3D BUILDING MODELING WITH MULTI-SOURCE DATA

A STUDY OF HIGH-DENSITY URBAN AREA IN HONG KONG

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OUTLINE

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3 Discussion & Future Research

1. BACKGROUND & OPPORTUNITY

1.1 BACKGROUND

- 3D modeling from measurement (as-built BIM†) (Volk *et al.*,2014)
  - The digital foundation of smart city development, *e.g.*
    - Smart construction and human-machine cooperation
    - Healthy aging and accessibility development
    - Energy consumption and waste emissions reduction
    - Facility management & built heritage conservations, *etc.*
  - Popular (semi-)auto methods & data types
    - Photogrammetry, point cloud-based, GIS-based, rules, *etc.*
    - Image (video), point clouds, GIS data layers, knowledge, *etc.*
  - Not new, but still very challenging in scenarios of CIM‡
    - Unsatisfactory semantic/abstraction
      - → huge size, poor reusability, & poor details in models
    - Obstacles: Complexity, incomplete data, noises, *etc.*
      - Especially for high-rise high-density urban areas

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

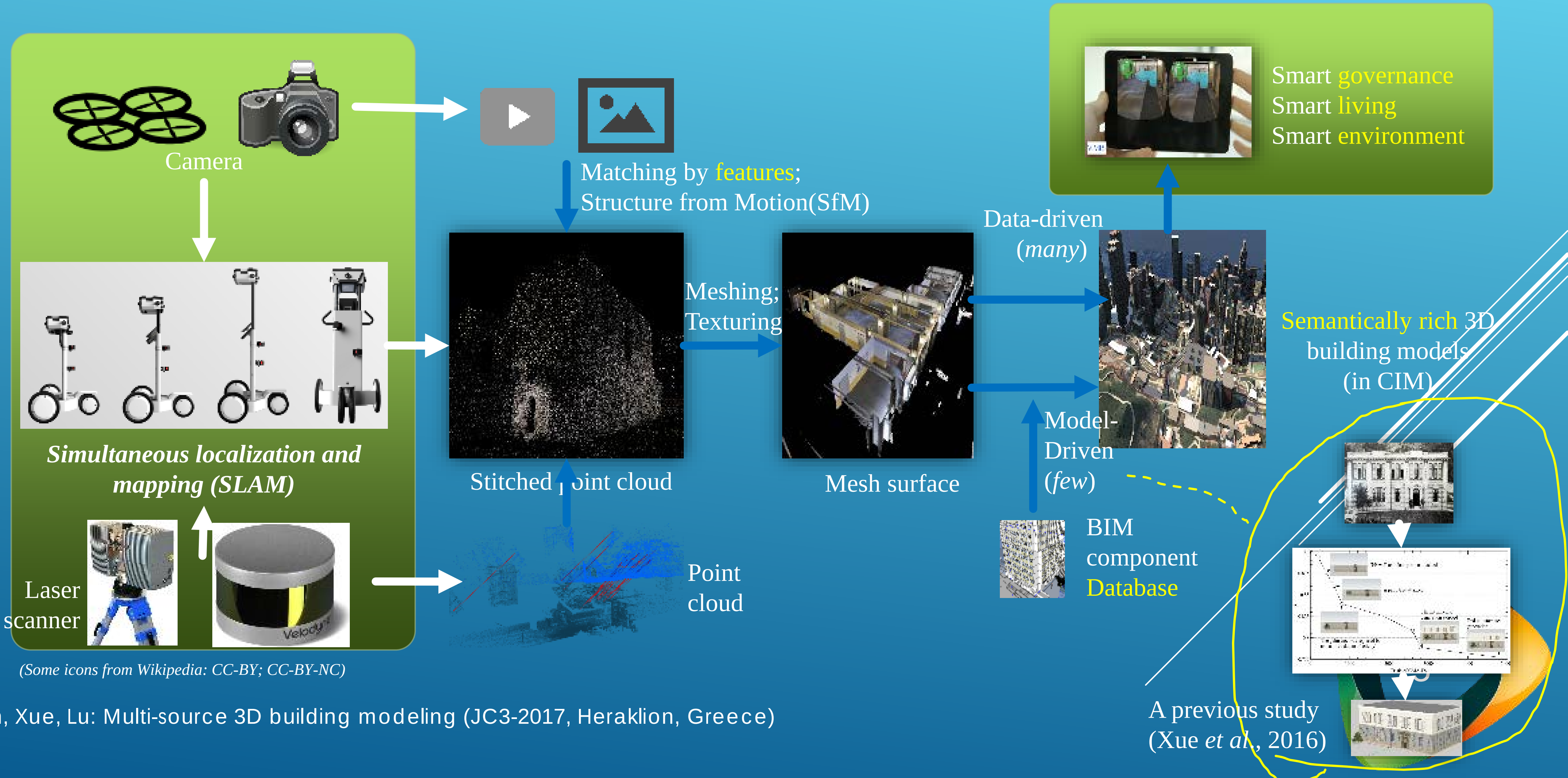
An example of point cloud: Pompei City (Source: MAP-Gamsau lab, CNRS, France)

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

†: Building information modeling

‡: City information modeling

1.1 BACKGROUND



(Some icons from Wikipedia: CC-BY; CC-BY-NC)

1.2 PREVIOUS STUDY & LOD

- There exist (semi-)automatic data-driven methods on single-source data
  - Adopted computer vision methods, *e.g.*, RANSAC†, SGM‡.
- CityGML* defines LoD (Level-of-Detail)
  - LoD0 (2.5D DTM☆)
  - LoD1 (prismatic block, flat roof)
  - LoD2 (+ roof shapes, assemblies) ← *where the auto single-source methods can go*
  - LoD3 (+ detailed outer surfaces, roof structures)

Data sources	No. of buildings	Auto?	LoD	Reference
Aerial images	city-scale	Yes	Between LoD1 and LoD2	Lafarge *et al*. (2008)
Aerial images	3	No	Between LoD2 and LoD3	Singh *et al*. (2014)
Aerial images	city-scale	Yes	LoD2	Haala *et al*. (2015)
Aerial images	375	Yes	Between LoD1 and LoD2	Li *et al*. (2016)
Satellite images	Univ. campus	No	LoD1	Fraser *et al*. (2001)
Satellite images	city-scale	No	LoD2	Kocaman *et al*. (2006)
LiDAR	51	Yes	Between LoD1 and LoD2	Maas and Vosselman (1999)
LiDAR	city-scale	Yes	Between LoD1 and LoD2	Poullis and You (2009)
LiDAR	<20	Yes	LoD2	Sun and Salvaggio (2013)
LiDAR	29	No	LoD2	Heo *et al*. (2013)
LiDAR	39	Yes	LoD2	Yan *et al*. (2016)

†: Random sampling consensus
‡: Semi-global matching
*: See Kolbe *et al*. (2005)
☆: Digital terrain model

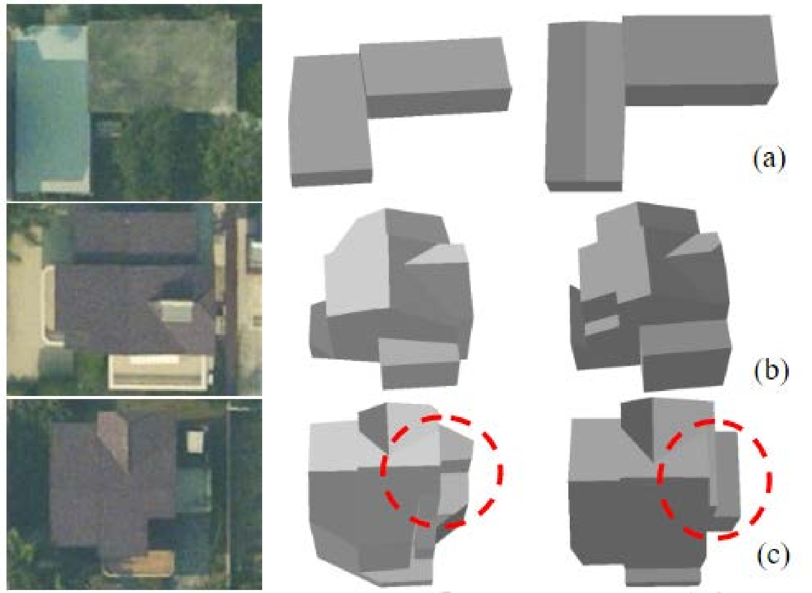
1.2 PREVIOUS STUDY & LOD

- Capability of multi-source methods was still limited to generating LoD2 models
  - If not involving manual work

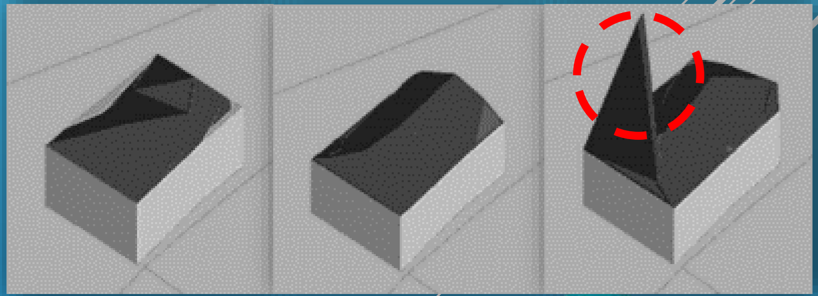
Data sources	No. of buildings	Auto?	LoD	Reference
Satellite images; LiDAR	170	Yes	LoD1	Sohn and Dowman (2007)
Aerial images; LiDAR	<30	Yes	Between LoD1 and LoD2	Rottensteiner and Jansa (2002)
LiDAR; Camera	city-scale	No	Between LoD2 and LoD3	Frueh and Zakhor (2003)
Aerial images; LiDAR	<50	Yes	LoD2	Cheng et al. (2011)
Aerial images; LiDAR	88	No	N/A (Roof only)	Awrangjeb et al. (2013)
Aerial images; LiDAR	107	No	LoD2	Siddiqui et al. (2016)
Aerial images; LiDAR; 2D vector map	170	No	Between LoD2 and LoD3	Zhang et al. (2005)
LiDAR; Building footprints	529	N.A.	LoD2	Alexander et al. (2009)
OpenStreetMap; Shuttle radar mission	city-scale	No	LoD1	Over et al. (2010)
OpenStreetMap; Aerial images	>700	Yes	LoD2	Rumpler et al. (2012)
Laser scanner; Ground plans	83	Yes	LoD2	Vosselman and Dijkman (2001)
LiDAR; Building footprints	370	No	LoD1	Ledoux and Meijers (2011)
LiDAR; Topographic map	109	Yes	LoD2	You and Lin (2011)
LiDAR; Land cadaster maps; Topographic map; Digital orthophotos; Building footprints; Non-spatial data	~2,300	No	LoD2	Agugiaro (2014)

1.3 OPPORTUNITY

- LiDAR and digital maps are extensively available, **but**
  - Unsatisfactory semantic/abstraction discovery
  - "For-profit" models (*e.g.*, Google) are not open
  - Existing LoD2 methods still have some flaws
    - many methods only illustrated in low-density areas
- Opportunity of a multi-source method
  - Object recognition from point clouds (**LiDAR data**)
    - Facilitated by **topographic map**
  - Some *a priori* rules about alignment (horizontal, parallel, perpendicular, *etc.*) as architectural **knowledge**
    - *E.g.*, parallel to the major edges of footprints (existing in **topographic map**)



Yan *et al.* (2016)'s space-cutting method



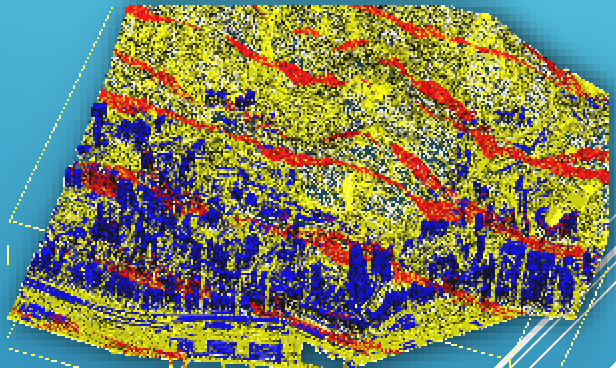
LiDAR: 1 p/m^2 16 p/m^2 40p/m^2
Alexander *et al.* (2009)'s aspect regulation

2. A PILOT OF A MULTI-SOURCE MODELING METHOD IN HK

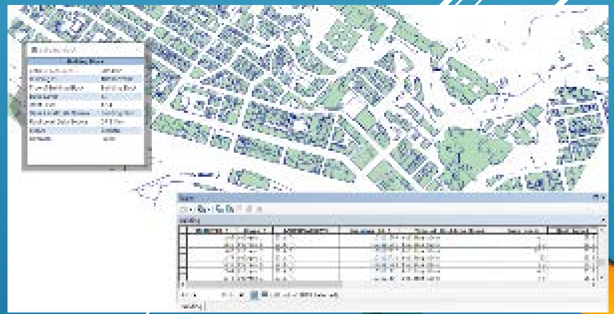
2.1 THE PILOT PROBLEM

- The pilot area
  - A 4 km^2 square area in Central & Western District, Hong Kong
  - 1,819 prisms (1,361 blocks) of densely distributed buildings
- Three inputs
  - Point clouds from LiDAR (4 p/m^2 , format: *.las*)
  - Building footprints & heights from topographic map (format: *.json*)
  - A list of architectural knowledge about rooftop elements from literature reviews (hard coded rules with parameters)
- One output
  - All building models in LoD2 in the area (format: *.dae & .json*)

The pilot area (Source: OpenStreetMap)



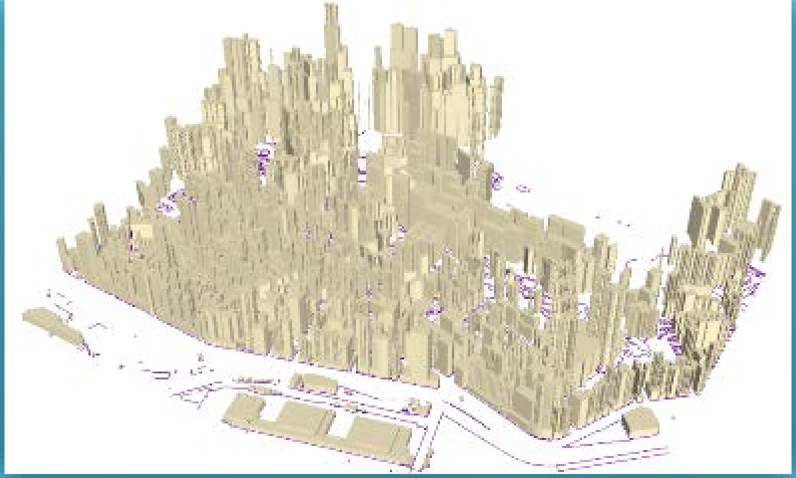
Airborne LiDAR data (.las format)



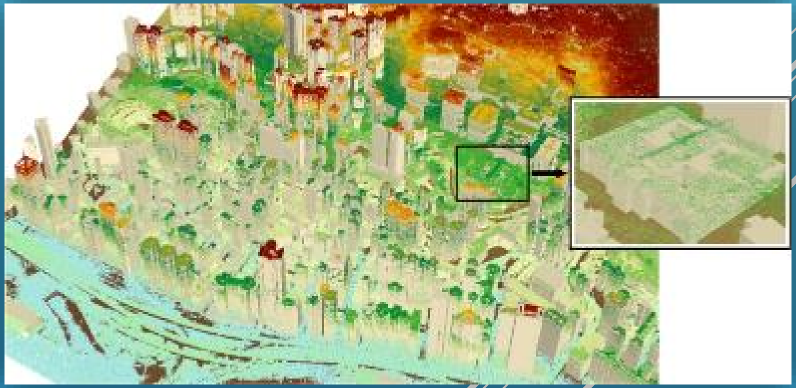
The *ib1000* topographic map & data layers (ArcGIS format)

2.2 A CLOSE LOOK

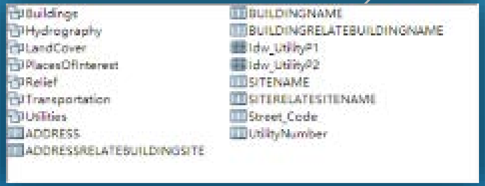
- LoD1 building models can be quickly generated in ArcGIS based on the topographic map
  - Extrusion of footprint
- LiDAR data contains geometric measurements of rooftop elements
  - It fits well onto the map (both in HK1980 grid system)
- The topographic map can export all necessary data in GeoJSON
  - Easy for in-house program development
- Knowledge-based rectification of rooftop elements
  - Must be in parallel or perpendicular (0°, 90°, 180°, 270°) with one or more directions of major edges of footprint



LoD1 models in ArcGIS



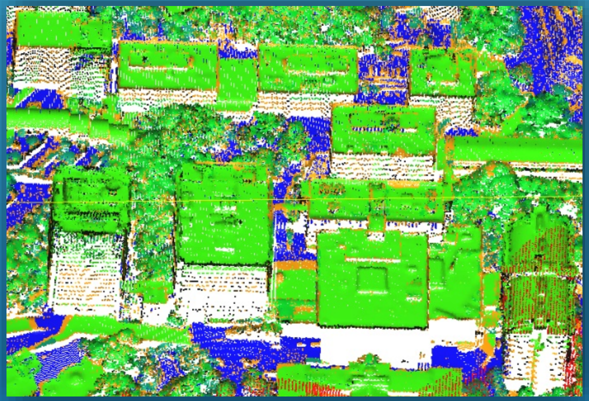
LiDAR point clouds are able to bring rooftop elements



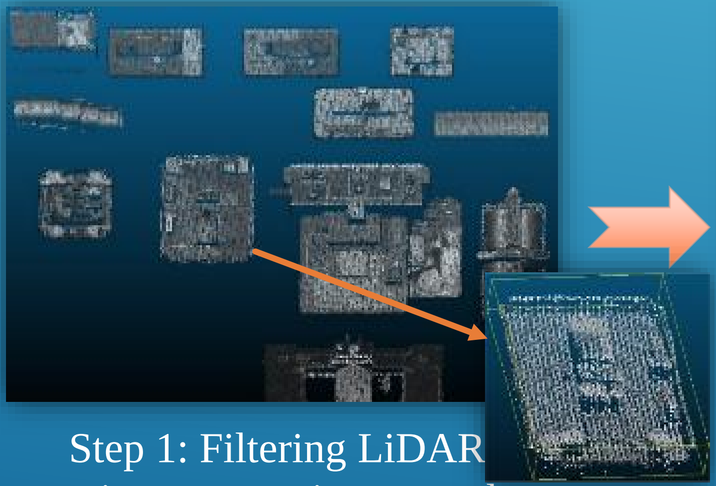
Extracting information from the map

2.3 THE PROCESS (STEPS 1~2)

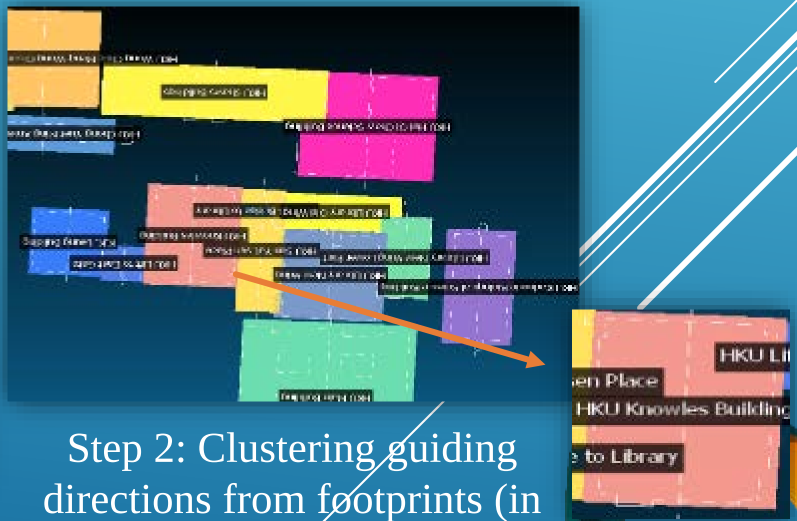
- Step 1: Filter the points of rooftop of each building with its footprint and roof level
  - Reduce the size of point cloud from ~10^7 (urban-scale) to ~10^3 (building-scale)
- Step 2: Cluster the directions of the longest edges in footprint
  - Find one, or more if there are more clusters, direction for each building



An example at HKU campus (Source: Google)



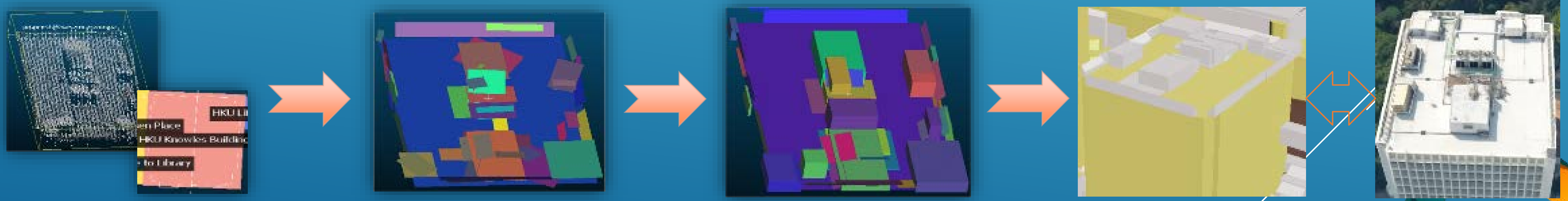
Step 1: Filtering LiDAR points, computing normal



Step 2: Clustering guiding directions from footprints (in dashed lines)

2.3 THE PROCESS (STEPS 3~5)

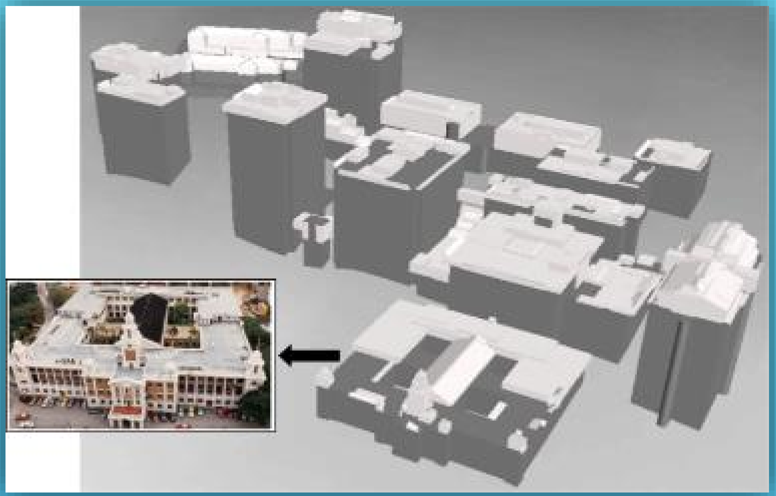
- Step 3: Planar primitives discovery by RANSAC
  - May contains a few unrealistic shapes
- Step 4: Rectification of the primitives with respect to the guiding directions of each building (*summarized from observations*)
  - If there are more than one guiding directions, the closest one is used
- Step 5: Create 3D rooftop elements from those are close to
  - (*i*) guiding directions and (*ii*) the horizontal plane for each building



An example building from Step 1,2 | Step 3: RANSAC (Schnabel *et al.*, 2007) | Step 4: Rectification | Step 5: Create 3D rooftop elements | Reference image (Source: Google)

2.4 RESULT OF THE PILOT TEST

- Pilot test
  - The 1,361 blocks of buildings in 4 km^2
  - By an in-house plugin for *CloudCompare 2.9* (single thread)
    - (Available soon)
  - On a notebook computer, i7 2.6GHz mobile CPU
- Time cost
  - Clustered guiding directions of all buildings: < 1.0 s
  - Generated 1,114 out of 1,361 building models: 319.7 s
  - Manual processing time: 0.0 s (geo-referencing by aircraft's GPS)
- Quality
  - Information richness: LoD2 in general
  - Geometric error (RMSE): 0.06~0.20m for segmented points
    - Acceptable, since the accuracy of LiDAR is 0.30 m (horizontal) and 0.10 m (vertical)



Result of the example area of HKU (dark=LoD1; light=rooftop in LoD2; photo source: dragageshk.com)

The area in Google Map/Earth

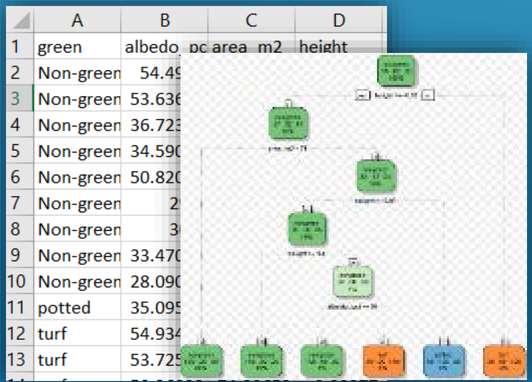
3. DISCUSSION & FUTURE RESEARCH

3.1 DISCUSSION

- Pros:
  - The proposed method is efficient
    - ~0.3 s per building, **linear increasing** overall time when scaling up to a district or a city
    - Should be attributing to the efficiency of the nested RANSAC
  - The error is acceptable
    - Because odd shapes were dropped by the rules and the guiding directions
- Cons:
  - Limited to planar primitives temporarily, not fitting precisely for curve shaped roofs
  - The airborne LiDAR contains little data of facades in high-density areas
    - There can be more inputs to fuse, *e.g.*, point clouds from synthetic aperture radar (SAR), freely online photos, SLAM prototype models, *etc*.
- Limitation: The pilot result is only visually tested yet

3.2 FUTURE RESEARCH

- Advancing LoD2 models to LoD3 with dense point clouds
  - E.g., unmanned aerial vehicles (UAVs), Simultaneous localization and mapping (SLAM)
  - With more architectural/construction knowledge to explore
- Semantic enrichment for applications, *e.g.*
  - Thermal properties → energy saving
  - A/C units, satellite dish, pipes, and green → facility management



Regression / Rules / Supervised learning

Albedo (reflectance) map, green roof map, *etc.*

Chen, Xue, Lu: Multi-source 3D building modeling (JC3-2017, Heraklion, Greece)

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THANK YOU!