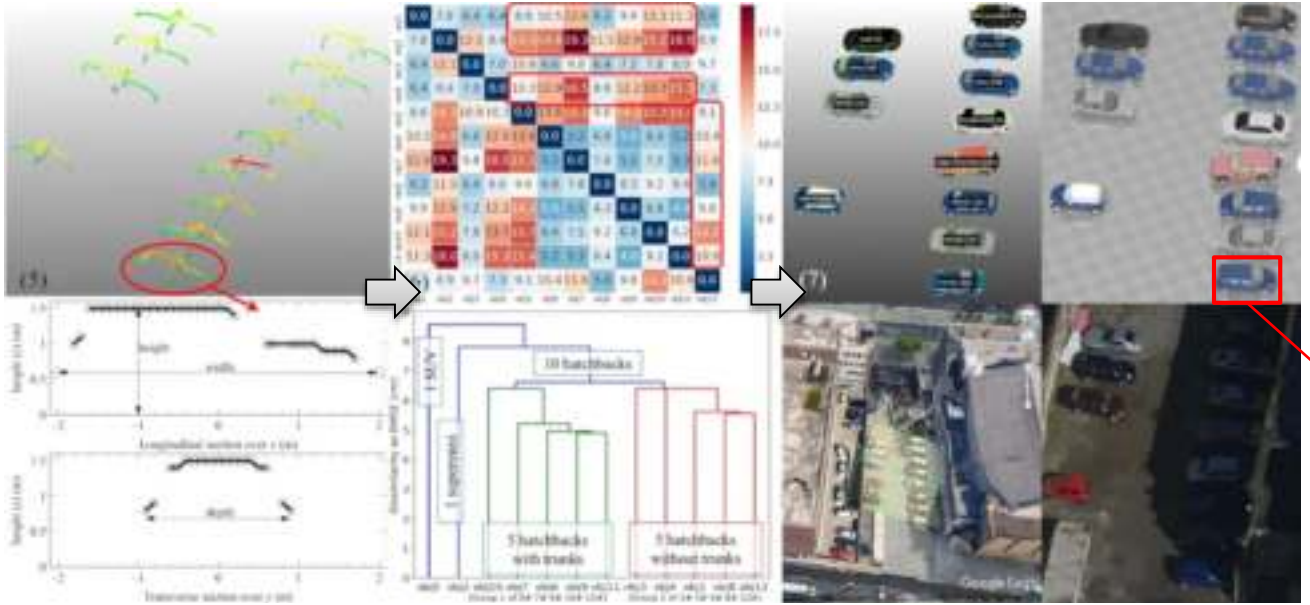
- Symmetry-based cross-sections **對稱截面** (Xue et al. 2020)
  - 1. Ground removal
  - 2. Connectedness
  - 3. Major symmetry
    - 3.1 Section #1
  - 4. Perpendicular
    - 4.1 Section #2
  - 5. Voxelization
- For unknown objects

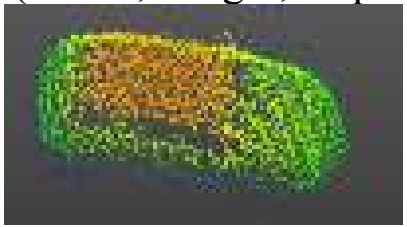
  無需訓練數據
  - Symmetric
  - Above ground



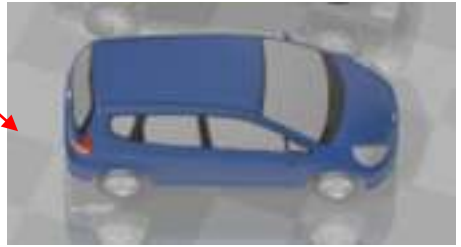
2.3 Cross-section clustering for object types (cont.)

- Similarity for clustering unknown **聚類**
  - 1. Cross-section-based registration
  - 2. Clustering using least RMSE
- Similarity to sections of known 3D objects
  - 1. Filters (Width, Height, Depth)





Input PCD

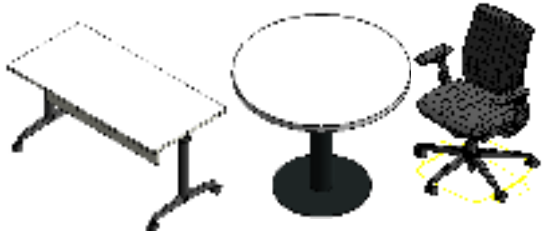


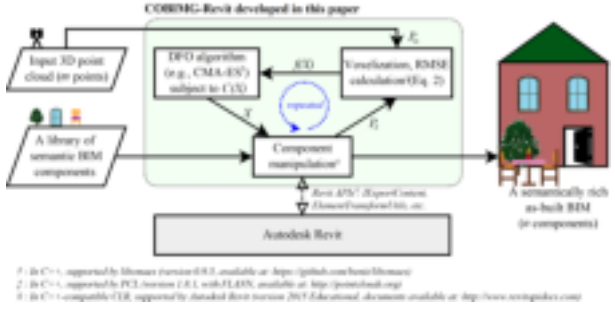
Output: Closest 3D object

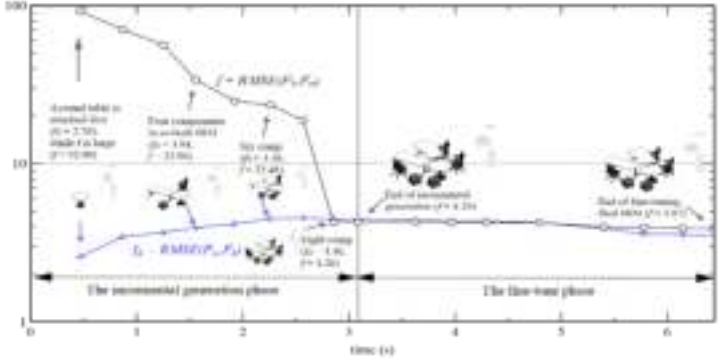
(2022 Featured article, *ISPRS P&RS*)

2.4 Similarity for objects and relations (Xue et al. 2016; 2019b)

- Time = 6.44s (Manual = 300s), RMSE = 3.87 cm

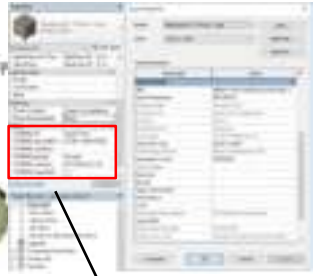






(a) A screenshot of the 3D view of the output as-built BIM

(b) A visual comparison between the input (grey points) and the output BIM



2.4 Two demo videos

Fitting BIM objects for location, rotation, and relational semantics (Xue 2019)

Fitting 3D columns at a carpark (Wu et al. 2022)

Section 3

SUMMARY

3.1 A recap

- Urban point cloud
  - Has advantages for buildings/urban applications
  - Semantics is a must-to-do for DT
- Semantics: Class labels, symmetry, objects, relationship
  - Can be detected in urban point clouds
    - With / without training data sets
    - With / without existing 3D resources
  - Powerful for understanding a point cloud if detected
    - Sometimes better than the factual (e.g., cars, chairs)
- Auto DTing of buildings/city in early stage
  - Wide frontier of urban semantics to explore toward 100% autonomy
  - More values lie in simulation/optimization

Acknowledgement

- Funding support
  - HK RGC GRF/ECS (17201717, 17200218, 27200520)
  - Guangdong Key R&D (2019B010151001)
  - Shenzhen-HK-Macau TRP (C) (SGDX20201103093600002)
- Students and alumni involved
  - Yijie Wu
  - Maosu Li
  - Zhe Chen
  - Cao Jin
- References details on requests

Let computers 'see' urban semantics through '01s' !

Q&A