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

iLab @ HKURBANlab
the urban big data lab

2023智慧城市与智能建造高端论坛
暨中国建筑学会智能建造学术委员会年会

综合无监督、监督和强化学习的全自动 Scan2BIM

Fully Automatic Scan-to-BIM:
Consolidation of unsupervised, supervised, and reinforced learning

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5 May 2023, Smart City and Construction Forum, Wuhan, China

Outline

iLab

1 背景 Introduction

2 概述 Types of Machine Learning

3 自动化 Automatic scan-to-BIM

关键词

“训练?”

“综合”

Section 1

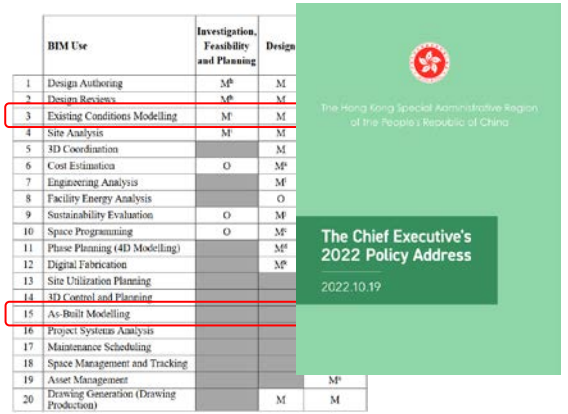
INTRODUCTION
背景

1 Smart construction & digitalization 智能建造

- Smart construction as a national strategy
  - 中央政府：“發展智能建造”——《十四五規劃和2035年遠景目標綱要》
  - 國家自然資源部：《关于全面推进实景三维中国建设的通知》
  - NDC 国家数字建造技术创新中心 National Center of Technology Innovation Digital Construction e-construction 工程管理研究所
- In Hong Kong
  - Election Manifesto of Chief Executive Election 2022
  - Development Bureau’s Technical Circular (2021)
  - CIC’s Construction Digitalization Roadmap (2021)
    - 6 Applications (DAs)

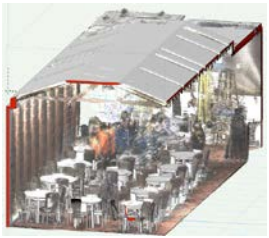
1 BIM is a key 关键

- HK market: ~HK$300 billion. 每年3000亿
- BIM in Hong Kong 越来越宽、越来越深
  - "Wider" by industry-wide mandatory uses
    - 所有All public works >HK$30M since 2020 (DevB, 2019)
    - 所有All private projects >HK$300M by 2026 (CIC, 2022)
  - "Deeper" for values
    - "A roadmap on BIM for plans submission" (Policy Addr 2022)
    - 20 mandatory BIM stages since 2022 (DevB, 2021)
- 3D point scans 激光点云 in top BIM uses
  - Surveys actual 3D dimensions, real assets
  - Every developer/contractor has a laser scan team

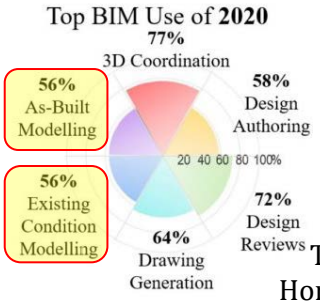


	BIM Use	Investigation, Feasibility and Planning	Design	
1	Design Authoring	M[a]	M	
2	Design Reviews	M[a]	M	
3	Existing Conditions Modelling	M[c]	M	
4	Site Analysis	M[c]	M	
5	3D Coordination		M	
6	Cost Estimation	O	M[b]	
7	Engineering Analysis		M[c]	
8	Facility Energy Analysis		O	
9	Sustainability Evaluation	O	M[c]	
10	Space Programming	O	M[c]	
11	Phase Planning (4D Modelling)		M[a]	
12	Digital Fabrication		M[a]	
13	Site Utilization Planning			
14	3D Control and Planning			
15	As-Built Modelling			
16	Project Systems Analysis			
17	Maintenance Scheduling			
18	Space Management and Tracking			
19	Asset Management			M[a]
20	Drawing Generation (Drawing Production)		M	M

BIM mandatory stages (DevB TC(W) No. 2/2021)



Scan-to-BIM (Moon Palace, Src: authors)

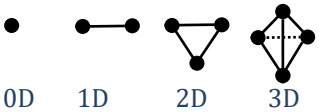


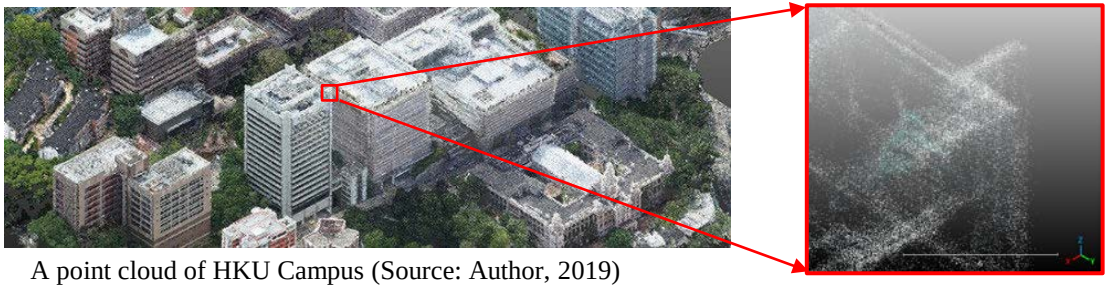
Top BIM uses in Hong Kong (Src: CIC)

Xue: Fully auto scan2BIM. Wuhan, China. 2023.

1 What is a point cloud 点云

- 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
- Point cloud (PC)



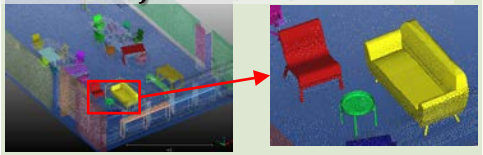


A point cloud of HKU Campus (Source: Author, 2019)

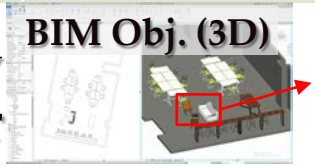
A close look of cloud at Mount Hua (Source: Author)

Xue: Fully auto scan2BIM. Wuhan, China. 2023.

1 Existing scan-to-BIM paradigms 现存范式

Paradigm	Key algorithm	Trained for HK	Software's output (Dimension of objects)	Labor-hour (30 rooms)	Applicability for BIM uses
1. Open-source mesher + *ifcopenshell*	Poisson reconstruction	✗	Mesh triangles (2D) 	200	Visualization
2. Aurivus® + open-source clustering	3D Deep Learning (DL)	✗	Points with labels (3D) 	140 (30% saved)	Visualization; Designed BIM verification;
3. Proposed SBASE	**Our** 3D DL + **frequent 3D BIM for HK**	✓	BIM Objects (3D) 	85 (60% saved) ✓	Visualization; Designed BIM verification; **BIM auditing; Lightweight CIM**

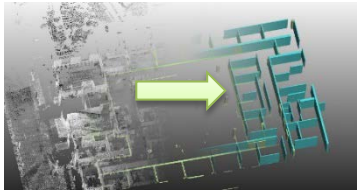
Reference BIM by a human modeler

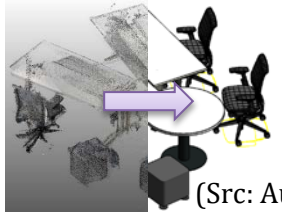
BIM Obj. (3D) 

Xue: Fully auto scan2BIM. Wuhan, China. 2023.

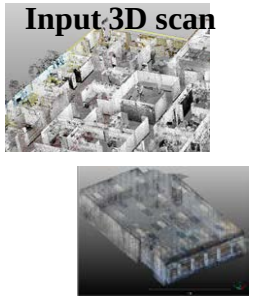
1 General workflow; 现存问题

- 4 steps
  - 1.1 Point-level 点级别
  - 1.2 Primitive-level 几何块级别
  - 1.3 3D BIM details 细节BIM
  - 2. Applications 应用

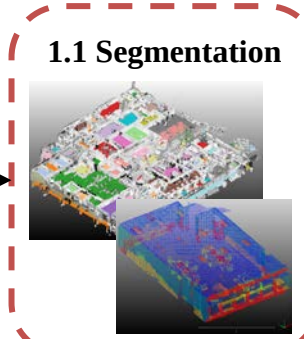




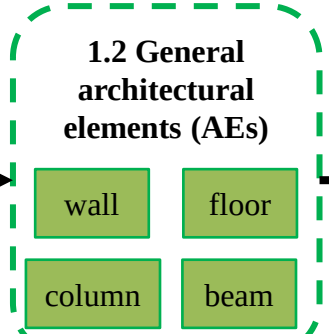
(Src: Authors)



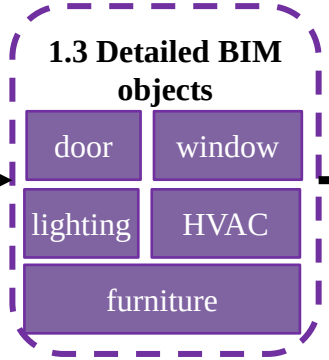
(Src: Authors)



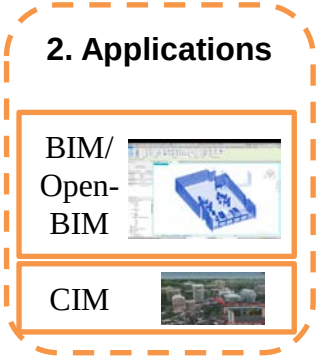
Time cost: ~5%



Time cost: ~20%



Time cost: **~75%**



(Src: Authors)

1. mesher + *ifcopenshell* → **Not covered** → **Not covered**

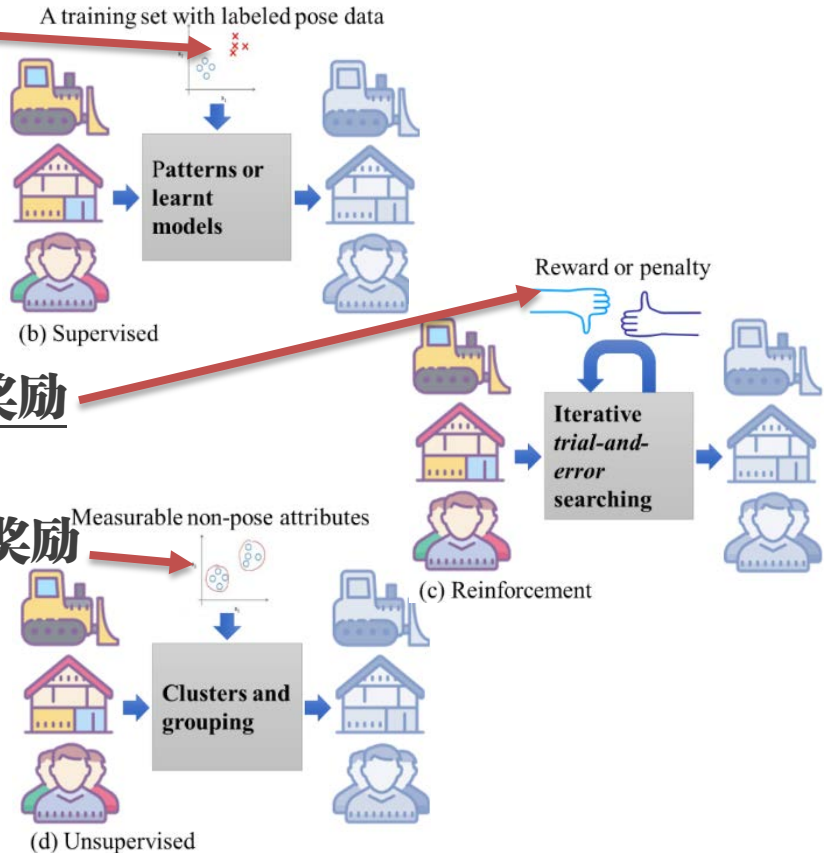
2. Aurivus® + clustering → → **Not covered**

Section 2

TYPES OF MACHINE LEARNING
概述

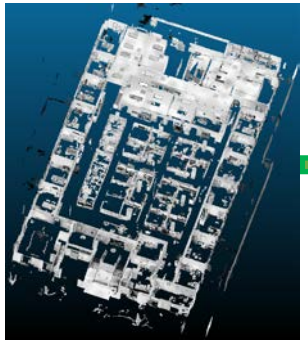
2 3 types of ML 机器学习三大类

- Supervised learning **监督：须标注数据**
  - Classification and regression
  - Meta learning
  - Automated ML (AutoML)
  - Deep learning
- Reinforcement learning **强化：无标注有奖励**
  - Simulation-based optimization
- Unsupervised learning**无监督：无标注无奖励**
  - Clustering
  - Association rules



2.1 Supervised segmentation 监督：须标注数据

- ‘KP’ of FLKPP: Kernels of points

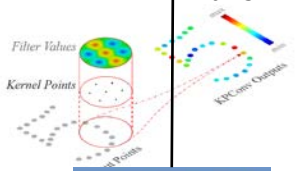


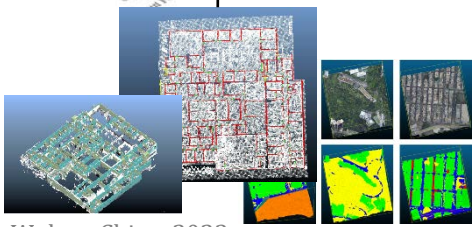
Input: point cloud after clutter removal

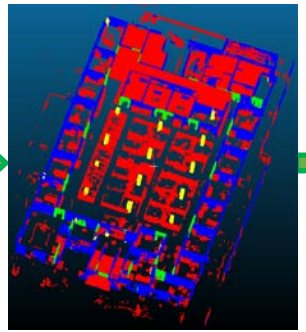
KPConv
(*Thomas et al. 2019*)

DL

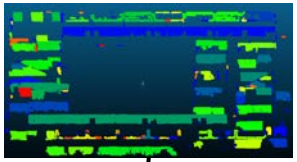
Trains

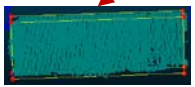




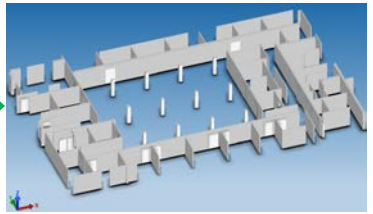


Output:
Segmented points of walls, doors, and stairs





RANSAC plane fitting



3D objects

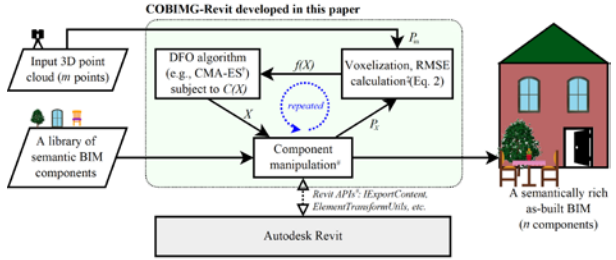
Wall Column Door Others

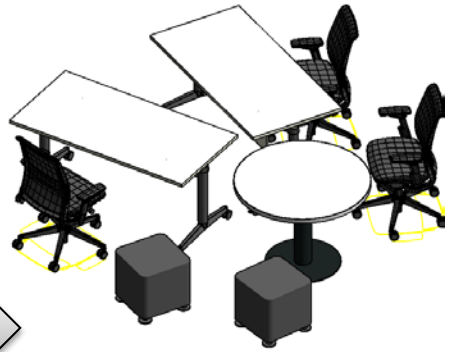
(Wu et al. 2022b)

Xue: Fully auto scan2BIM. Wuhan, China. 2023.

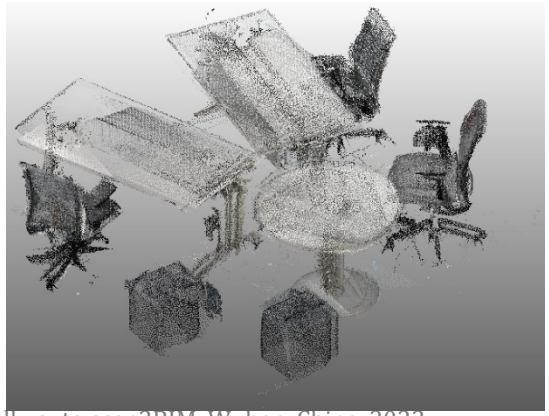
2.2 Reinforcement 3D pose 强化：无标注有奖励 (Xue et al. 2019b)

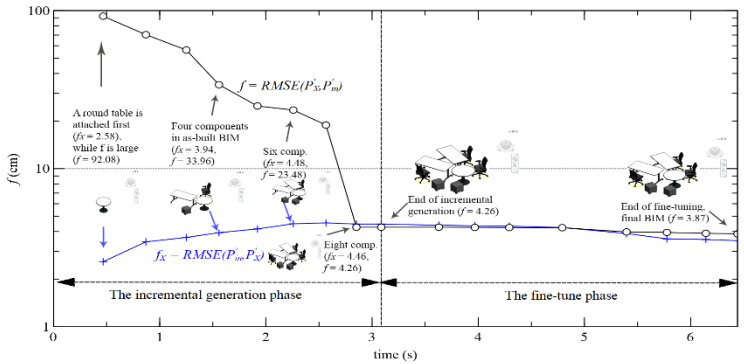
- **惩罚：** BIM与点云匹配误差
  - Time = 6.44s (Manual = 300s), RMSE = 3.87 cm

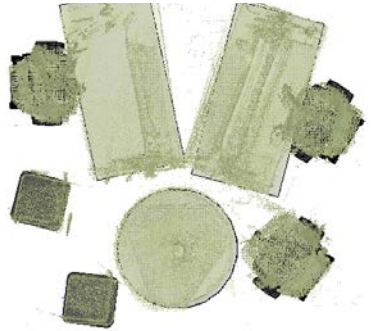




(a) A screenshot of the 3D view of the output as-built BIM







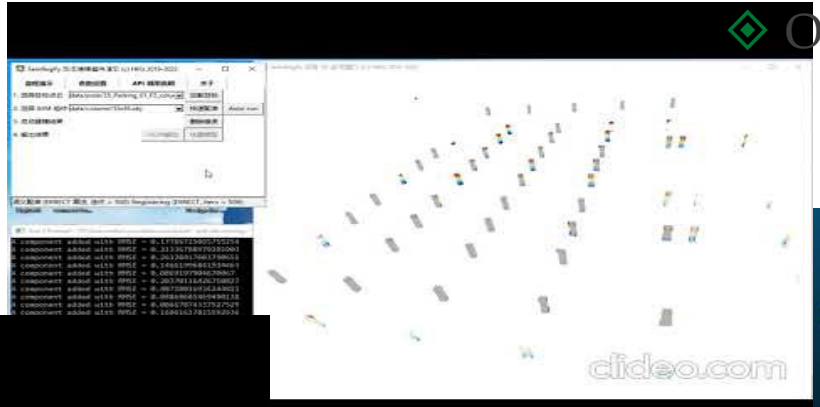
(b) A visual comparison between the input (grey points) and the output BIM

Xue: Fully auto scan2BIM. Wuhan, China. 2023.

2.2 Reinforcement 3D pose 强化：demo

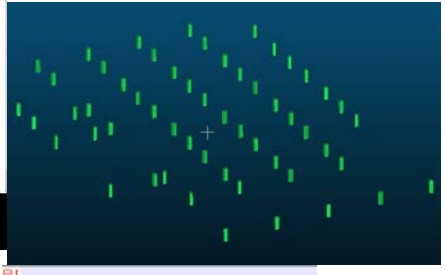
iLab

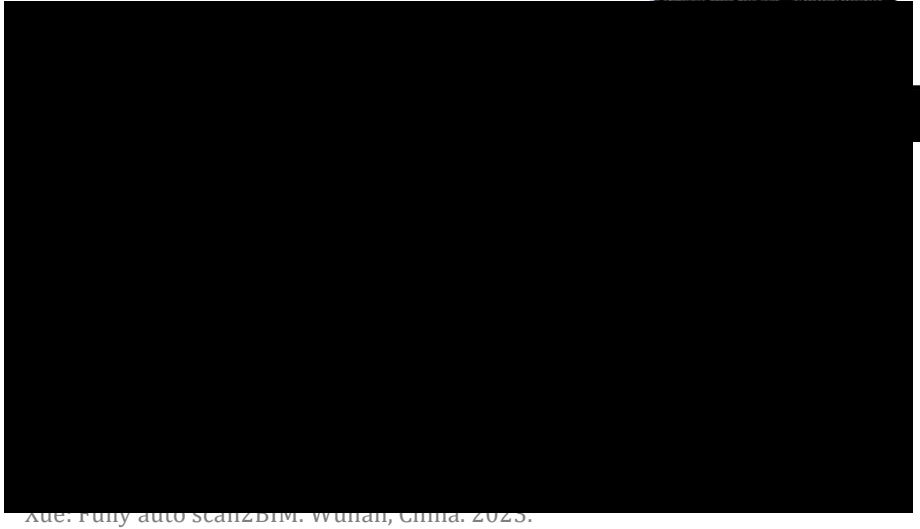
Fitting BIM objects for location, rotation, and relational semantics (Xue 2019)



Output formats

- BIM
- JSON



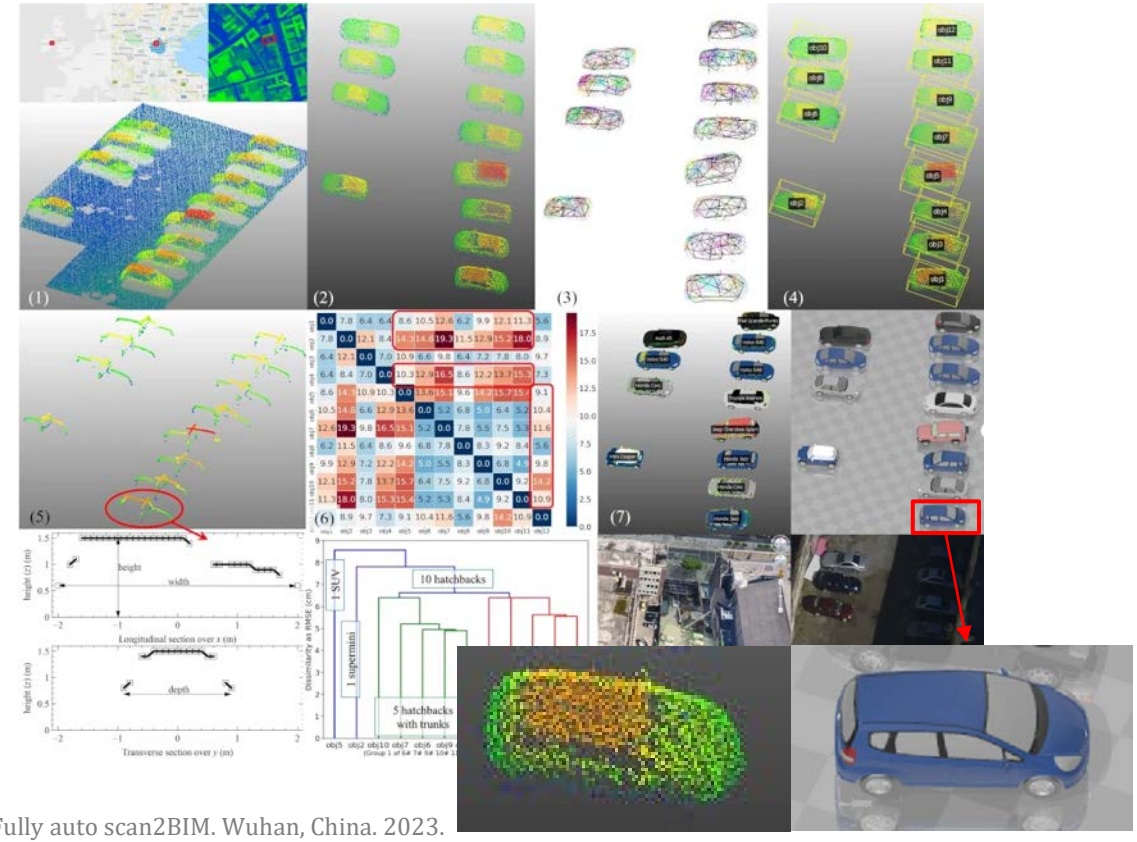


Another demo of 3D pose estimation of columns (Wu et al. 2022b; https://youtu.be/kdMYD0Po7kY)

Xue. Fully auto scanzBIM. Wuhan, China. 2023.

Xue et al (2020)

2.3 Unsupervised clustering无监督：无标注无奖励



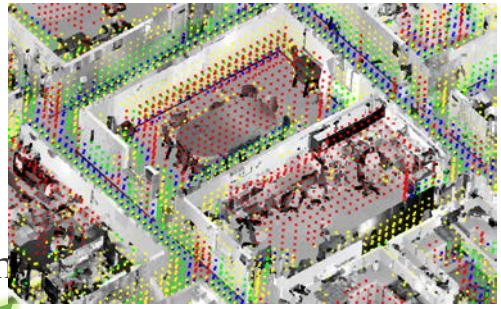
- Ground (planar) removal
- Clustering patches
- Symmetry detection
  - By optimization (RL)
  - For cross-sections
  - Longitudinal / transverse
- Clustering objects using cross-sections
  - 无成本，快速
- Fitting 3D model

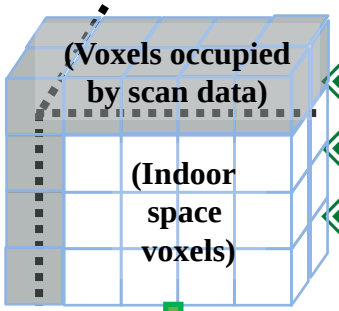
Xue: Fully auto scan2BIM. Wuhan, China. 2023.

2.3 Unsupervised clustering无监督：无标注无奖励

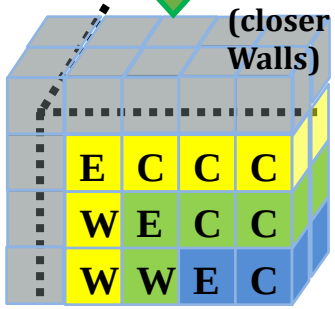
- ‘FL’ of FLKPP: floor layers
  - Room clustering 聚合室内“空间”
  - Room-base noise and clutter removal 去噪
- Space voxels labeling
- Region growing to segment rooms
- Clutter removal (using head levels in room

(Zoom-in)

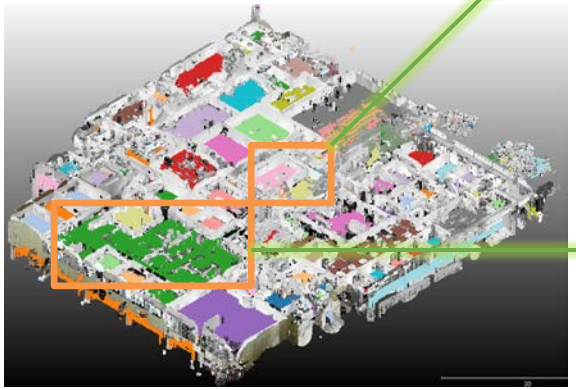


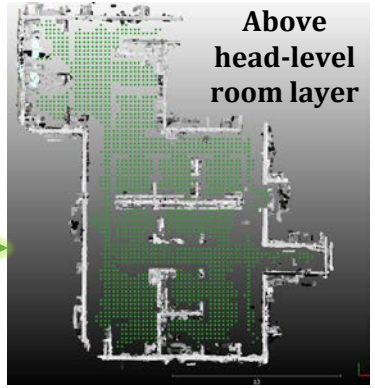


1. Space voxels (closer to Edge, Ceiling, Walls)



2. Room clustering (using voxels 1m to ceilings)





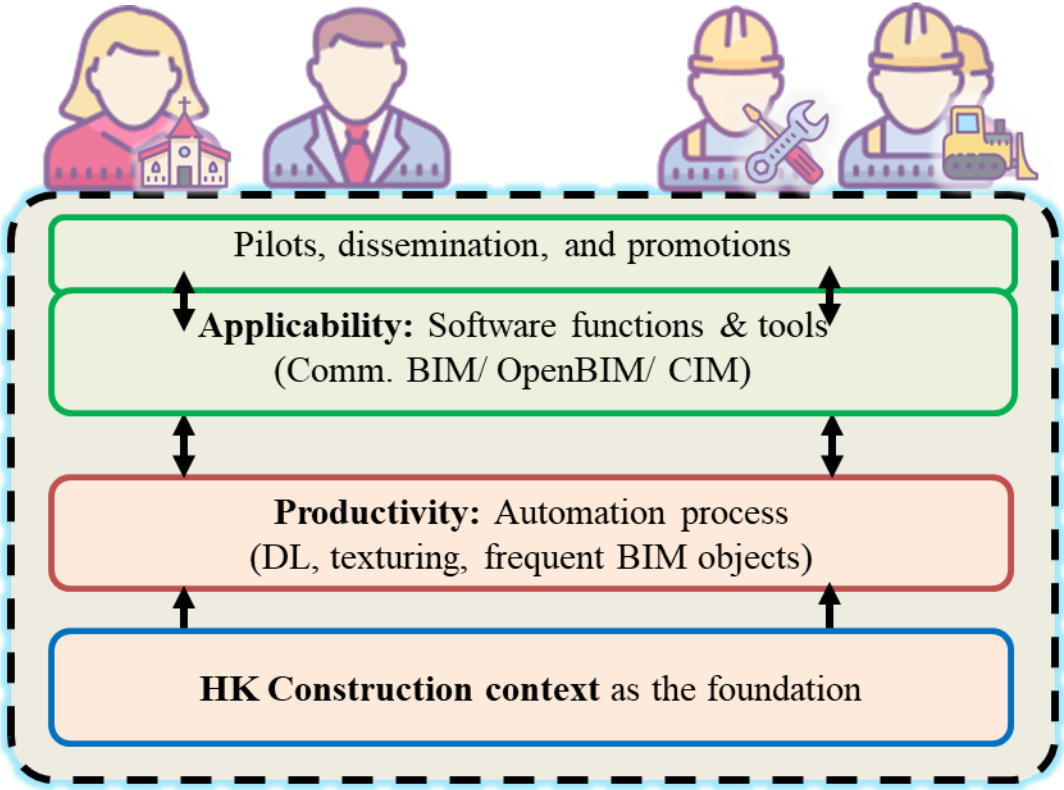
Xue: Fully auto scan2BIM. Wuhan, China. 2023.

Section 3

AUTOMATIC SCAN-TO-BIM
全自动化

3 SBASE项目 : Fully automation

- SBASE 项目
  - Scan-to-BIM Auto SystEm
- Step 1.1 :
  - Unsupervised + supervised
- Step 1.2:
  - Unsupervised + rules
- Step 1.3:
  - Unsupervised + reinforcement
- Step 2:
  - Localized apps

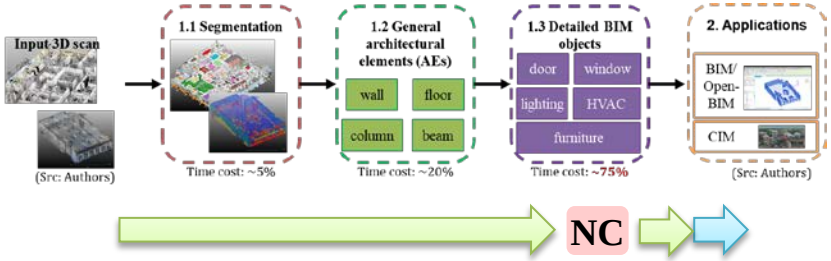


Xue: Fully auto scan2BIM. Wuhan, China. 2023.

3.1 SBASE 项目: Funding and team

- Funding
  - Hong Kong ITF Tier-1: HK$ 7.51M (in total 751万) 2023-2025
- Team
  - PC 主持: F Xue
  - Co-PI: Prof Anthony Yeh 叶嘉安院士
  - Co-PI: Prof Wilson Lu 吕伟生教授
  - Co-I: Dr Ke Chen 陈珂（华科）
- Automation level: Full, limitations in 1.3
- Job vacancies **虚位以待**
  - Postdoc 博士后 1 名
  - RA 助理研究 6 名



Xue: Fully auto scan2BIM. Wuhan, China. 2023.

3.2 A recap

- Scan-to-BIM
  - Vital to smart construction
  - Automation is limited currently
- Types of Machine Learning “**训练?**”
  - Supervised: 3D语义分割
  - Reinforcement:最佳BIM族匹配
  - Unsupervised: 对比、聚类
- Auto scan-to-BIM “**综合**”
  - Consolidation 按需求整合
  - Huge potentials 大有可为

Xue: Fully auto scan2BIM. Wuhan, China. 2023.

References

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感谢！欢迎提问