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

iLab @ HKURBANlab
the urban big data lab

Understanding unstructured 3D point clouds for creating digital twin city

An unsupervised hierarchical clustering approach

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Outline

1 Background

2 An unsupervised method to PCD

3 Discussion

Section 1

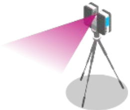
BACKGROUND

1.1 Motivation

- Digital twin city / semantic enrichment for CIM
  - Real-time/as-is/as-built modeling of
    - The built environment (4D)
    - Moving objects (4D persons, vehicles)

  - Vital to
    - Architecture, urban planning
    - Construction, conservation, smart city
    - Self-driving car, *etc*.

- Popular models and technologies



  - Point clouds (Photogrammetry, laser scanning)
  - Triangle mesh models (3D Maps)
  - Volumetric as-built BIMs

Example of photogrammetry: Kowloon Wall City
(Source: patrick-@sketchfab.com)

Example of point cloud: Pompei City
(Source: MAP-Gamsau lab, CNRS, France)

Example of GIS-based: 3D Berlin
(Open Data, source: berlin.de)

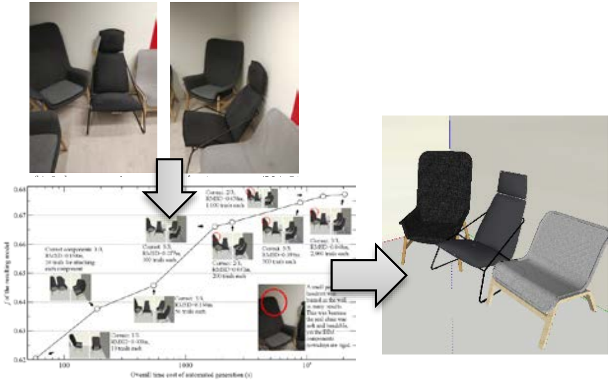
†: Architecture, Engineering and Construction/ Facilities Management

1.2 Existing as-built modeling methods

- Manual reconstruction?
  - Expensive, tedious, **and** impractical for DTC
- Two paradigms of *automatic* reconstruction
  - (1) Semantic segmentation
    - Step 1: To cut and label data to small patches (objects) (e.g., slicing bridge piers/deck)
    - Step 2: To fit object parameters (e.g., width, height of a wall)
  - (2) Semantic registration
    - Step 1: To annotate standard BIM components

      E.g., online open BIM resources
    - Step 2: To register into the **whole data**

Example of Step 1 of Paradigm (1)
(Qi et al. 2017)



Example of Step 2 of Paradigm (2)
(Xue et al. 2018)

1.2 Review the methods in the ML perspective

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Machine learning

- Supervised learning
  - E.g., flower classification
- Reinforced learning
  - E.g., iterative *AlphaZero* chess/Go score optimization
- Unsupervised learning
  - E.g., clustering of nearest points, animal spicies

As-built modeling

- Semantic segmentation
  - E.g., with *PointNet*, *Semantic3D*
- Semantic registration
  - E.g., iterative RMSE optimization by fitting free BIM components
- An opportunity
  - Based on existing unsupervised methods

Section 2

AN UNSUPERVISED METHOD TO PCD

2.1 Overview

◇ Hierarchical clustering approach

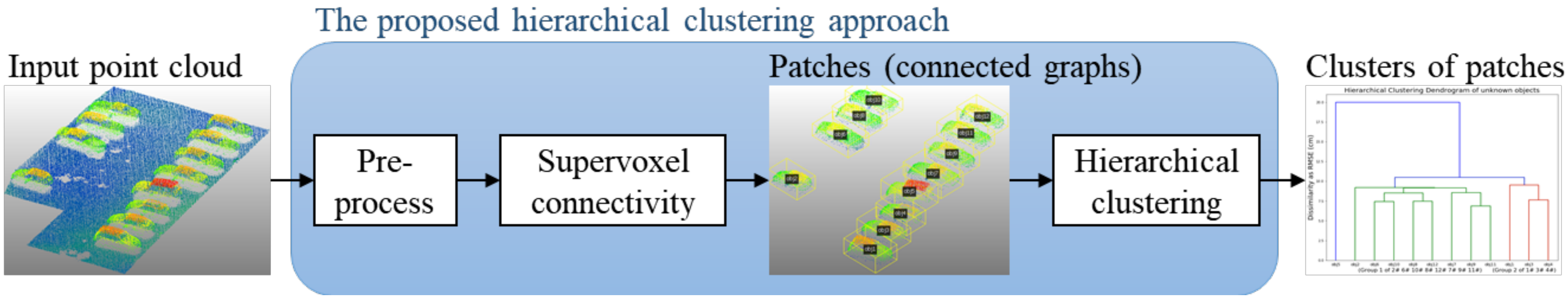


Figure 1: An overview of the proposed hierarchical clustering approach

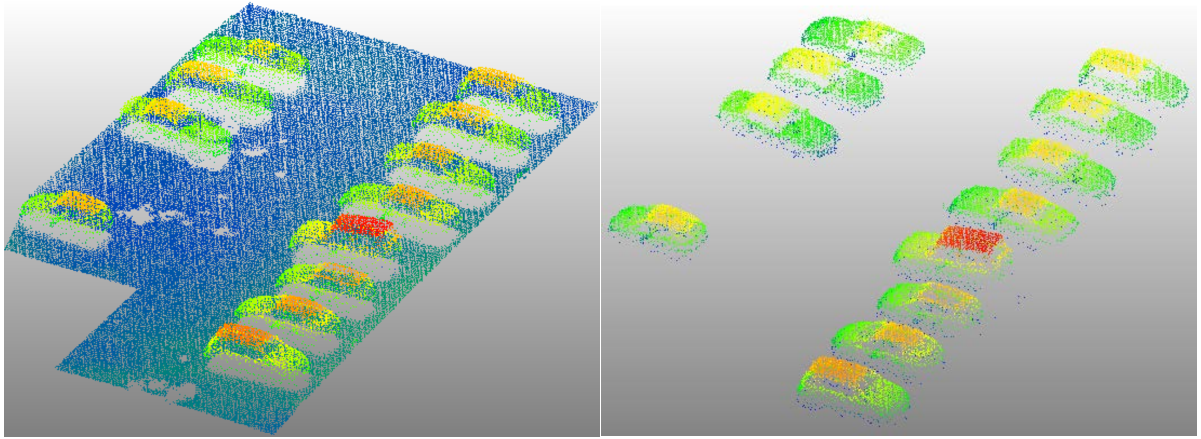
◇ Objective

- No training data
- Evidence: Connectivity, (dis)similarity of PCD patches

$$\mathit{dissimilarity}(P_i, P_j) = \min_{r,\, t \in \mathbb{R}^3} \mathit{RMSE}(P_i, \text{translate}(\text{rotate}(P_j, r), t))$$

2.2 Pilot case

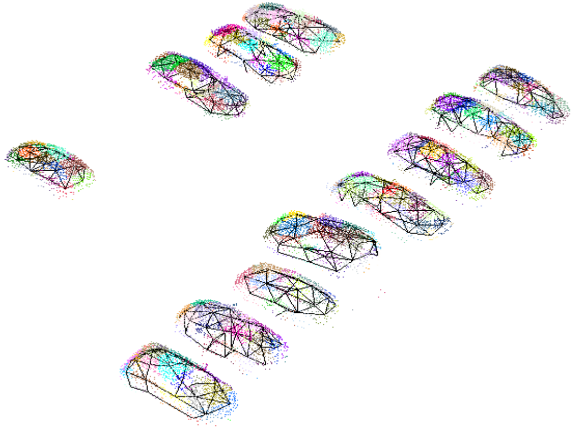
- A car park
  - Dublin dataset (Laefer et al. 2017).
  - 112,999 points (6.78MB)
  - 12 cars: 8 “short”, 3 “tall”, 1 SUV
  - 24,126 points after ground removal



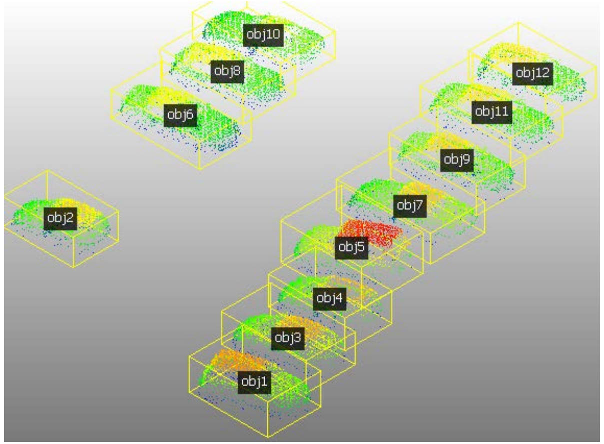
(a) 112,999 LiDAR points (color indicates height) (b) After the preprocess of planar removal

2.2 Pilot case (cont.)

- 368 small patches segmented
  - Normal, point-level connectivity
- 12 patches clustered
  - Patch connectivity
  - The 12 cars



(a) 368 small patches (by color) and the connectivity (lines) detected in 1.3s

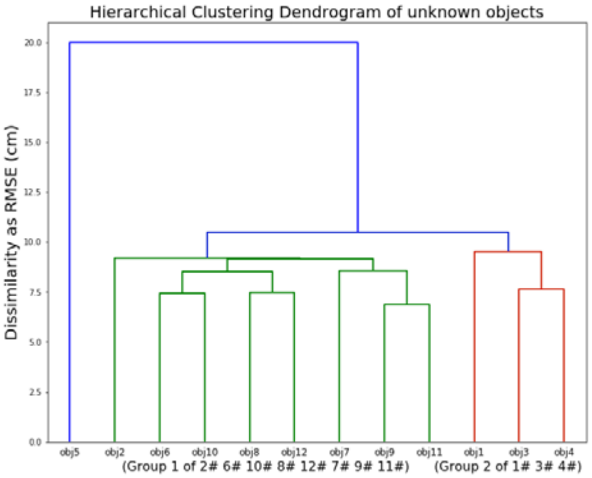


(b) 12 patches (obj_1 to obj_{12}) was clustered via the connectivity of patches in (a)

2.2 Pilot case (cont.)

- Hierarchical clustering
  - Dissimilarity matrix in 109.4s
  - Based on top algorithms benchmarked in Xue et al. (2019a)
- 3 clusters seen
  - Green: 9 “short” cars
  - Red: 3 “tall” cars
  - Blue: 1 SUV
  - All correct
- Understanding
  - Relative relationships
  - X, y, z locations
  - Groups, “near-by” etc.

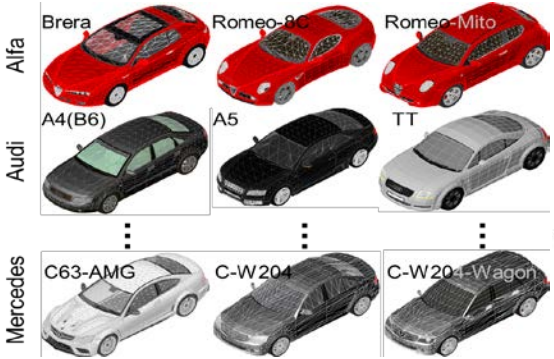
(a) The dissimilarity matrix computed in 109.4s (unit = cm, color depth indicates the dissimilarity)



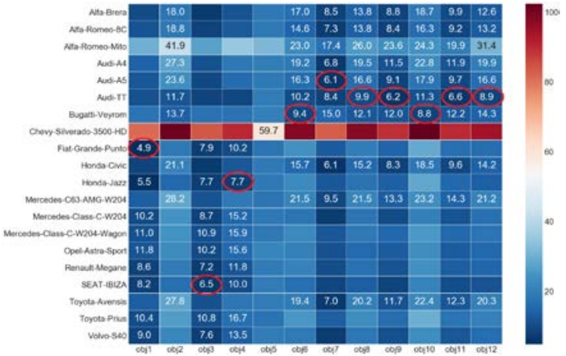
(b) Hierarchical clusters of similar patches (grouping threshold = 10cm)

2.3 Additional model registration

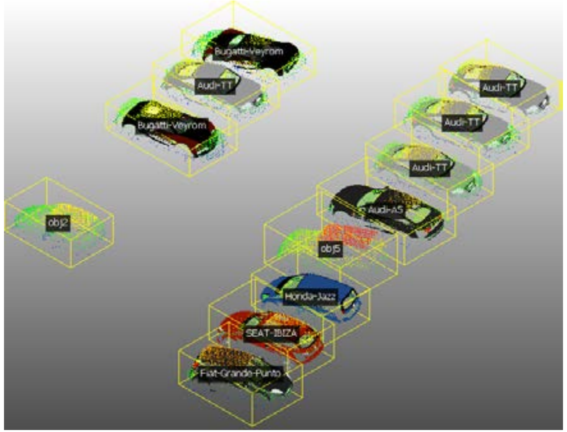
- After understanding
  - Towards a real DTC
  - By semantic registration (Xue et al. 2018, 2019b)
  - Some models/colors were wrong
    - No RGB in input

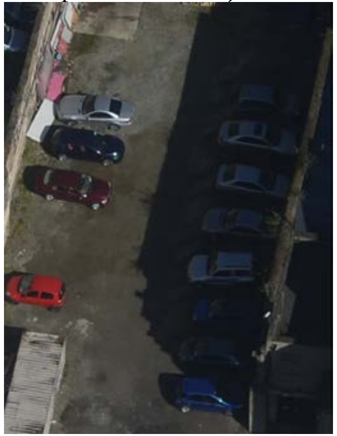


(a) Online open CAD files of 20 known car models



(b) The dissimilarity matrix (unit = cm, best model for each patch is circled)



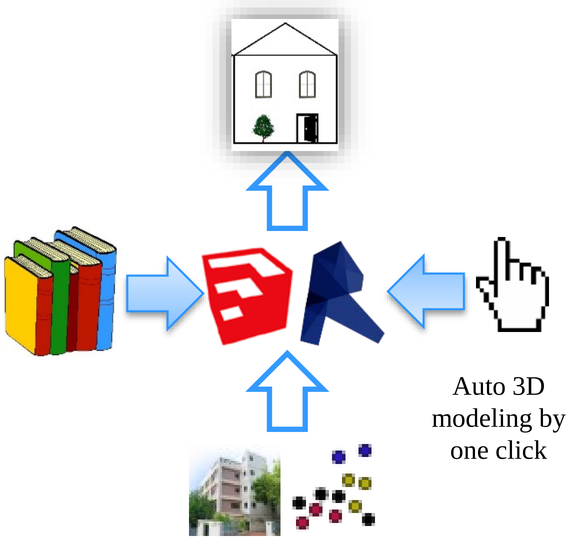


Section 3

DISCUSSION

3.1 Discussion

- DTC/as-built modeling
  - Converts geometric raw data to semantics
  - May reuse BIM resources
  - Can be unsupervised
    - Automatic
    - Accurate
    - Efficient
    - Good for large-scale, complex-shaped objects
- Drawbacks
  - Limited understanding
  - Require Model registration/annotations afterwards



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Thank You !