THE UNIVERSITY OF HONG KONG 香港大學
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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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29 Apr 2022 , Guangzhou, China

Outline

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 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

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

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
- 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

2004

2007

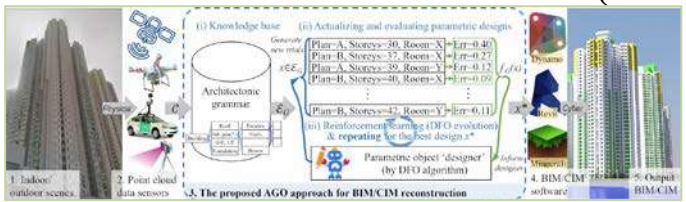
2012

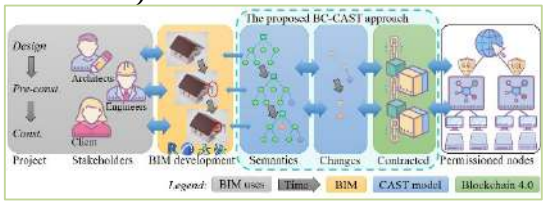
- Engineering
  - ISE, CEM, EIE
- Computer Science
  - AI, OR, ML
- Economics
  - SCM
- Professional
  - MACM, SMCGS, MIEEE, MHKGISA
  - V.C. ACM-HK, Com. CGS-BIM

0.2 Recent research projects

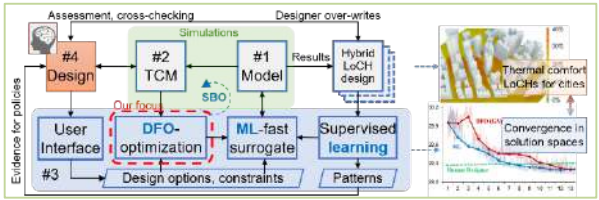
On-going 在研

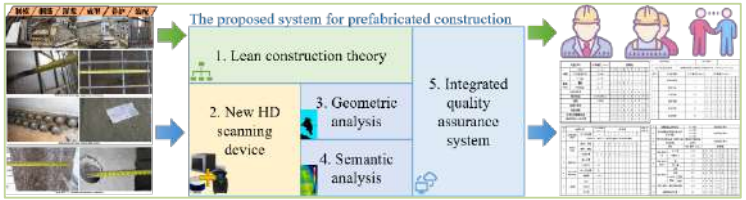
- PI: HK RGC GRF/ECS (17200221, 27200520)





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



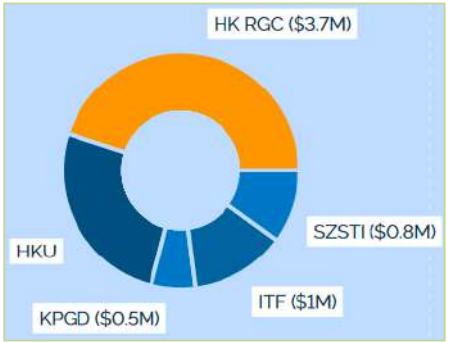


Completed 完成

- 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



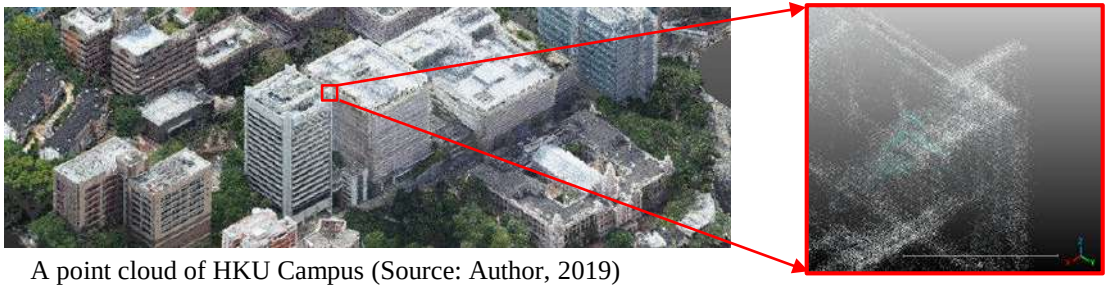
Sponsors of projects as PI/PC/Co-PI

Section 1

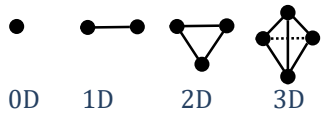
URBAN POINT CLOUDS
城市点云

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



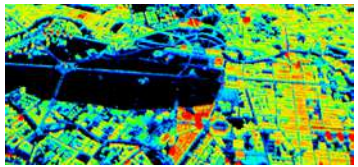
A point cloud of HKU Campus (Source: Author, 2019)

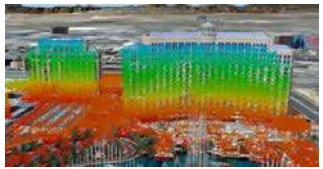


A close look of cloud at Mount Hua (Source: Author)

1.1 Major sources of urban point clouds

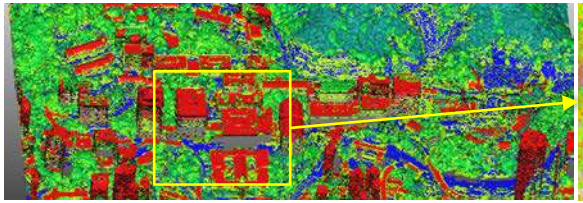
- SAR 合成孔径雷达

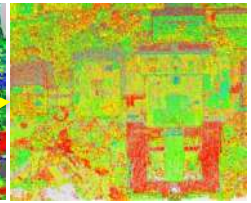




Bellagio Hotel, Las Vega
(Zhu & Bamler 2014)

- LiDAR 光达

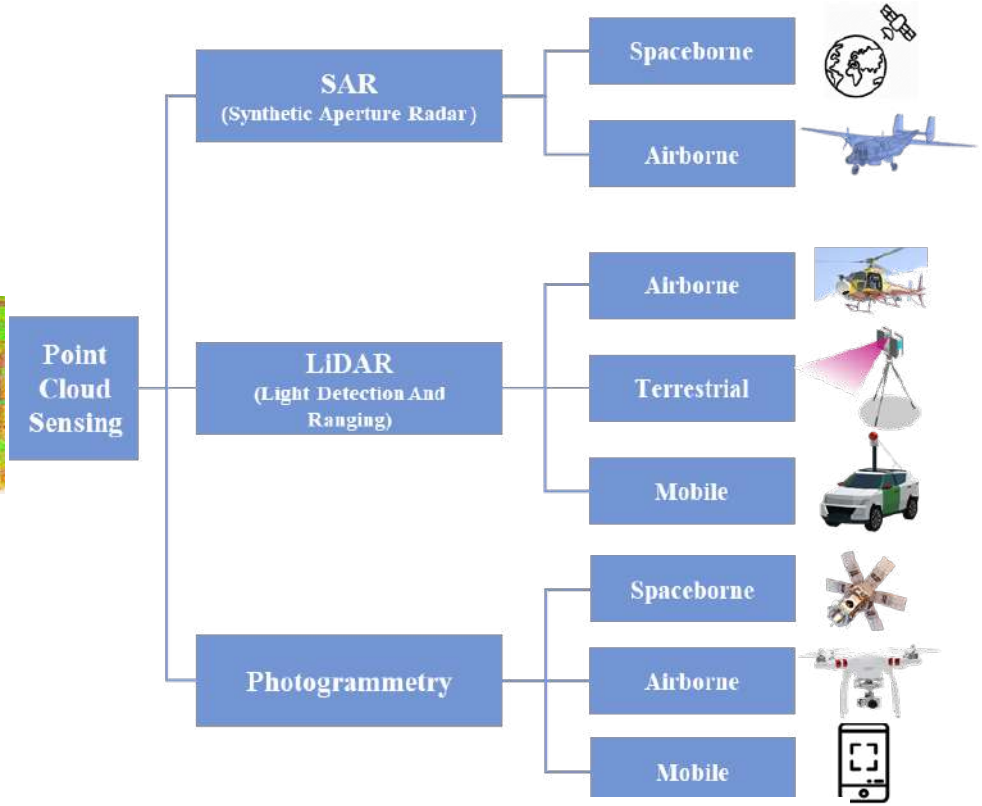




HKU Campus (Xue et al, 2019f)

- Photogrammetry 摄影测量

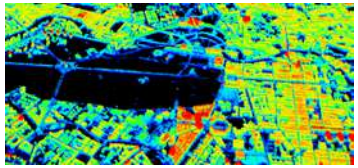
Building rooftop (Xue et al, 2019d)

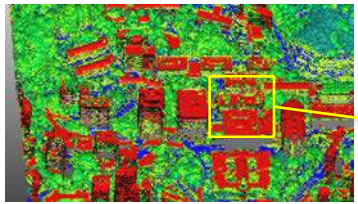


(Xu et al, 2018)

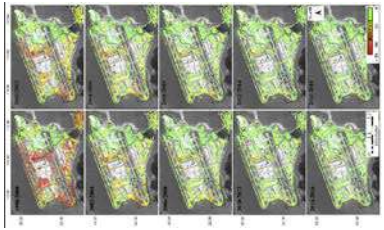
1.1 Advantages and applications

- 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

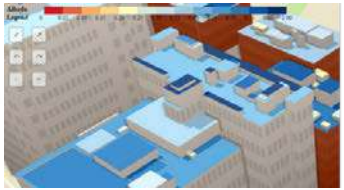




- Use cases 用例



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

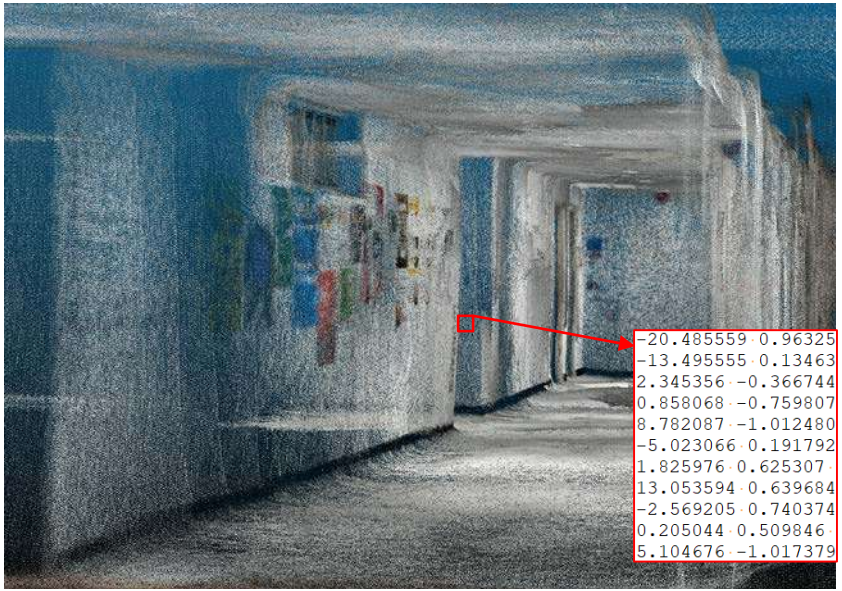


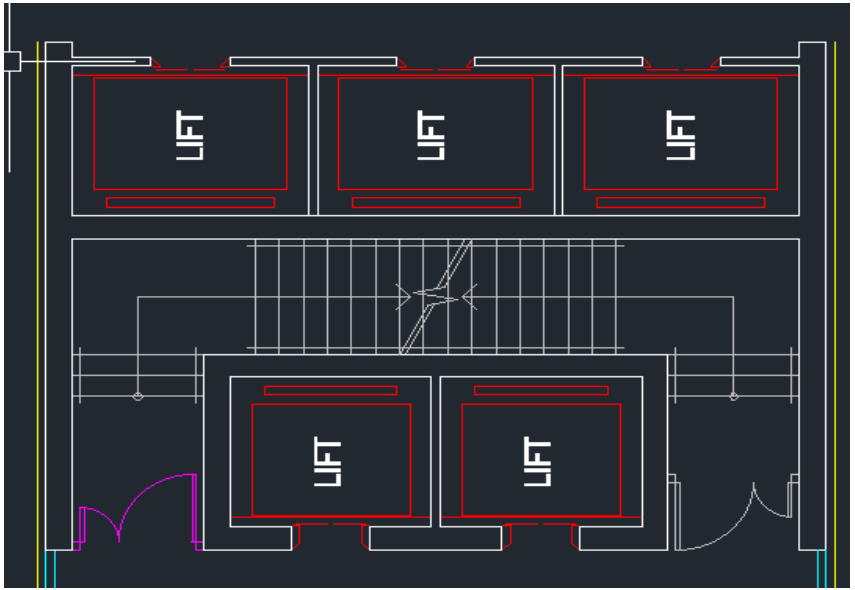
Roof albedo (Xue et al. 2019f), indoor CFD simulation (Source: Author, 2022)

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

HKU @MineCraft (Source: Author, 2021)

1.1 Point clouds compared to CAD/BIM drawings





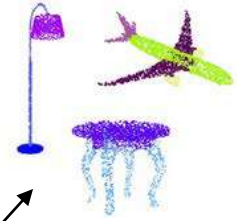
✓Rich in details and 3D appearance (*texture*)
✓Consistent with the real 3D layouts (*z*)
✗A lot of defects, e.g., sparse, noisy, and misaligned
✗Unstructured, low semantic info, massive disk size

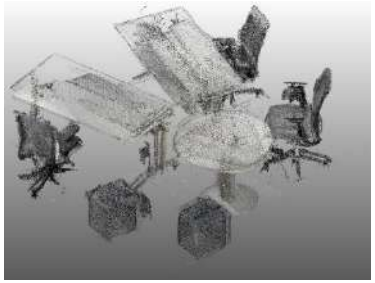
✓Precise, compact, and parametric geometry (*x*, *y*)
✗A lack of appearance
✗Possibly inconsistent with the real 3D layouts

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

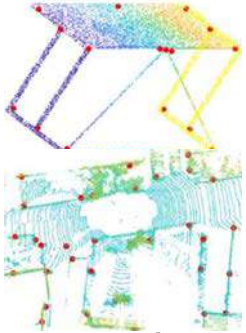




SensatUrban (Hu et al, 2021)

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**

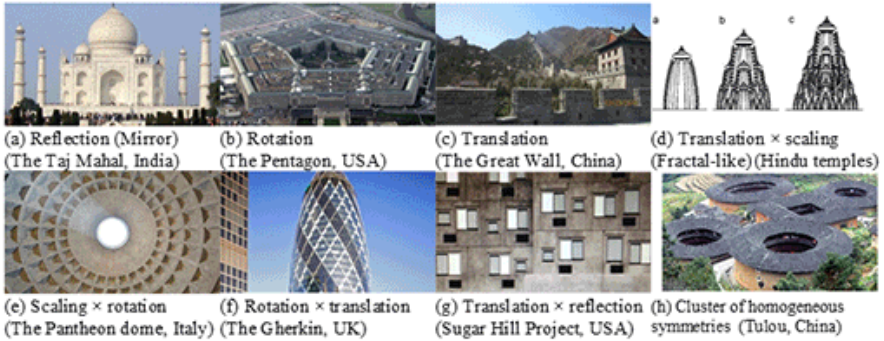


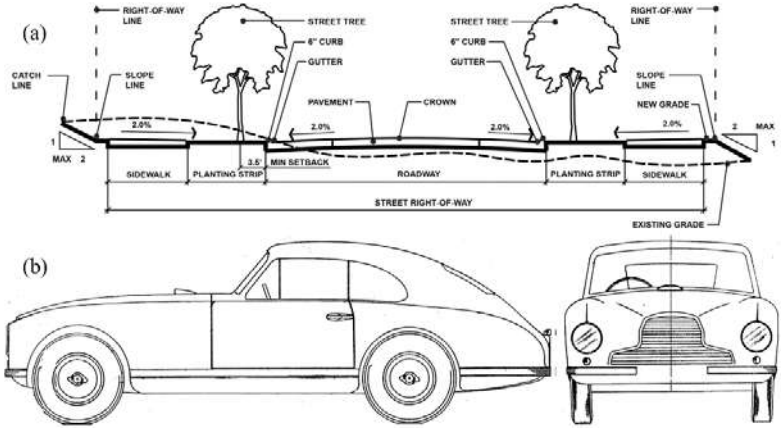
Keypoint detection (Li & Lee 2019)

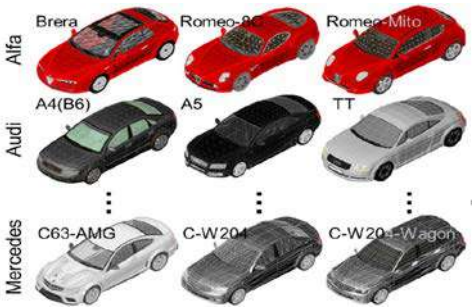
Example of semantic segmentation (Qi et al. 2017)

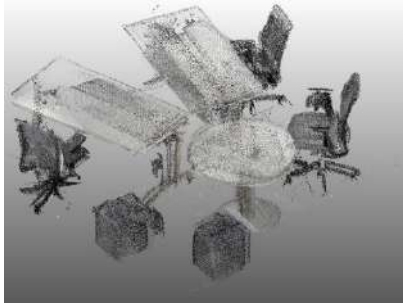
1.3 Symmetry and similarity as domain-specific

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









(Xue et al, 2019d)

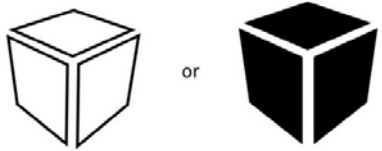
Section 2

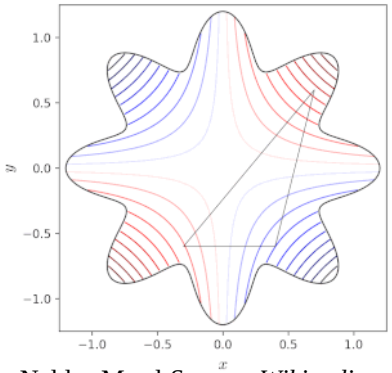
SYMMETRY AND SIMILARITY DETECTION

对称、相似性检测

2.1 “White-box” formulations for optimization

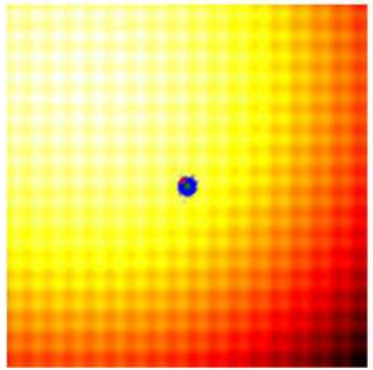
- “White-box” objective function **白盒目标**
  - f_x = RMSE(Reflect(C, $\boldsymbol{x}$), C)
  - f_x = RMSE(AffineTrans(C_1, $\boldsymbol{x}$), C_2)
  - Pre-requisite:
    - Closer densities
  - RMSE can be any error metric





Nelder-Mead *Source: Wikipedia.org*

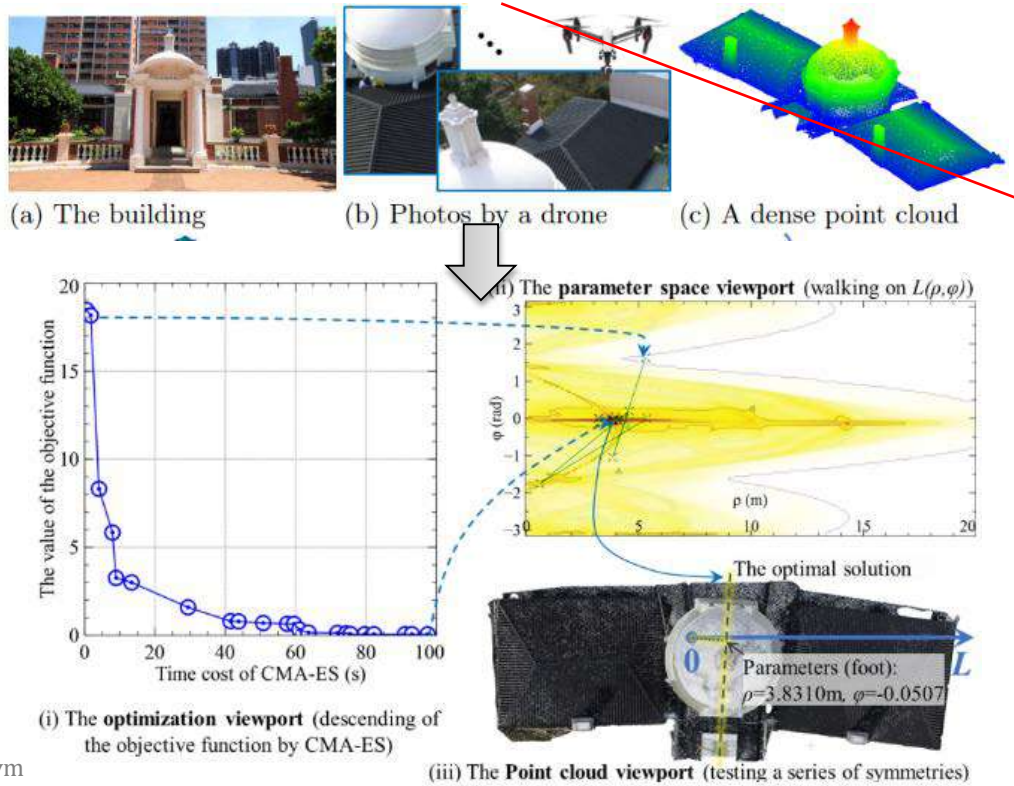
- Nonlinear optimization formulation **统一形式：非线性优化**
  - **arg min** f_x
  - **s.t.** x in *Range*
  - Constraints $(x) \leq 0$
- 50+ off-the-peg solvers for complex optimization**可用算法**
  - In C++/Python/… (see right)



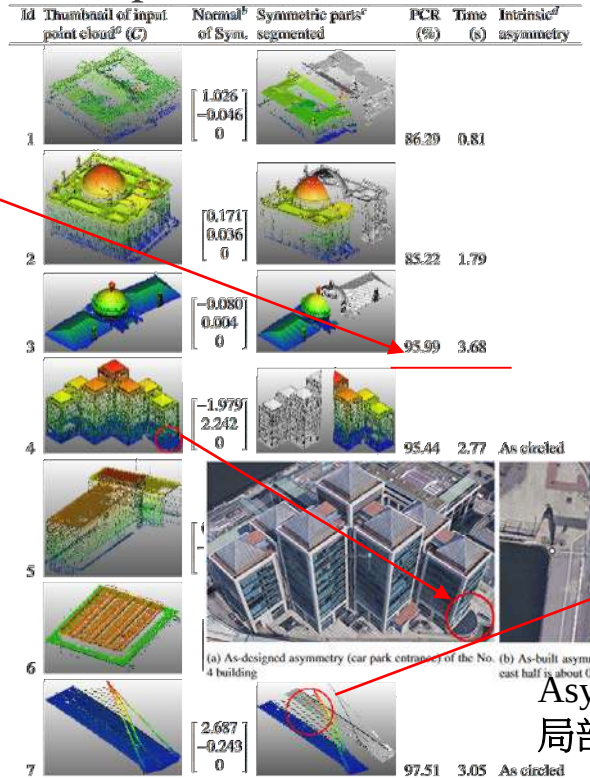
CMA-ES *Source: otoro.net*

2.1.1 Symmetry detections (early, vs updated)

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



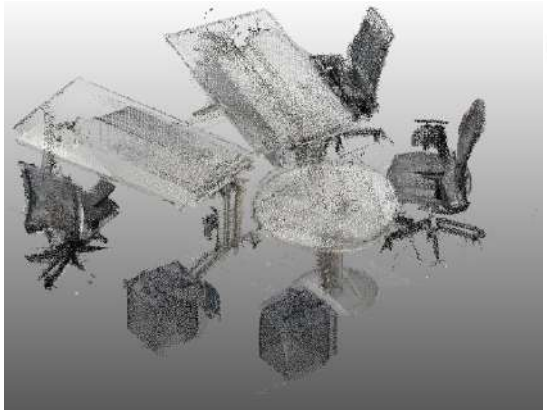
- Updated in (Xue et al. 2019a)

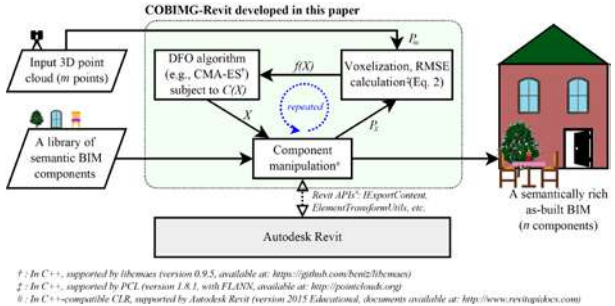


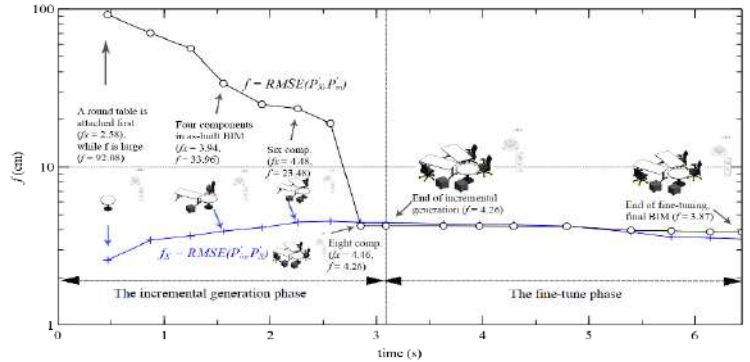
Asymmetries
局部非对称

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

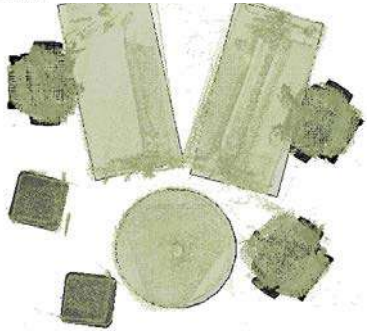
- Time = 6.44s (Manual = 300s), RMSE = 3.87 cm







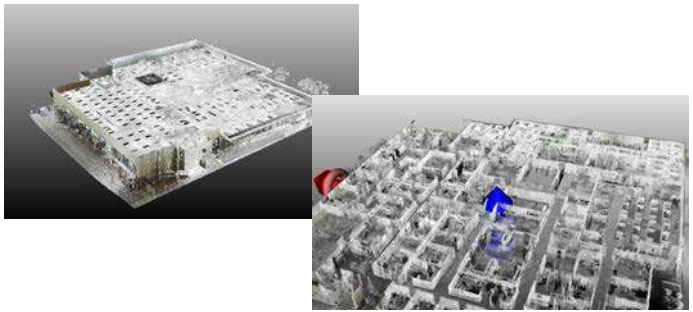
(a) A screenshot of the 3D view of the output as-built BIM

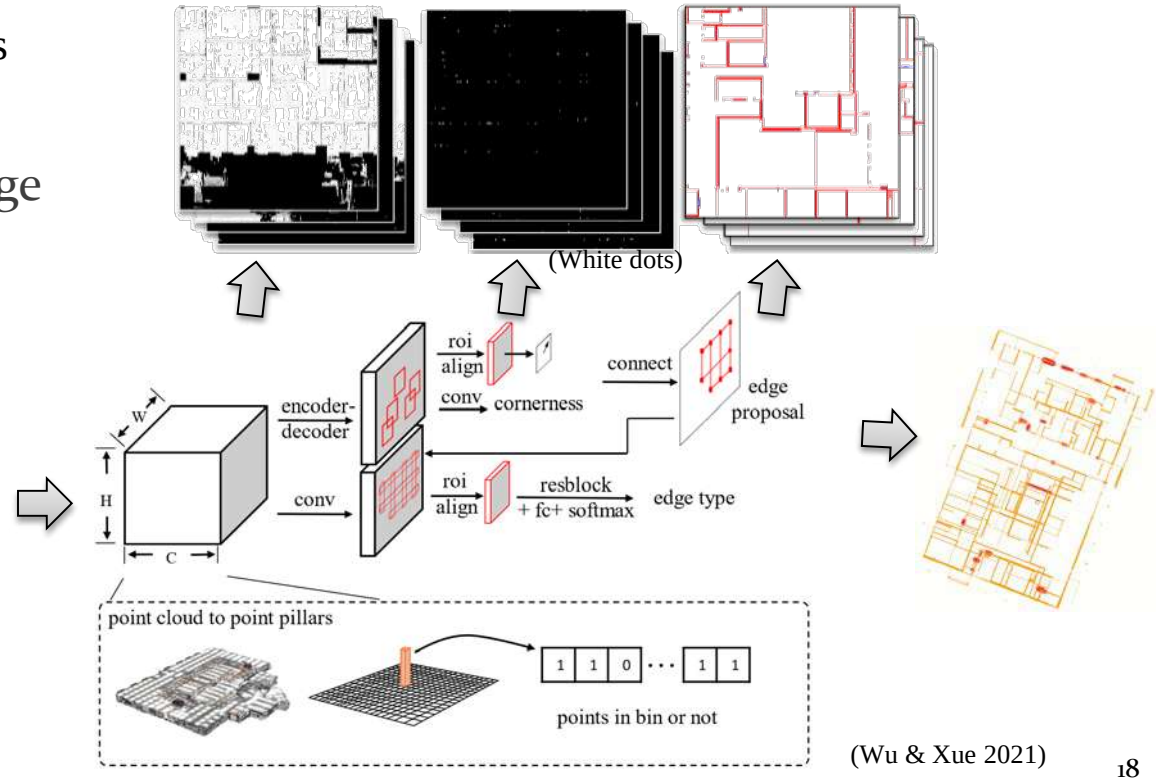


(b) A visual comparison between the input (grey points) and the output BIM

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

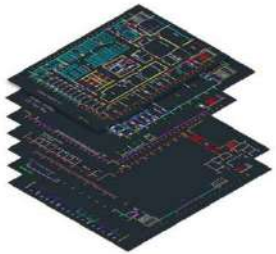




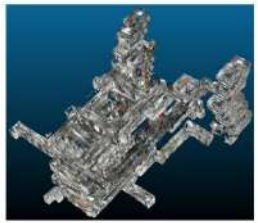
(Wu & Xue 2021)

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

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

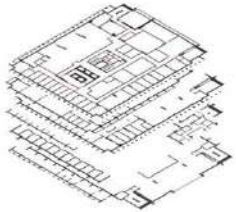


CAD drawings



Smartphone's point clouds

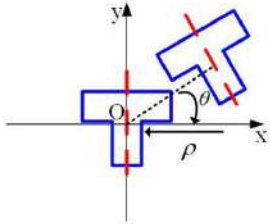
Inputs



Vertical structure extraction (Plan2Polygon)

Story separation

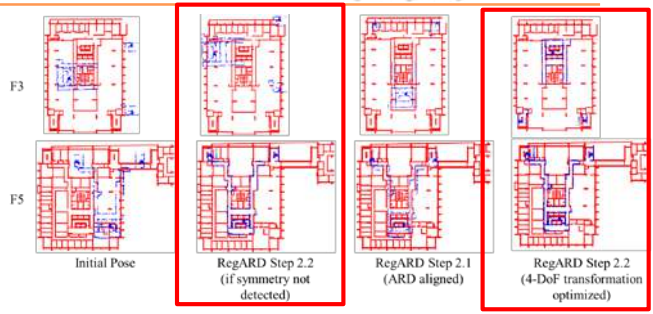
Preprocessing (In-house developed)

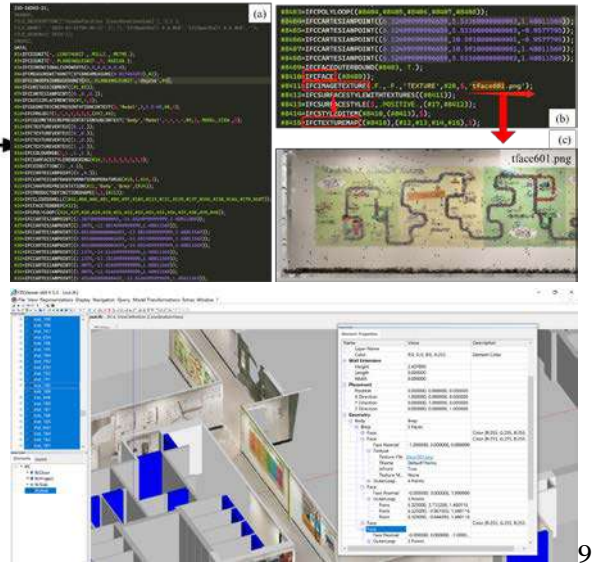


Step 1. Architectural reflection detection and initial alignment

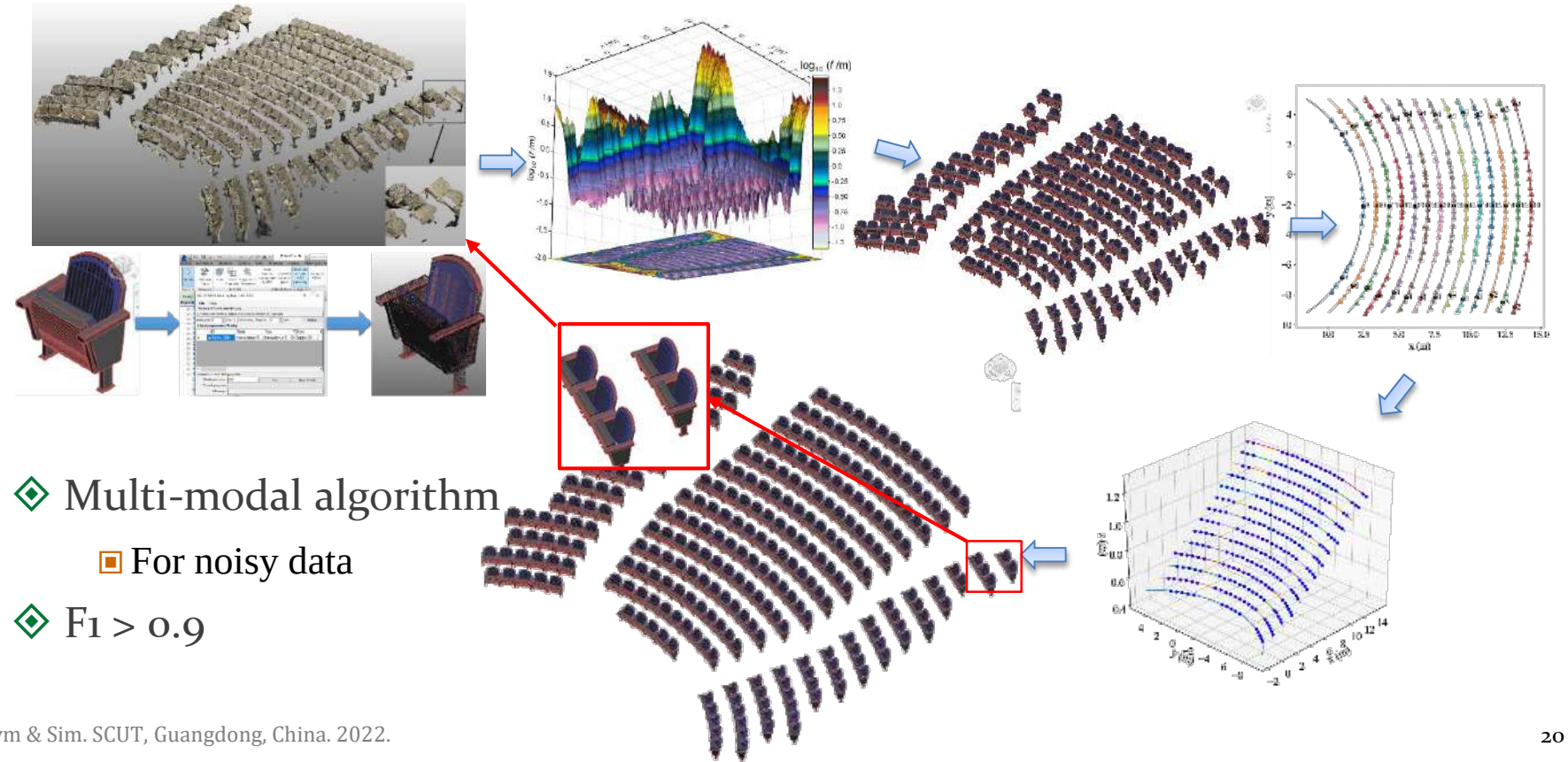
Step 2. Optimization-based coarse registration

Registration (The proposed RegARD method)





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

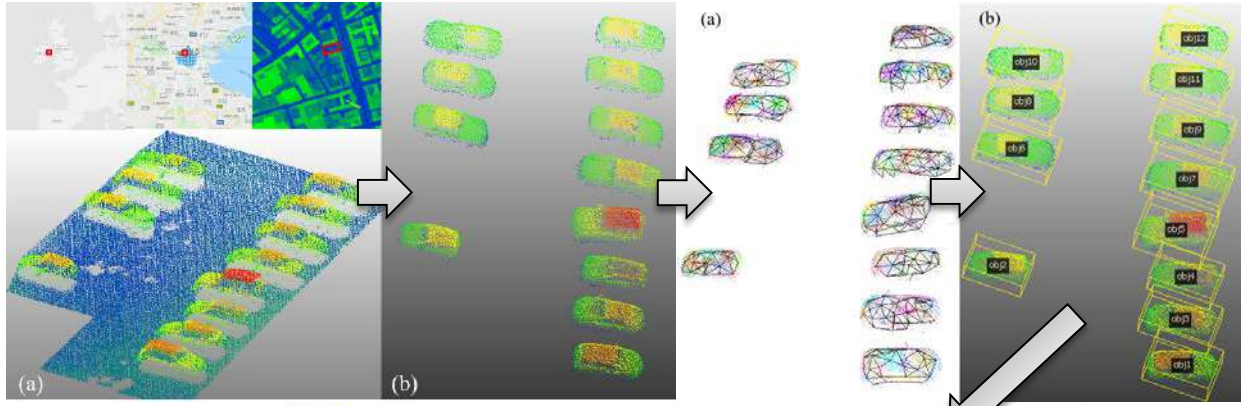


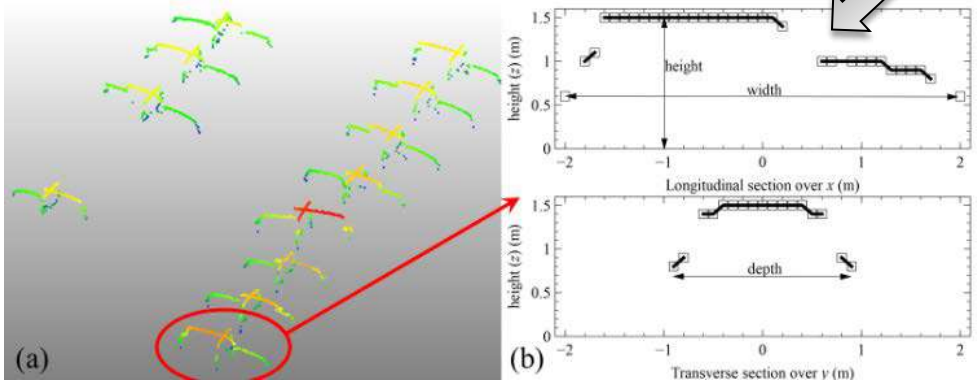
- Multi-modal algorithm
  - For noisy data
- F1 > 0.9

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
    - 3.1 Section #1
  - 4. Perpendicular
    - 4.1 Section #2
  - 5. Voxelization
- For unknown objects

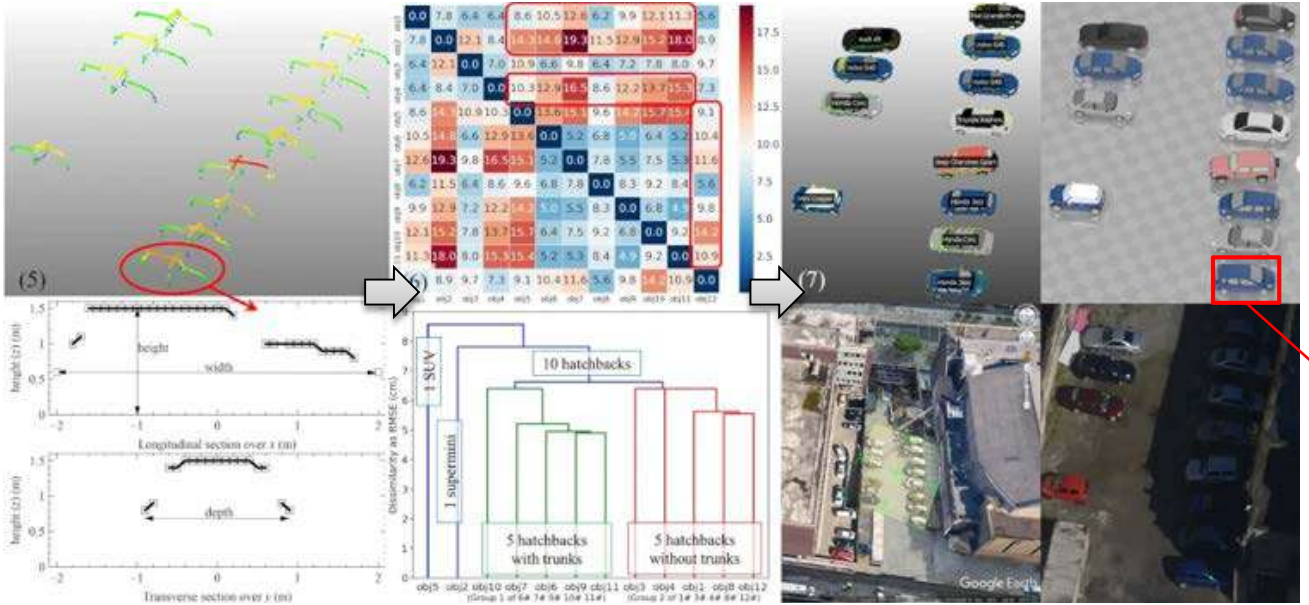
  无需语义分割
  - Symmetric
  - Above ground

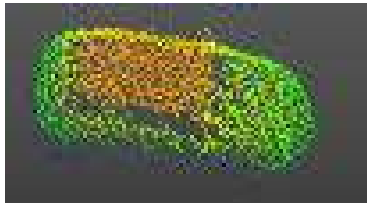




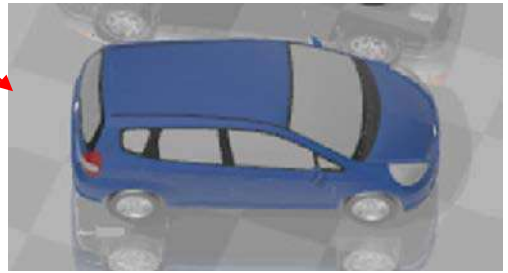
2.3 Case 3: Sym+Sim for city objects 案例3 (2/2)

- 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

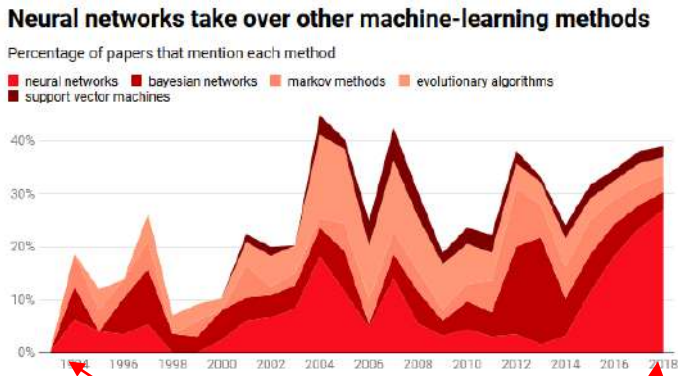
SUMMARY
小结

3.1 A recap

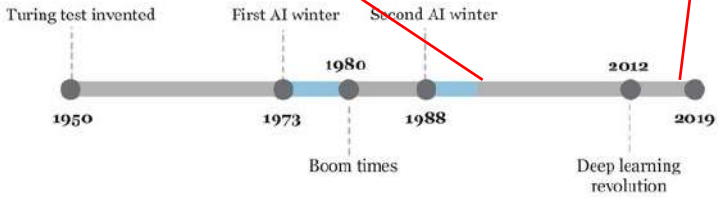
- Urban point cloud **城市点云**
  - Has advantages for buildings/urban applications
  - Understanding is a must-to-do for machines
- Symmetry and similarity **对称、相似**
  - Can be formulated as
    - “white-box” formulations
    - “black-box” formulation
  - Very powerful for understanding a point cloud if 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)



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Keep awesome!

感谢！欢迎提问