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

iLab @ HKURBANlab
the urban big data lab

華南理工大學 | 土木与交通学院
SCHOOL OF CIVIL ENGINEERING & TRANSPORTATION
SOUTH CHINA UNIVERSITY OF TECHNOLOGY

SIR Frontiers @ SCUT
学术前沿系列讲座

面向城市点云理解的对称和相似性检测

Symmetry and Similarity Detection for Urban Point Cloud Understanding

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Outline

iLab

1 点云 Urban Point Clouds

2 检测 Symmetry and Similarity detection

3 小结 Summary

0.1 HKU iLab: The urban big data hub

iLab

◈ iLab 实验室

- Director: Prof. Wilson Lu
- 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)

iLabHKU

https://ilab.hku.hk/

Lab workshop

iLab | @HKURBANlab the urban big data lab

0.2 About me

Homepage
(full-text PDFs)

- A mixed background 背景
  - BEng in Automation, CAUC
  - MSc in Computer Science, CAUC
  - PhD in System Engineering, HKPU
  - PDF/RAP/AP in Construction IT

2004

2007

2012

- Research interests 方向
  - Urban sensing and computing
  - As-built BIM and digital twin
  - Automation/IT in construction
  - Applied operations research, ML
  - Distributed (blockchain) applications to construction

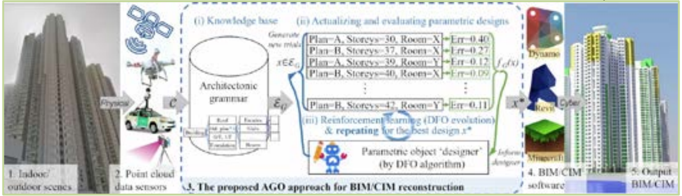
- Engineering
  - ISE, CEM, EIE
- Computer Science
  - AI, OR, ML
- Economics
  - SCM

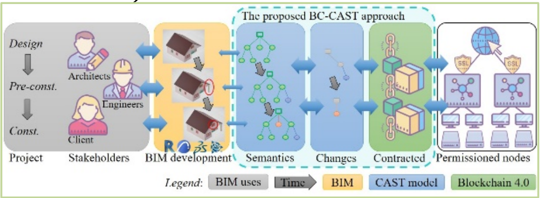
- Professional
  - MACM, SMCGS, MIEEE, MHKGISA
  - V.C. ACM-HK, Com. CGS-BIM

0.2 Recent research projects

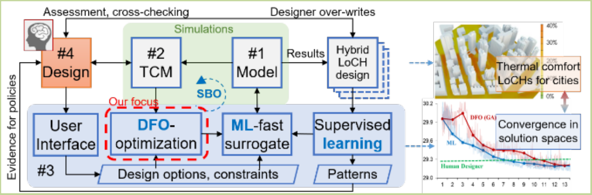
◇ On-going 在研

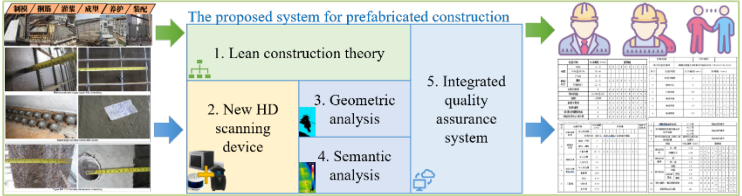
▣ PI: HK RGC GRF/ECS (17200221, 27200520)





▣ PC/Co-PI: RGC TRS (T22-504/21-R), SZ-HK-MC TRP T(C), ITF T-1





◇ Completed 完成

▣ PI: HK RGC GRF (17201717, 17200218), etc.

▣ Co-I: NSFC *2, NSSFC, SPPR, ECF, etc.

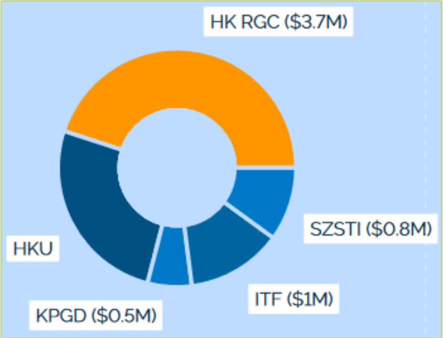
◇ Keywords

▣ BIM/CIM

▣ 3D point cloud

▣ Derivative-free optimization

▣ Urban semantics



Sponsors of projects as PI/PC/Co-PI

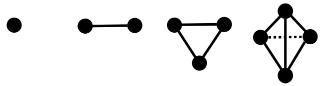
Section 1

URBAN POINT CLOUDS

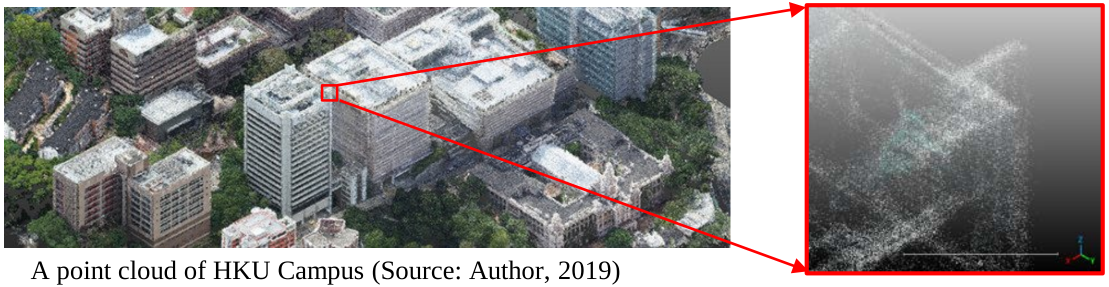
城市点云

1 Introduction

- Point 点
  - A location in space, 0D (no width, length, or thichness)
  - Structured format: {x, y, z}, [R, G, B, Nx, Ny, Nz, Cls, Int., …]



- Cloud 云
  - An unstructured collection [of water droplets or ice crystals]
  - Dense when looking at a distance, sparse closely
- Urban point cloud 城市点云

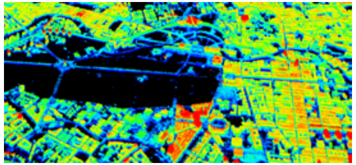


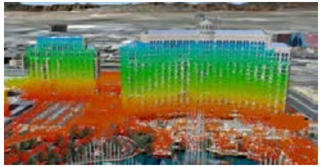
A point cloud of HKU Campus (Source: Author, 2019)

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

1.1 Major sources of urban point clouds

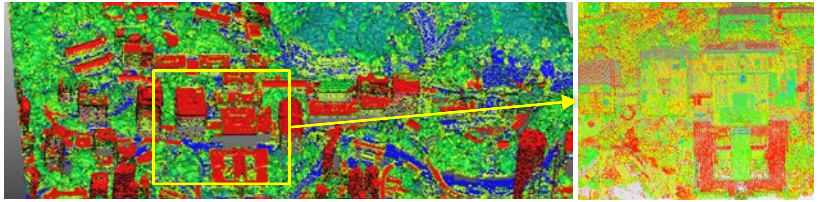
◈ SAR 合成孔径雷达





Bellagio Hotel, Las Vega
(Zhu & Bamler 2014)

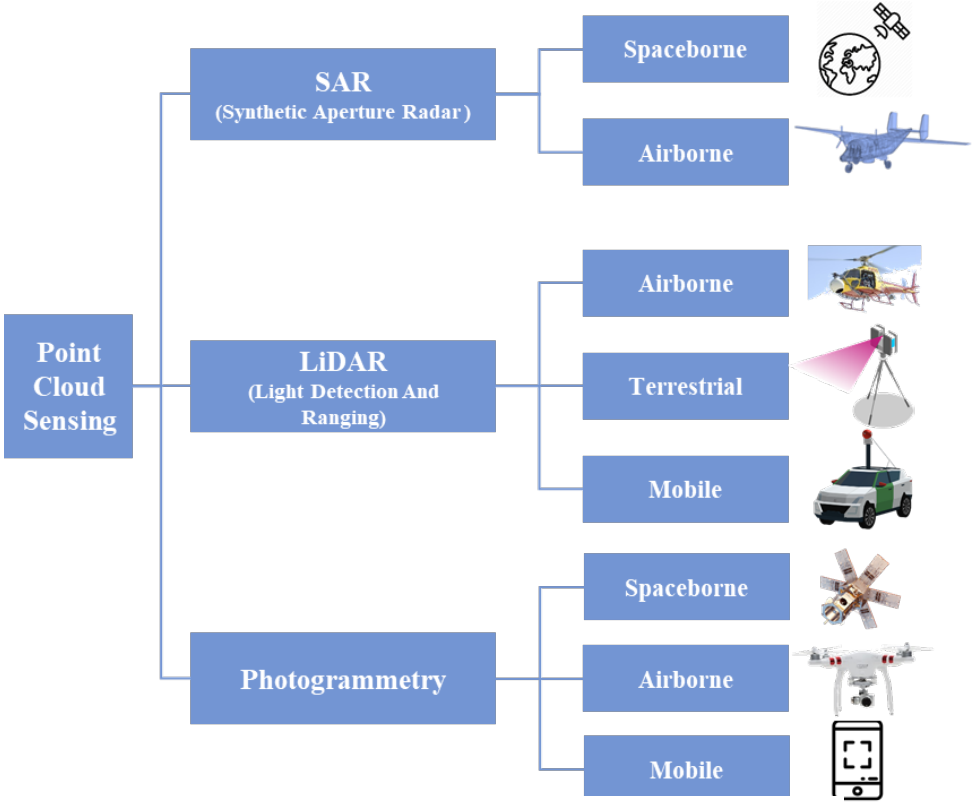
◈ LiDAR 光达



HKU Campus (Xue et al, 2019f)

◈ Photogrammetry 摄影测量

Building rooftop (Xue et al, 2019d)

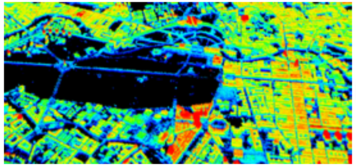


(Xu et al, 2018)

1.1 Advantages and applications

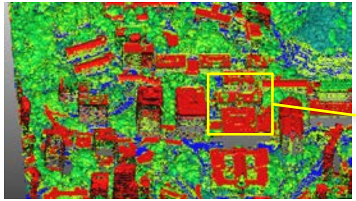
◇ SAR 合成孔径雷达

- mm-accuracy
- Coverage



◇ LiDAR 光达

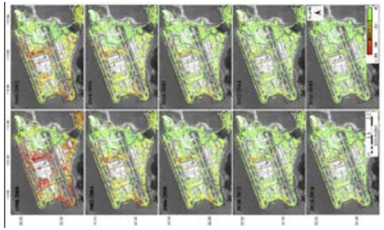
- mm/cm/dm
- No distortion
- Intensity



◇ Photogrammetry 摄影测量

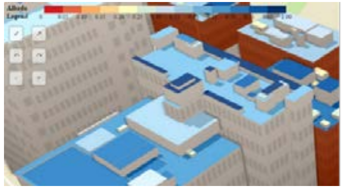
- cm-accuracy
- Colorful
- Cheaper

◇ Use cases 用例



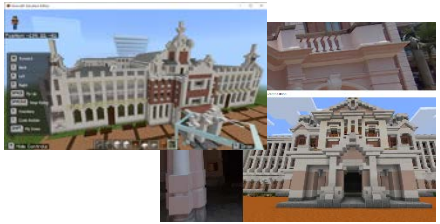
(a) Coherent pints overlaid on a Google Earth city model

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



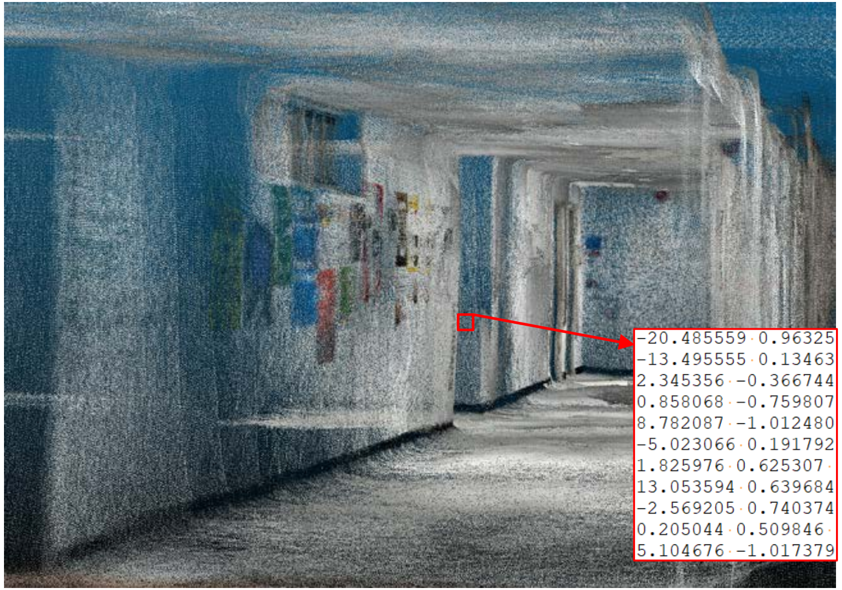
Roof albedo (Xue et al. 2019f), indoor CFD simulation (Source: Author, 2022)

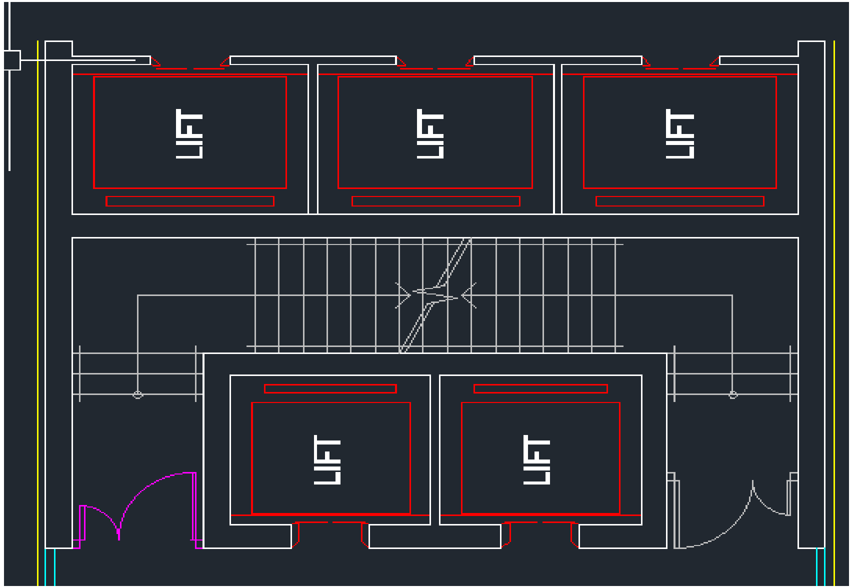
Kowloon Wall City 3D model
(Source: patrick-@sketchfab.com)



HKU @MineCraft (Source: Author, 2021)

1.1 Point clouds compared to CAD/BIM drawings





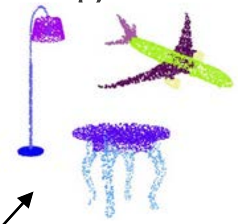
✓Rich in details and 3D appearance (*texture*)
✓Consistent with the real 3D layouts (*z*)
✗A lot of defects, e.g., sparse, noisy, and misaligned
✗Unstructured, low semantic info, massive disk size

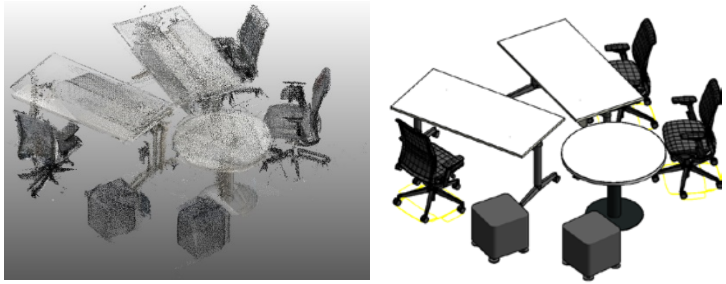
✓Precise, compact, and parametric geometry (*x, y*)
✗A lack of appearance
✗Possibly inconsistent with the real 3D layouts

(Wu et al, 2021)

1.2 PC Understanding

- Urban point cloud understanding include
  - 3D classification
  - 3D object detection
  - 3D semantic segmentation
  - 3D parts and combinations
  - 3D scene recognition
  - 3D relations/topology recognition
  - 4D motions (construction site, auto-driving)



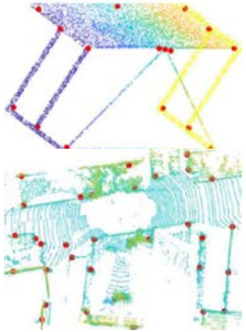


SensatUrban (Hu et al, 2021)

- Related, but different from
  - Image understanding (2D)
  - Point cloud processing (registration, editing, etc.)

1.2 Some existing methods for the tasks

- 3D classification 分类
  - Spatial/shape features (Corner, SIFT, etc.)
  - CNN deep features (e.g., *PointNet++)*
    - GraphNN features
- 3D object detection 目标检测
  - RANSAC (Random Sampling Consensus)
  - Perfect normals + geometric shapes (e.g., walls, ceiling)
- 3D semantic segmentation 语义分割
  - Sliding windows / region proposal / anchorless + 3D classification
- 3D scene / relationship 场景、关系
  - 3D Object/parts/topology/semantics-based
- Most are general, any Building/Urban characteristic? 特色

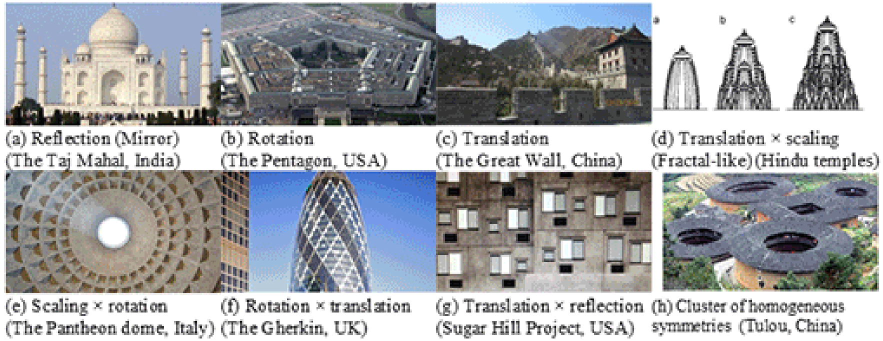


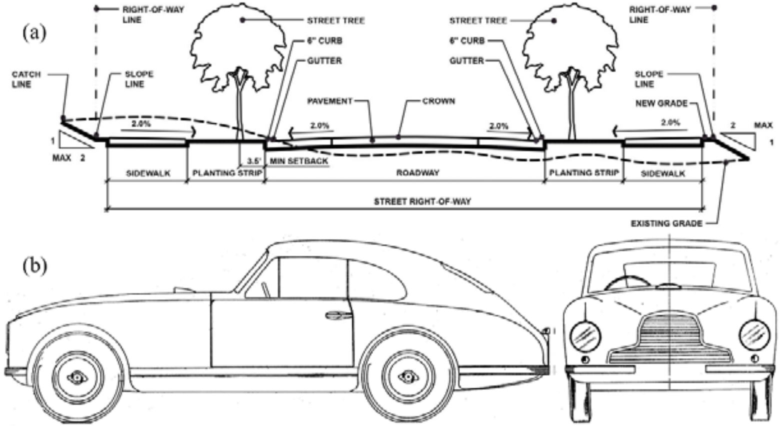
Keypoint detection (Li & Lee 2019)

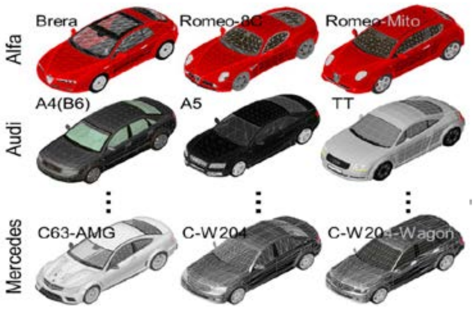
Example of semantic segmentation (Qi et al. 2017)

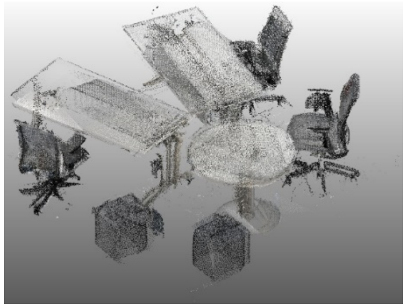
1.3 Symmetry and similarity as domain-specific

- Symmetry **对称**
  - $\mathrm{Reflect}_x(C) \approx C$ 镜面对称
- Similarity **相似**
  - $\mathrm{AffineTrans}_x\,(C_1) \approx C_2$ 仿形变换
- Guided by design/engineering laws









(Xue et al, 2019d)

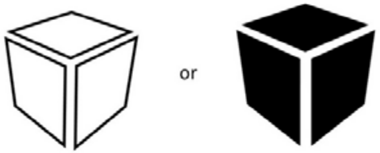
Section 2

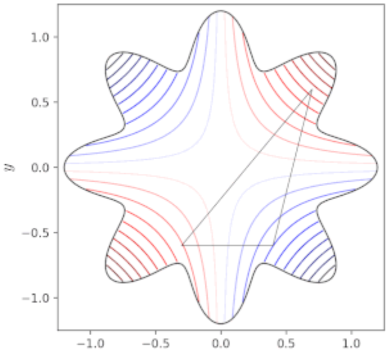
SYMMETRY AND SIMILARITY DETECTION

对称、相似性检测

2.1 “White-box” formulations for optimization

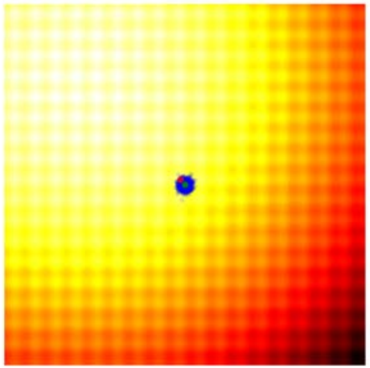
- “White-box” objective function **白盒目标**
  - f_x = RMSE(Reflect(C, $\mathbf{x}$), C)
  - f_x = RMSE(AffineTrans(C_1, $\mathbf{x}$), C_2)
  - Pre-requisite:
    - Closer densities
  - RMSE can be any error metric





Nelder-Mead *Source: Wikipedia.org*

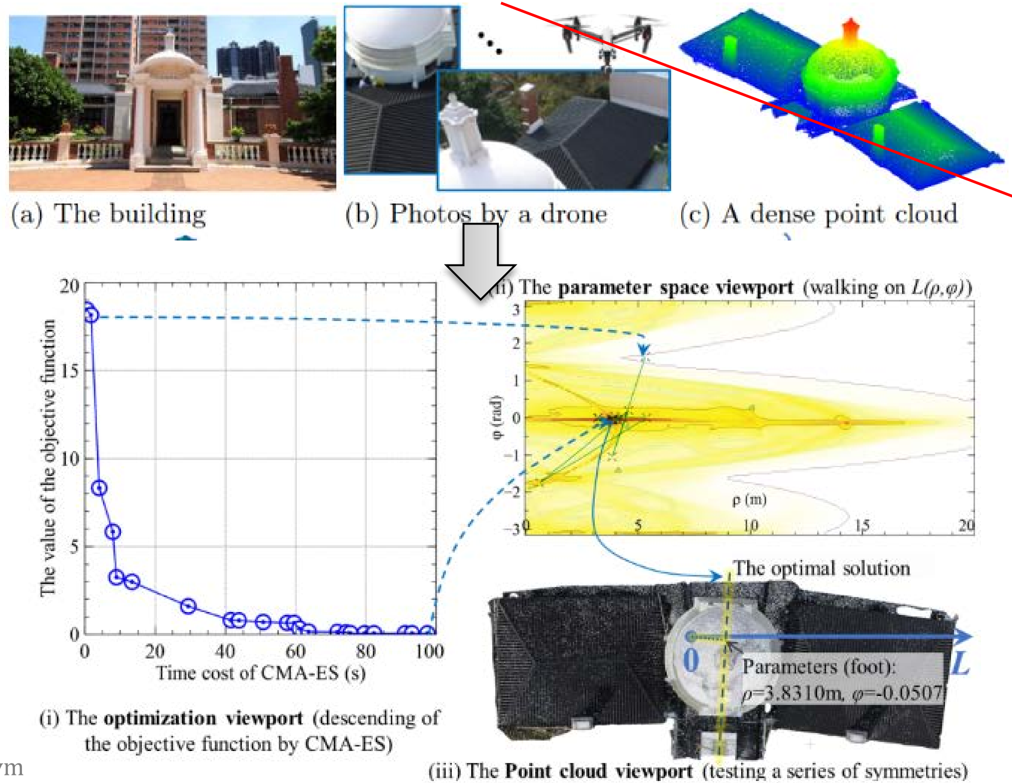
- Nonlinear optimization formulation **统一形式：非线性优化**
  - **arg min** f_x
  - **s.t.** x in *Range*
  - Constraints $(x) \leq 0$
- 50+ off-the-peg solvers for complex optimization**可用算法**
  - In C++/Python/… (see right)



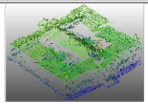
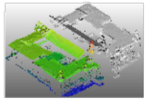
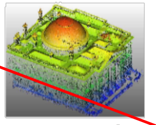
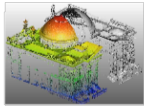
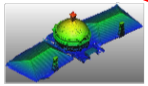
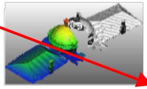
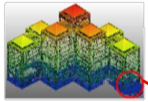
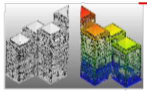
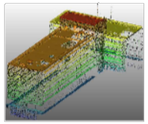
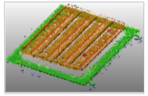
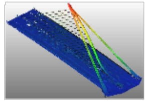
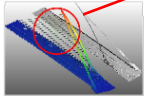
CMA-ES *Source: otoro.net*

2.1.1 Symmetry detections (early, vs updated)

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



Updated in (Xue et al. 2019a)

Id	Thumbnail of input point cloud[a] (C)	Normal[b] of Sym.	Symmetric parts[c] segmented	PCR (%)	Time (s)	Intrinsic[d] asymmetry
1		[1.026, −0.046, 0]		86.29	0.81	
2		[0.171, 0.036, 0]		85.22	1.79	
3		[−0.080, 0.004, 0]		95.99	3.68	
4		[−1.979, 2.242, 0]		95.44	2.77	As circled
5						
6						
7		[2.687, −0.243, 0]		97.51	3.05	As circled

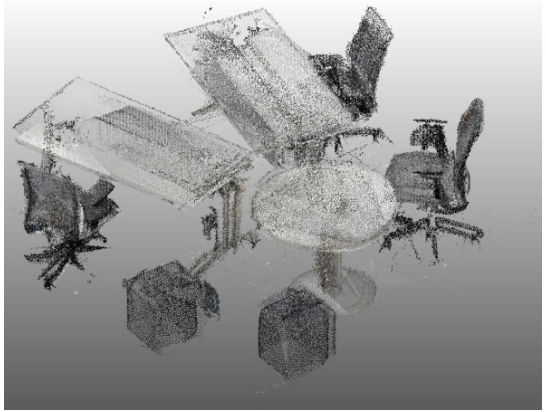
(a) As-designed asymmetry (car park entrance) of the No. 4 building

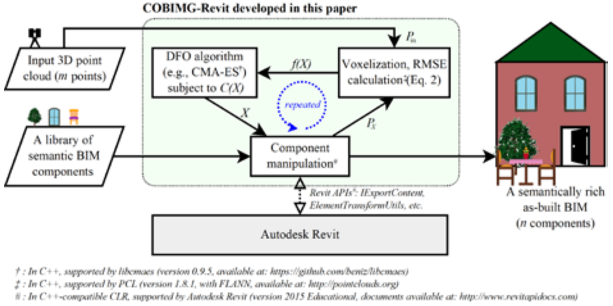
(b) As-built asymmetry on the deck of No. 7, where the east half is about 0.5m wider

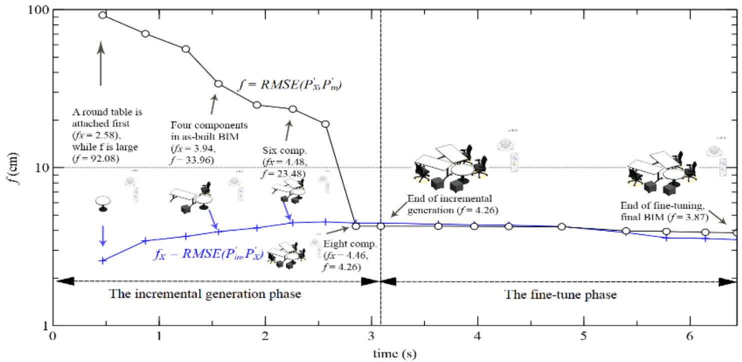
Asymmetries
局部非对称

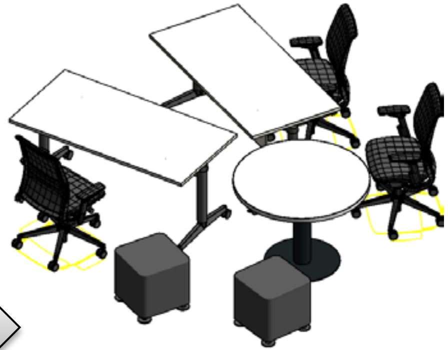
2.1.2 Similarity detection for as-built BIM (Xue et al. 2019b)

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

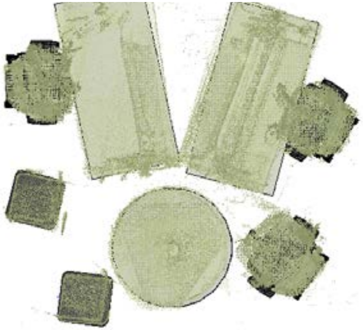








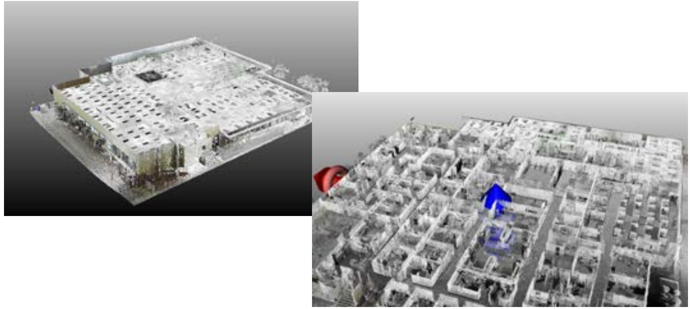
(a) A screenshot of the 3D view of the output as-built BIM

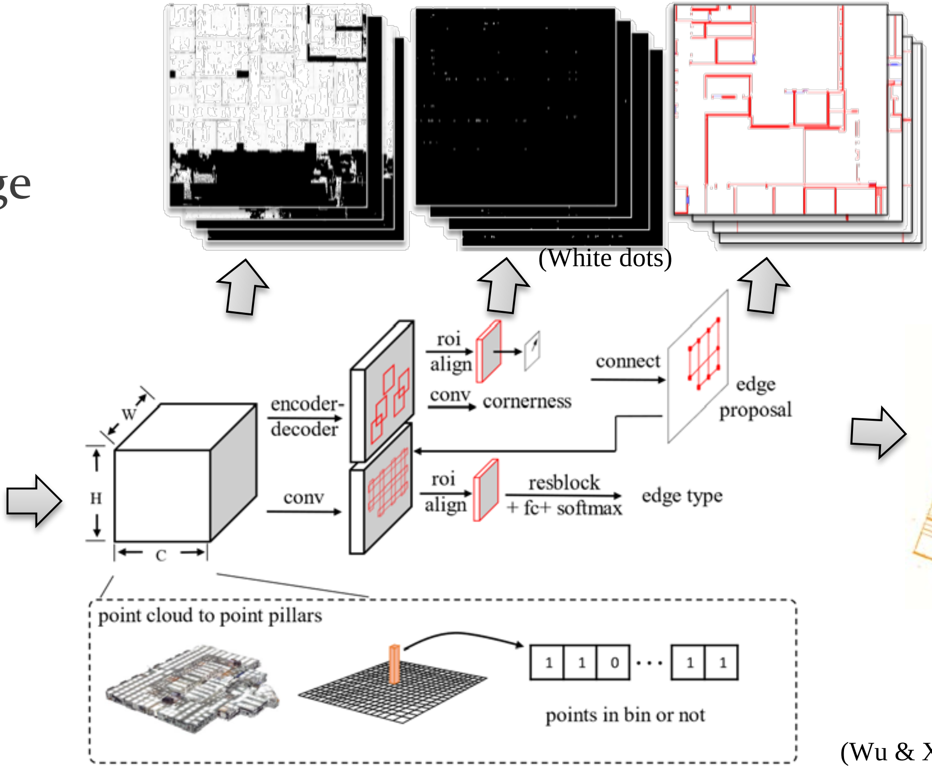


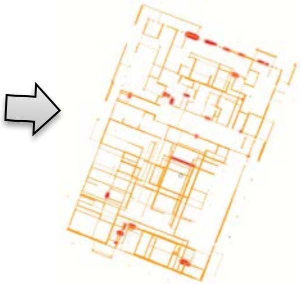
(b) A visual comparison between the input (grey points) and the output BIM

2.2 A "Black-box" formulation for deep learning

- Floor corners are symmetric, as an ML task **墙角**
  - Input: A top view of voxels
  - Output: Corners and walls
- First Scan-to-BIM challenge
  - 12% IoU for 2D track
  - The Second Runner-up
  - Plenty of room to improve



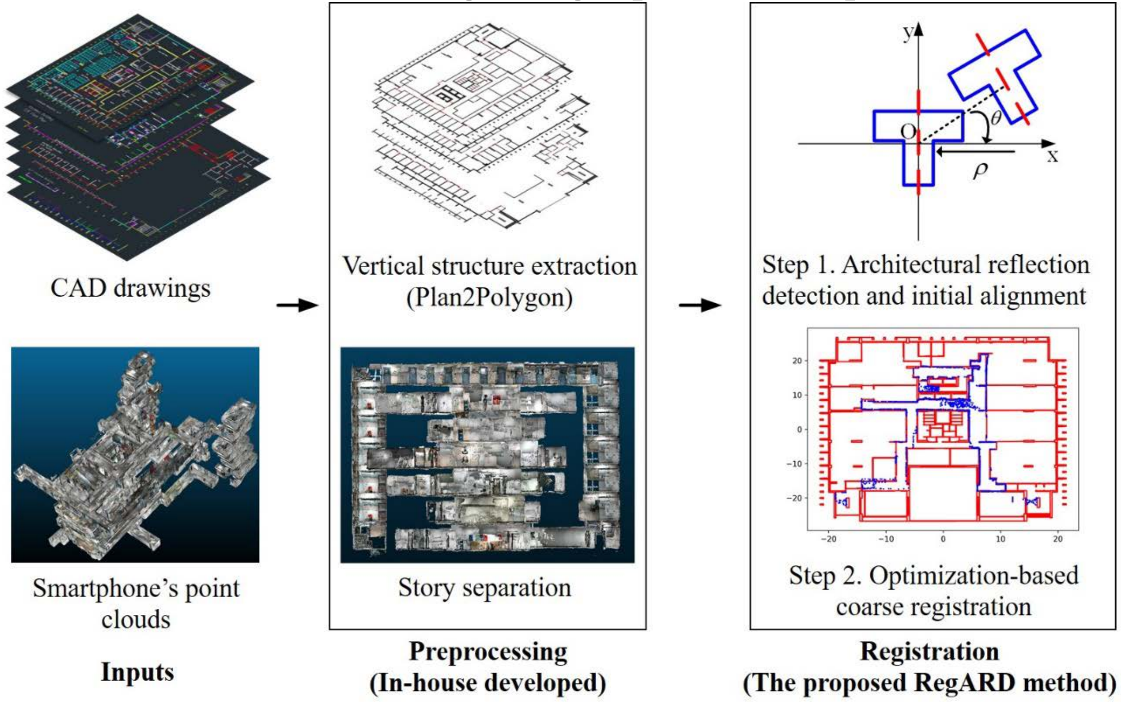


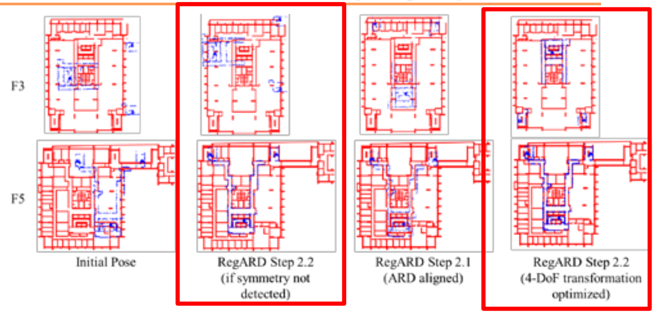


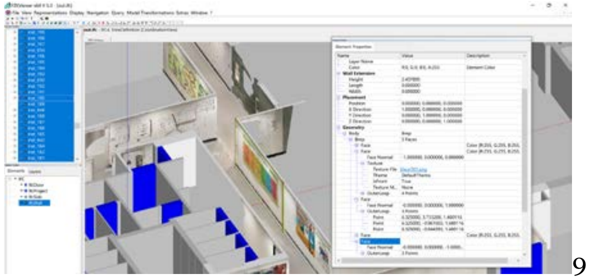
(Wu & Xue 2021)

2.3 Case 1: Symmetry-guided as-built BIM 案例1

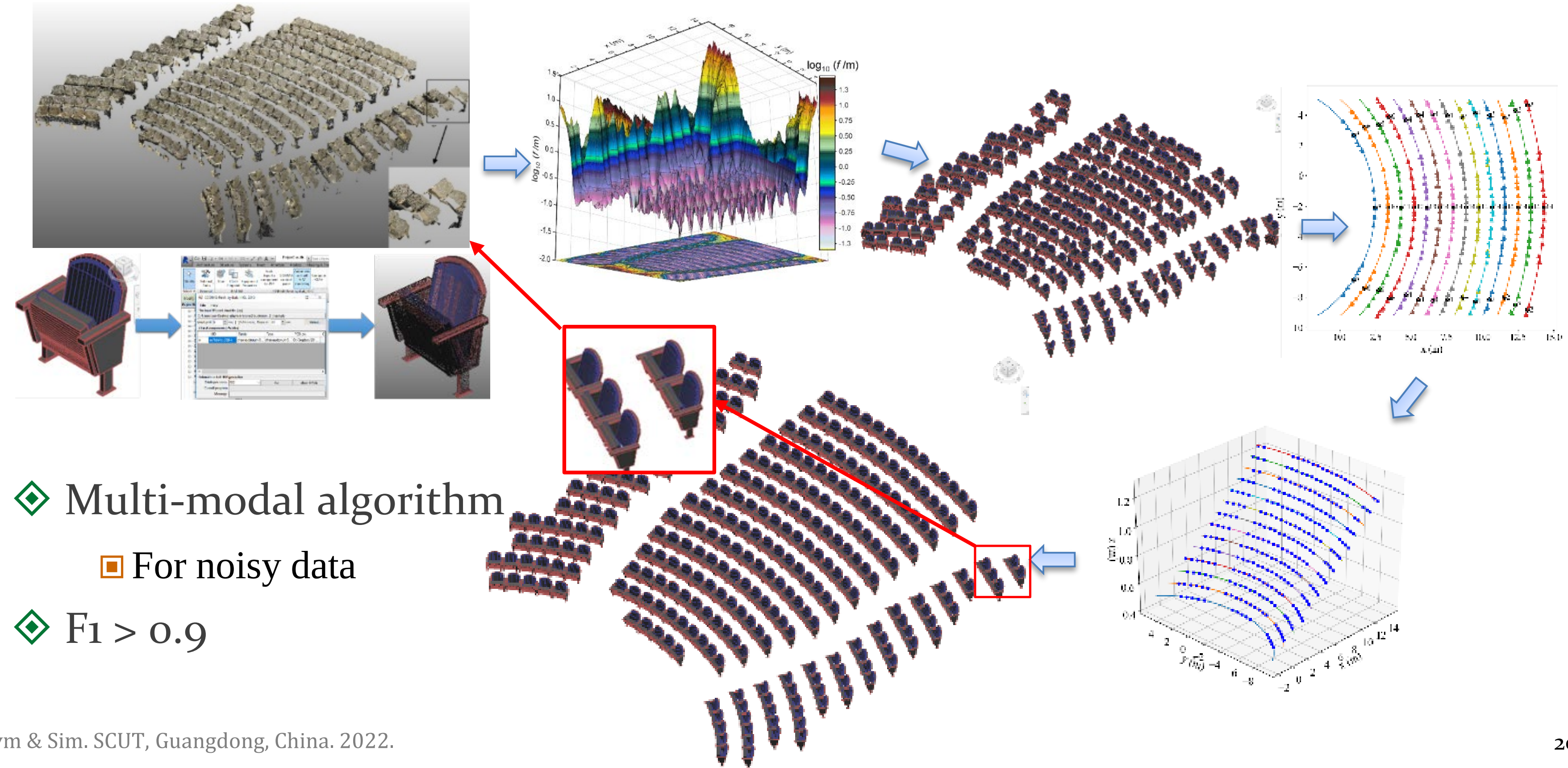
- Wu et al. (2021)
  - Merit Award, Hong Kong OpenBIM / OpenGIS Award







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

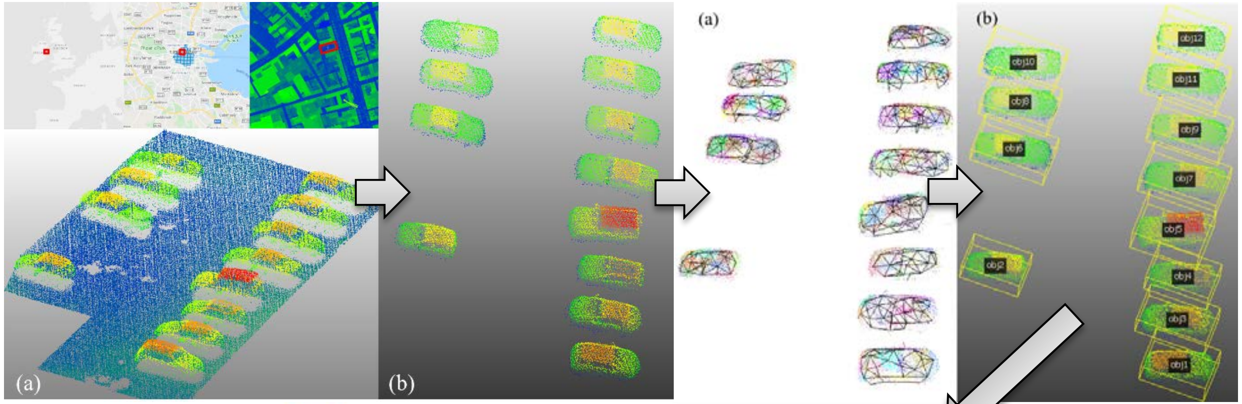


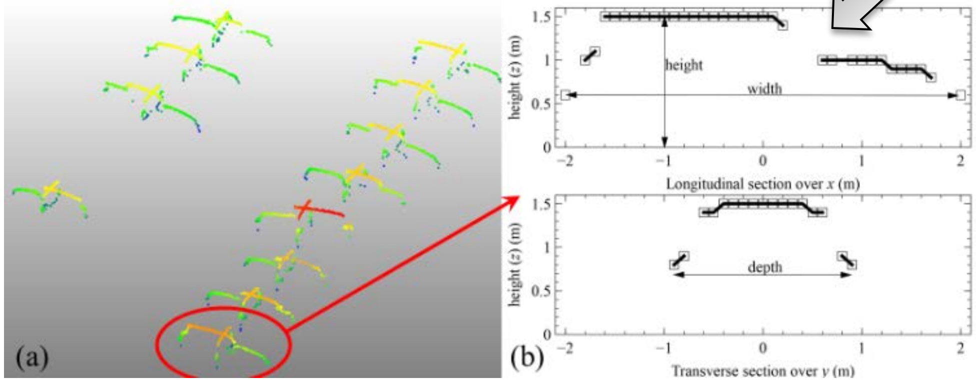
- Multi-modal algorithm
  - For noisy data
- F1 > 0.9

2.3 Case 3: Sym+Sim for city objects 案例3 (1/2)

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

  无需语义分割
  - ▣ Symmetric
  - ▣ Above ground





2.3 Case 3: Sym+Sim for city objects 案例3 (2/2)

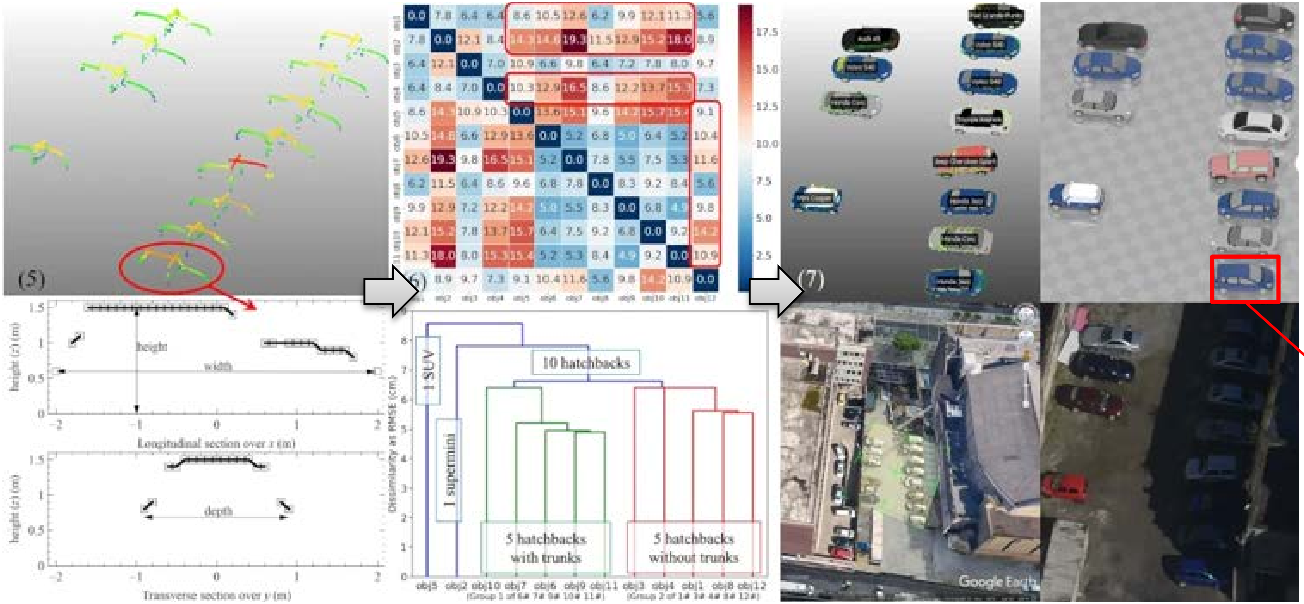
◈ Similarity for clustering unknown 相似聚类

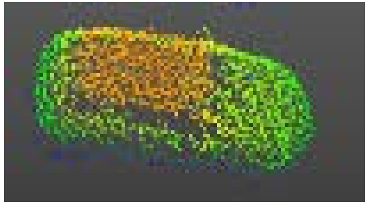
▣ 1. Cross-section-based registration

▣ 2. Clustering using least RMSE

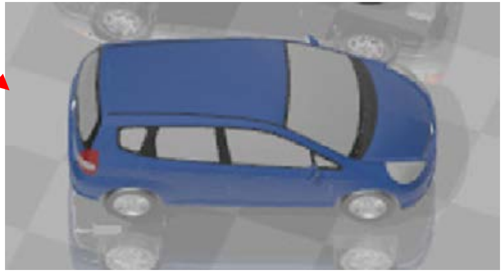
◈ Similarity to sections of known 3D objects 匹配已知语义模型

▣ 1. Filters (Width, Height, Depth)





Input PCD



Output 3D object

Xue: Sym & Sim. SCUT, Guangdong, China. 2022.

Section 3

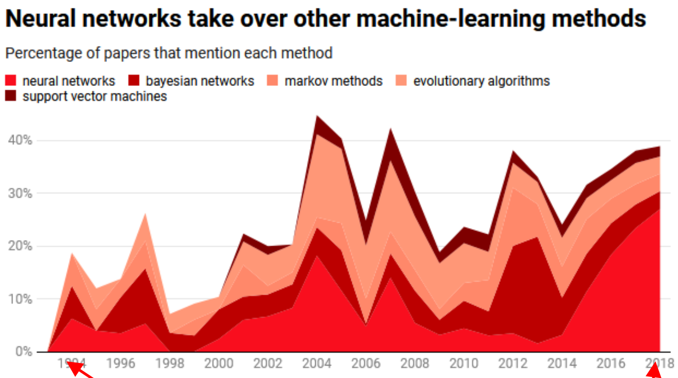
SUMMARY
小结

3.1 A recap

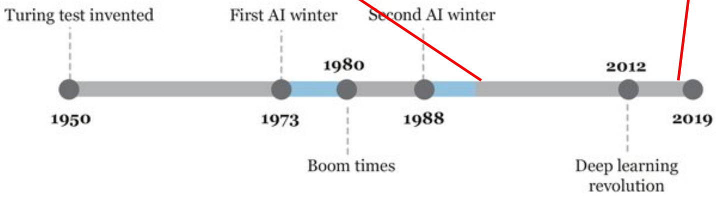
- Urban point cloud 城市点云
  - Has advantages for buildings/urban applications
  - Understanding is a must-to-do for machines
- Symmetry and similarity 对称、相似
  - Can be formulated as
    - "white-box" formulations
    - "black-box" formulation
  - Very powerful for understanding a point cloud if detected
    - Sometimes better than the factual (e.g., cars, chairs)
- Yet, 有待研究
  - There is plenty of room to improve

3.2 Some personal view points 个人看法

- Artificial Neural Networks overheating? **过热**
  - Anyway, the "Evolutionary Algorithms" for our "white-box" modeling are still viable
- AI winters or capital winters? AI**寒冬**
  - 1973: Exiting Bretton Woods system (布雷顿森林体系)
  - 1987: "Black Monday" stock market crash
- Beyond symmetry and similarity? **未来工作**
  - Shape grammars (on-going)
  - Between interior and exterior (on-going)
  - Semi-supervised learning of relations



Keywords statistics of 16,625 AI papers (Schuchmann 2019)



References

- Hu, Q., Yang, B., Khalid, S., Xiao, W., Trigoni, N., & Markham, A. (2021). Towards semantic segmentation of urban-scale 3D point clouds: A dataset, benchmarks and challenges. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition* (pp. 4977-4987).
- Li, J., & Lee, G. H. (2019). Usip: Unsupervised stable interest point detection from 3d point clouds. In *Proceedings of the IEEE/CVF International Conference on Computer Vision* (pp. 361-370).
- Qi, X., Liao, R., Jia, J., Fidler, S., & Urtasun, R. (2017). 3d graph neural networks for rgbd semantic segmentation. In *Proceedings of the IEEE International Conference on Computer Vision* (pp. 5199-5208).
- Schuchmann, S. (2019). *Analyzing the prospect of an approaching AI winter*
- Tan, T., Chen, K., Lu, W., & Xue, F. (2019, September). Semantic enrichment for rooftop modeling using aerial LiDAR reflectance. In *2019 IEEE International Conference on Signal Processing, Communications and Computing (ICSPCC)* (pp. 1-4). IEEE.
- Wu, Y., Shang, J., & Xue, F. (2021). RegARD: Symmetry-Based Coarse Registration of Smartphone's Colorful Point Clouds with CAD Drawings for Low-Cost Digital Twin Buildings. *Remote Sensing*, 13(10), 1882.
- Wu, S., Yang, Z., Ding, X., Zhang, B., Zhang, L., & Lu, Z. (2020a). Two decades of settlement of hong kong international airport measured with multi-temporal InSAR. Remote Sensing of Environment, 248, 111976.
- Wu, S., Le, Y., Zhang, L., & Ding, X. (2020b). Multi-temporal InSAR for Urban Deformation Monitoring: Progress and Challenges. **雷达学报**, 9(2), 277-294.
- Xu, J., Chen, K., Xue, F., & Lu, W. (2018). 3D point cloud data enabled facility management: A critical review. In *The 23rd International Symposium on Advancement of Construction Management and Real Estate, CRIOCM2018*. https://doi.org/10.1007/978-981-15-3977-0_49
- Xue, F., Lu, W., Chen, Z., & Webster, C. J. (2020a). From LiDAR point cloud towards digital twin city: Clustering city objects based on Gestalt principles. *ISPRS Journal of Photogrammetry and Remote Sensing*, *167*, 418-431. (2020 Featured Article)
- Xue, F., Wu, L., & Lu, W. (2021). Semantic enrichment of building and city information models: A ten-year review. Advanced Engineering Informatics, 47, 101245.
- Xue, F., Lu, W., Chen, K. (2018). Automatic generation of semantically rich as-built building information models using 2D images: A derivative-free optimization approach. Computer-Aided Civil and Infrastructure Engineering, 33(11), 926-942.
- Xue, F., Lu, W., Webster, C. J., & Chen, K. (2019a). A derivative-free optimization-based approach for detecting architectural symmetries from 3D point clouds. ISPRS Journal of Photogrammetry and Remote Sensing, 148, 32-40.
- Xue, F., Lu, W., Chen, K., & Zetkulic, A. (2019b). From Semantic Segmentation to Semantic Registration: Derivative-Free Optimization–Based Approach for Automatic Generation of Semantically Rich As-Built Building Information Models from 3D Point Clouds. Journal of Computing in Civil Engineering, 33(4), 04019024.
- Xue, F., Lu, W., Chen, K., & Webster, C. J. (2019c). BIM reconstruction from 3D point clouds: A semantic registration approach based on multimodal optimization and architectural design knowledge, Advanced Engineering Informatics, 42, 100965.
- Xue, F., Chen, K., & Lu, W. (2019d). Architectural symmetry detection from 3D urban point clouds: A derivative-free optimization (DFO) approach. In Advances in Informatics and Computing in Civil and Construction Engineering (pp. 513-519). Springer, Cham.
- Xue, F., Chen, K., & Lu, W. (2019e). Understanding unstructured 3D point clouds for creating digital twin city: An unsupervised hierarchical clustering approach. CIB World Building Congress 2019.
- Xue, F., Lu, W., Tan, T., & Chen, K. (2019f). Semantic enrichment of city information models with LiDAR-based rooftop albedo. In *Sustainable Buildings and Structures: Building a Sustainable Tomorrow* (pp. 207-212). CRC Press.
- Zhu, X. X., & Bamler, R. (2014). Superresolving SAR tomography for multidimensional imaging of urban areas: Compressive sensing-based TomoSAR inversion. *IEEE Signal Processing Magazine*, *31*(4), 51-58.

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Keep awesome!

感谢！欢迎提问