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

iLab @ HKURBANlab
the urban big data lab

From geometric landscape to fitness landscape

As-built BIM reconstruction through optimization

从几何到适应度景观

应用优化算法自动重建 BIM 模型

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Outline

iLab

1 **Background & Opportunities**

2 **The Method**

3 **Discussion**

Section 1

BACKGROUND & OPPORTUNITIES

1.1 As-built modeling

- As-built modeling (Volk et al. 2014)
  - Increasingly important for AEC/FM†
    - Construction management
    - Facility management
    - Built env. 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
    - Also: As-designed, as-planned, as-demolished

建成BIM ⇨

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)

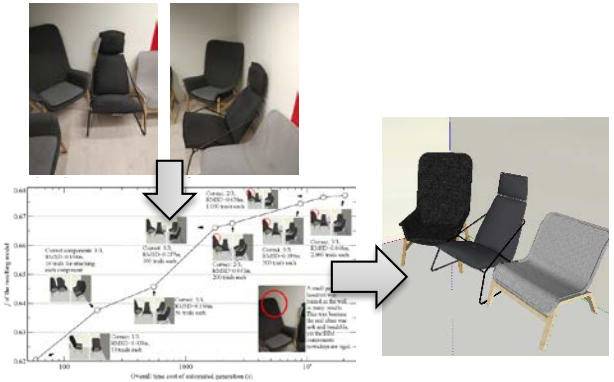
†: Architecture, Engineering and Construction/ Facilities Management

1.1 As-built BIM reconstruction

- Manual reconstruction?
  - Accurate, high-quality, & responsible
  - Expensive, tedious, or impractical for frequent update/cities
- Two paradigms of automatic reconstruction
  - (1) Semantic segmentation 语义分割
    - 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)
  - 本节 ⇨ (2) Semantic registration 语义对齐
    - 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 Geometric landscape in semantic registration

- Landscape

景观

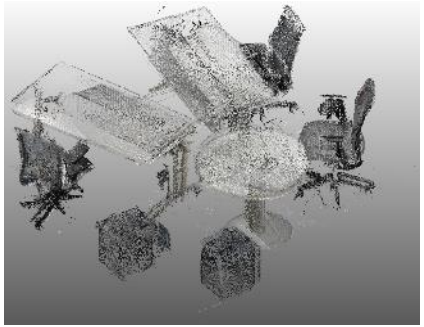
  - Land – scape: Appearance of land
  - Nature: Continuous surface
  - Peaks and valleys

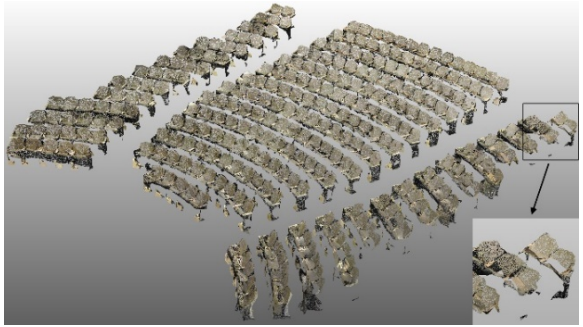
Landscape
(Source: Wikipedia)

- Geometric landscape in 3D data of building scenes

几何景观

  - Also appearance
  - Nature: Point/surface polygon
    - Discrete, noisy, cluttered
  - Peaks and valleys
    - On building elements





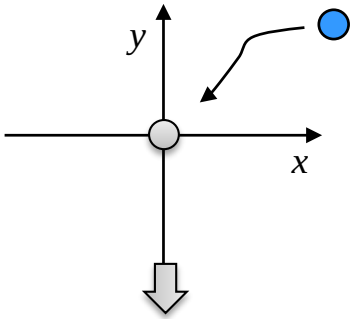
Geometric landscapes (non-repetitive and repetitive) in building scenes
(Xue et al. 2019b; 2019c)

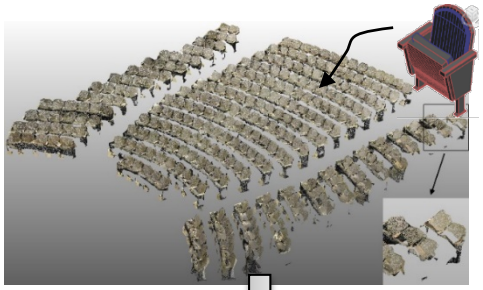
1.2 Problem: Fitness landscape in optimization

- Optimization problem
  - Find the best solution (e.g., min $f(x) = |x|$)
- Fitness landscape

适应度景观

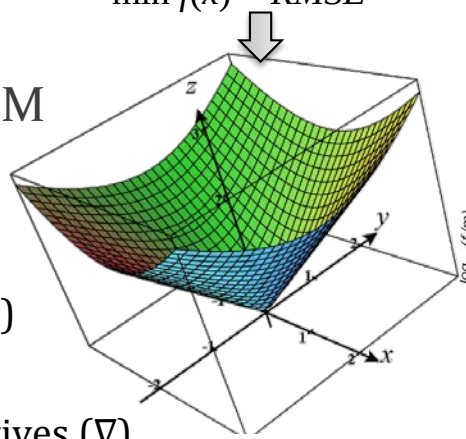
  - Appearance of f
  - Peaks/valleys contain the solutions
    - Where gradient $\nabla f = 0$
- Fitness landscape for registering BIM
  - Reflecting the geometric landscape
  - Many methods are not working
    - Up to 9 degree-of-freedoms (DoFs)
    - Continuous, jugged
    - Too expensive to calculate derivatives (∇)

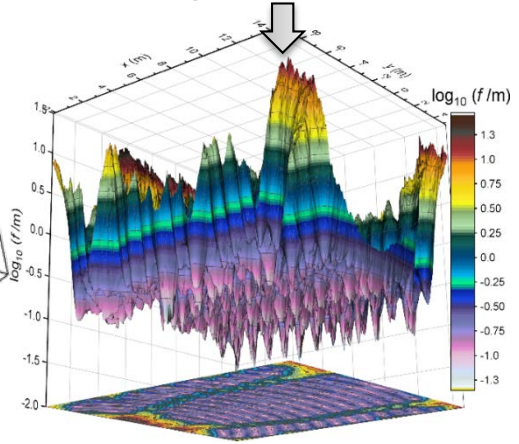




min $f(x)$ = *RMSE*

min $f(x)$ = *RMSE* …

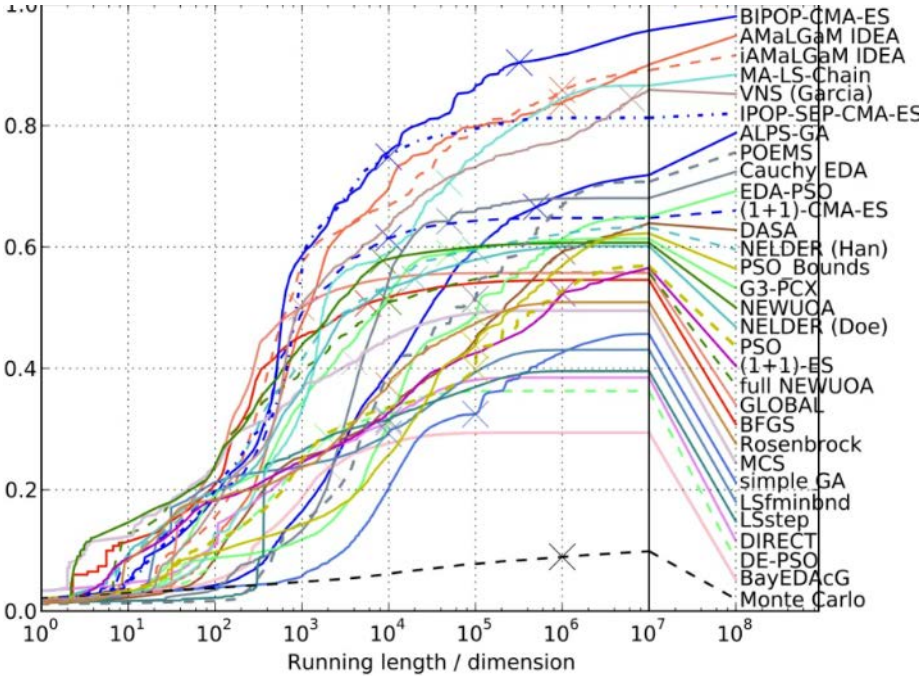




Fitness landscapes of registering BIM to 1 point (left) and real 3D point cloud (right)

1.3 Opportunity: Derivative-free optimization

- *Derivative-free optimization* (DFO) algorithms solve **without explicit ∇**
  - Surrogate methods
    - CMA-ES and its variants are competitive
  - Trust-region methods
    - DIRECT, NEWUOA, etc.
  - Metaheuristics (GA, PSO, VNS, *etc*.)
  - Hyper-heuristics, data mining
  - … and Monte Carlo
- DFO can bridge the two landscapes
  - Accuracy? Efficiency?



Comparison of algorithms for BBOB-2009 (Black-Box Optimization Benchmarking, higher is better) (Auger et al., 2010) *Image courtesy: Inria*

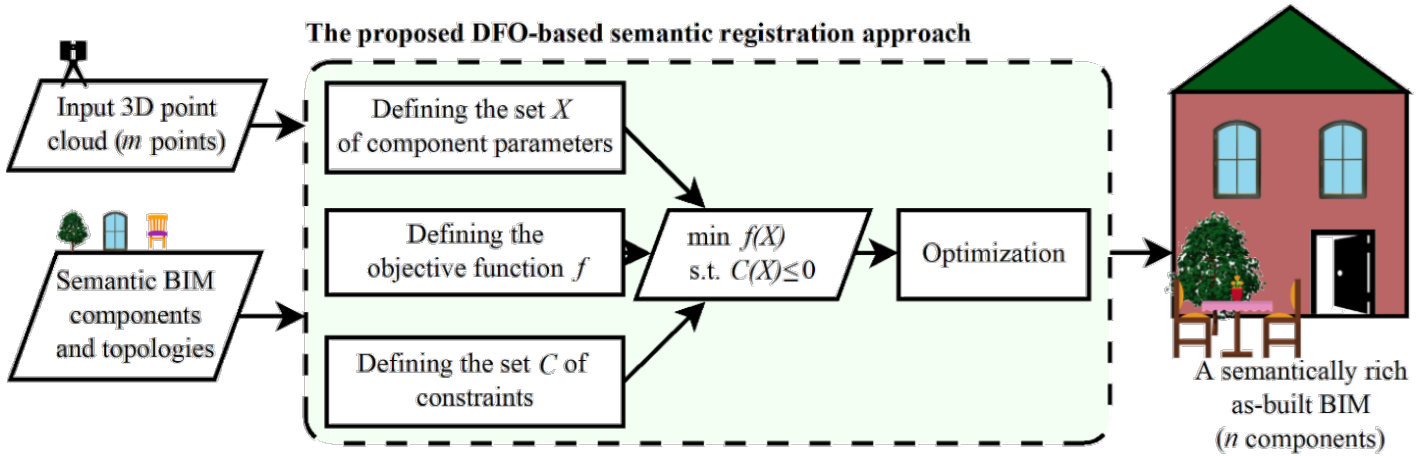
Section 2

THE METHOD

2.1 Overview

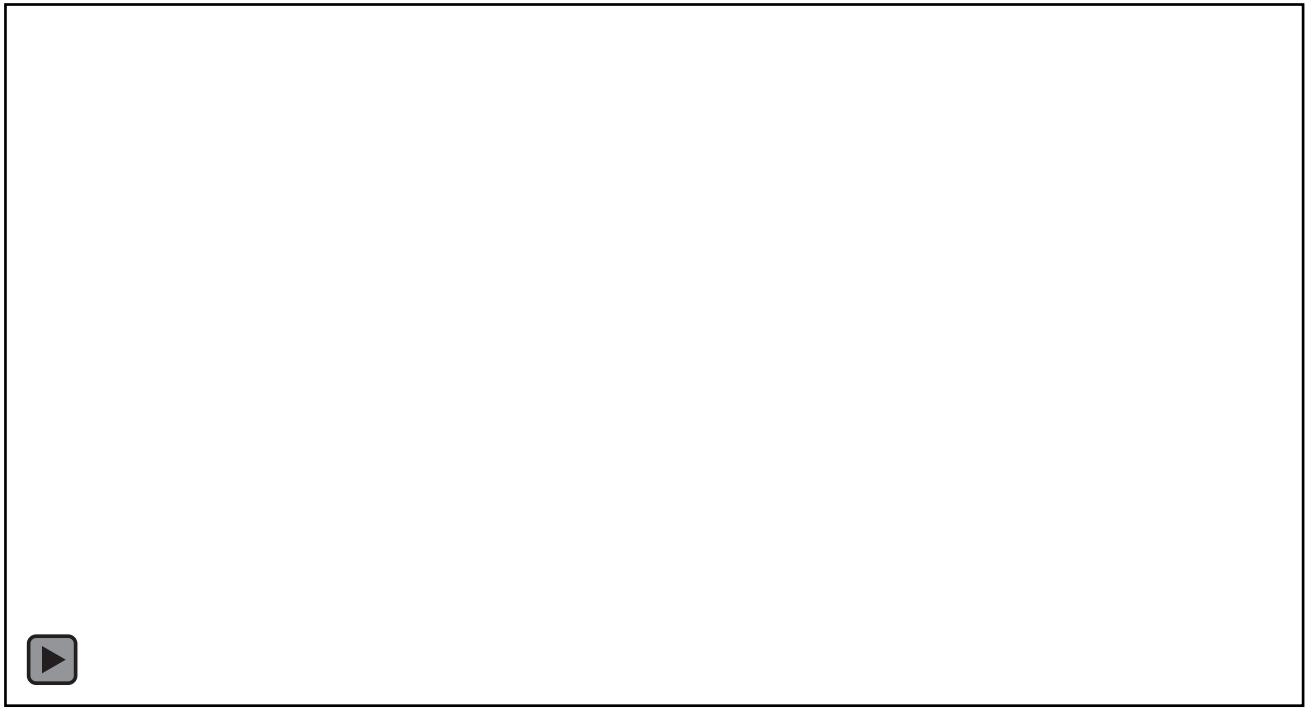
- Semantic registration through optimization
  - Two inputs, BIM (pose/relationship) output
  - Function : Minimize error (or maximize similarity)
  - Variables : 3D transformation
  - Subject to: Topological constraints

$$\min\ f(X)$$
$$\text{s.t. } C(X) \leq 0$$



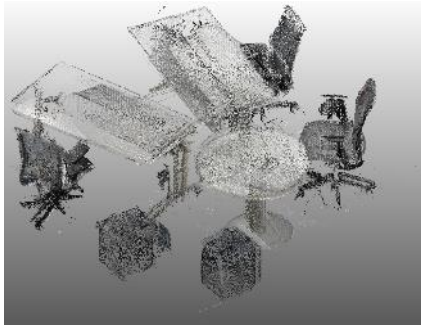
2.2 Prototype demo (Xue et al., 2018; 2019b)

- PCD/2D photos + BIM objects → as-built BIM
  - Automatic
  - Segmentation-free
  - Semantic
  - Accurate
  - Efficient
- COBIMG
  - DFO: CMA-ES
- A quick demo

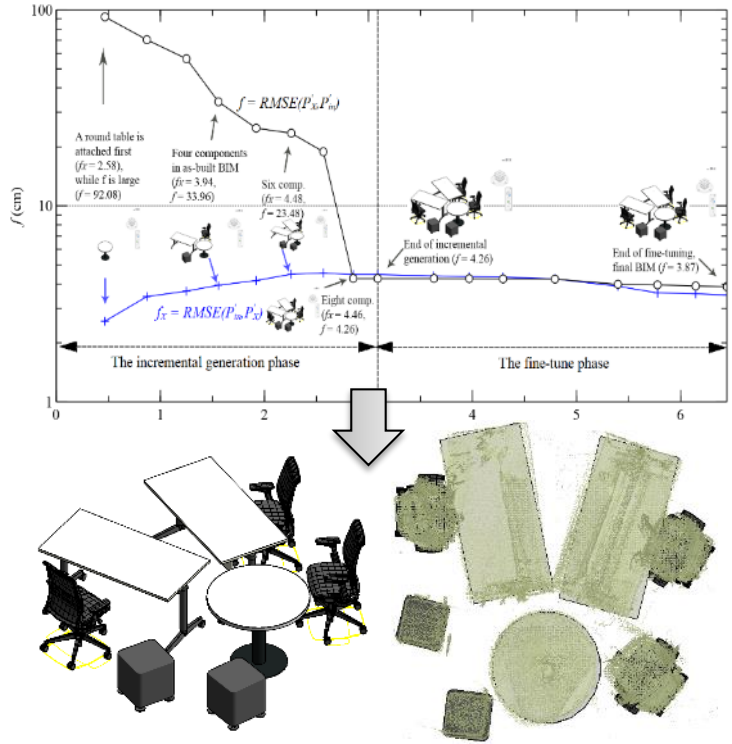


(Language: C++, CLR; Data formats: Autodesk Revit, Stanford polygon)

2.3.1 Case 1: An indoor office scene (Xue et al., 2019b)



$$\begin{aligned}
\min \quad & f(X) = RMSE\big(BIM(X), P_{in}\big) \\
\text{s.t.} \quad & C(X) \le 0. \\
& f(X) = RMSE(BIM(X), P_{\text{in}}) \\
& \approx RMSE(P_X, P_{\text{in}}) \\
& \approx RMSE(P_X^{'}, P_{\text{in}}^{'}) \\
& = \sqrt{\Sigma_{p \in P_{\text{in}}^{'}} nndist^2(p, P_X^{'})/m^{'}} \\
& \approx RMSE(P_{\text{in}}^{'}, P_X^{'}) \\
& = \sqrt{\Sigma_{p \in P_X^{'}} nndist^2(p, P_{\text{in}}^{'})/\|P_X^{'}\|}
\end{aligned}$$

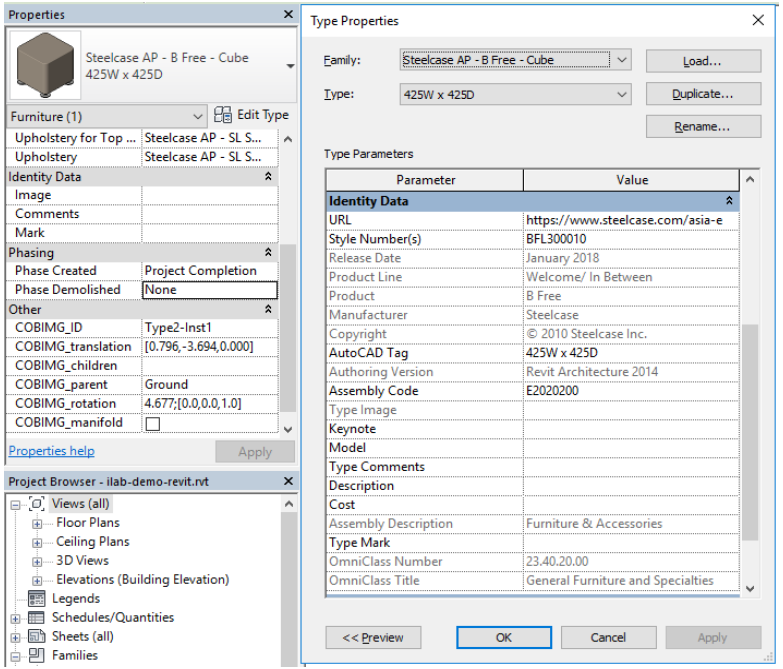


(Language: C++, CLR; Data formats: Autodesk Revit, Stanford polygon)

2.3.1 Case 1

- Indoor modeling
  - Accurate: 3.87 cm, 100% recall
  - Fast: 6.44 s
  - Rich semantics: Product, assembly, *etc*.

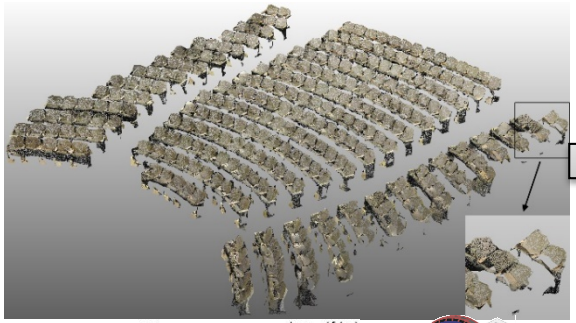
Modeler No.	Experience	Correctness (out of 8)	RMSE (cm)	Time cost (s)
1	Expert (3 years)	**8**	**3.79**	363.9
2	Average (1 year)	**8**	3.90	335.4
3	Beginner	**8**	4.22	691.1
COBIMG -Revit		**8**	3.87	**6.44**
COBIMG-Revit + annotation		**8**	3.87	~ 246.0

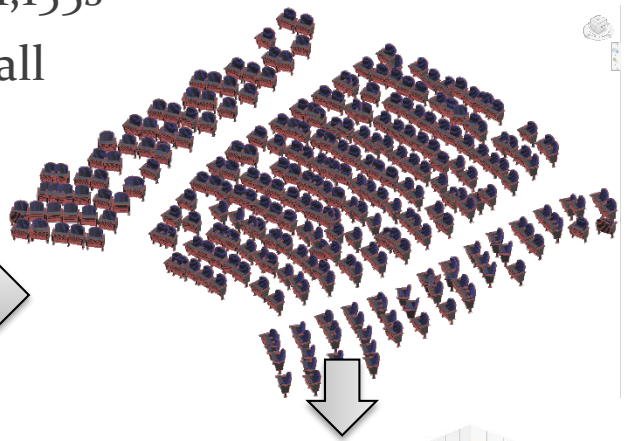


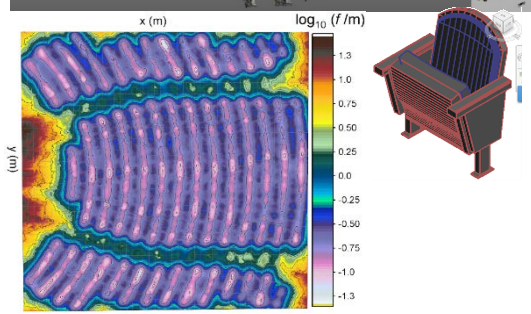
(Language: C++, CLR; Data formats: Autodesk Revit, Stanford polygon)

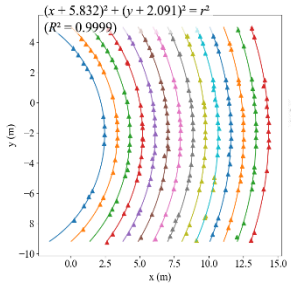
Case 2: A lecture hall (Xue et al. 2019c)

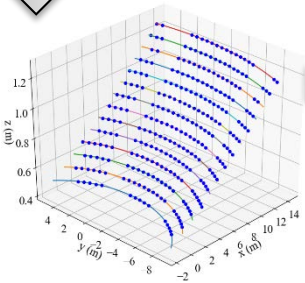
- RMSE= 8.97cm, time = 1,155s
- 99% precision, 98% recall

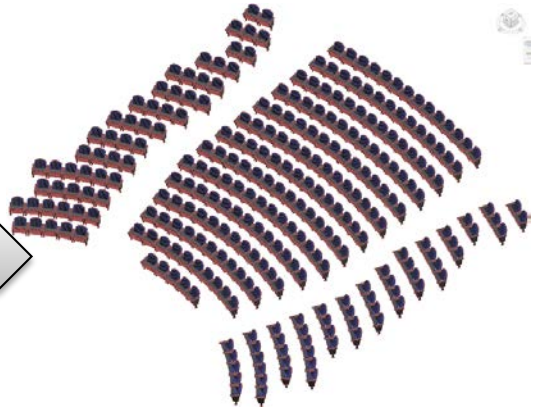




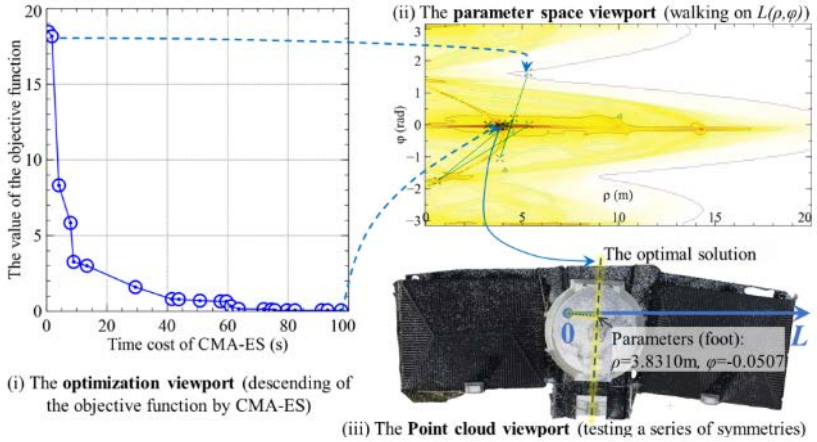


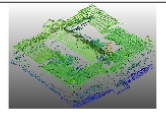
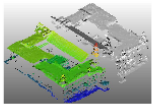
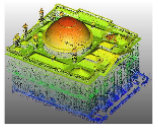
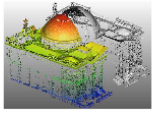
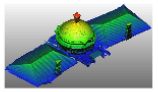
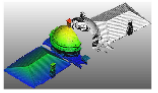
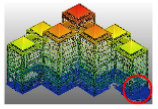
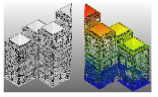
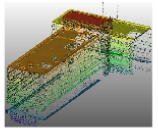
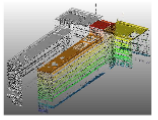
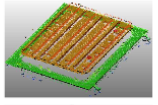
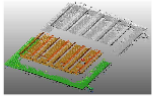
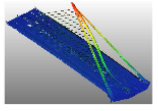
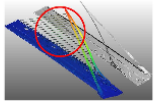






Case 3: Architectural symmetry (Xue et al. 2019a)



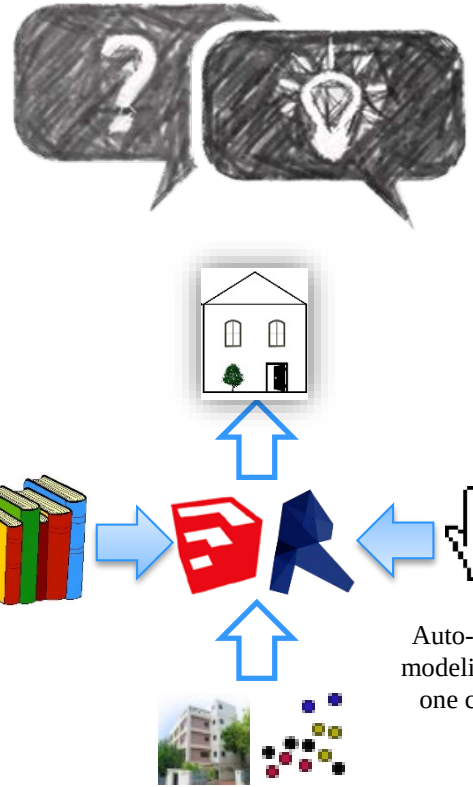
Id	Thumbnail of input point cloud[a] (C)	Normal[b] of Sym.	Symmetric parts[c] segmented	PCR (%)	Time (s)	Intrinsic[d] asymmetry
1		$\begin{bmatrix}1.026\\-0.046\\0\end{bmatrix}$		86.29	0.81	
2		$\begin{bmatrix}0.171\\0.036\\0\end{bmatrix}$		85.22	1.79	
3		$\begin{bmatrix}-0.080\\0.004\\0\end{bmatrix}$		95.99	3.68	
4		$\begin{bmatrix}-1.979\\2.242\\0\end{bmatrix}$		95.44	2.77	As circled
5		$\begin{bmatrix}0.956\\-3.256\\0\end{bmatrix}$		97.11	2.21	
6		$\begin{bmatrix}0.251\\0.068\\0\end{bmatrix}$		96.96	0.60	
7		$\begin{bmatrix}2.687\\-0.243\\0\end{bmatrix}$		97.51	3.05	As circled

Section 3

DISCUSSION

3.1 Discussion

- Semantic registration for as-built BIM
  - Converts geometric landscape to fitness landscape
  - Reuses online open BIM resources
  - Finds optima (objects in as-built BIM) using DFO
    - Automatic
    - Segmentation-free
    - Accurate
    - Efficient
    - Good for complex-shaped objects
- Drawbacks
  - Require annotations beforehand
  - Killer (downstream) applications



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Thank You !
谢 谢!