Semantic Enrichment for BIM & GIS

A Computational Perspective

计算视角下的 BIM 及 GIS 语义充实研究

Coll. of Civil Eng., SZU 深圳大学 土木工程学院
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Aim and scope

- Aim of this presentation 目的
  - To introduce the HKURBANlab – iLab 自报家门
  - To revisit the concepts about information 审视基础概念
  - To discuss a novel research topic 探讨一个新课题
  - To share several recent studies 分享若干新进展
  - To engage critiques and debates 希批评指正
  - To promote collaborations (and citations) 促进合作
- Scope 范畴
  - Extension: Urban information databases (BIM, GIS) 外延：城市信息库
  - Intention: Semantic enrichment 内涵：语义充实
  - Methods: Computational methods 方法：计算方法

Outline

iLab

简介 1 Introduction to iLab

背景 2 Background & Opportunities

正文 3 Semantic Enrichment for BIM & GIS

讨论 4 Discussion & Future Work

Section 1

INTRODUCTION TO ILAB

ILAB介绍 — “一波强行植入”

1.1 HKURBANlab

iLab

- Faculty of Architecture, HKU 建筑学院
  - 3 Departments: Arch., REC, DUPAD
  - 2 Divisions: Landscape Arch., Arch. Conservation
- HKURBANlab 实验中心
  - Newly branded research arm of FoA
  - 1 Academician (CAS), 10 full professors
  - 12 labs on

Urban planning;	Property rights;
Chinese architecture;	Rural;
Health;	Sustainability;
Fabrication and materials;	Conservation;
iLab (data and information);	Virtual Reality; ...

HKURBANlab

香港大學
建築學院

www.arch.hku.hk

1.1 iLab: The urban big data hub

- iLab 实验室
  - Urban big data hub
  - 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)
    - *Geographical Information Systems* (GIS)
    - *Global Positioning Systems* (GPS)
    - *Urban Remote Sensing* (URS)
    - *Building Information Model* (BIM)
    - *Internet of Things* (IoT)
    - *virtual design and construction* (VDC)
    - *integrated project delivery* (IPD)

iLabHKU

fac.arch.hku.hk/iLab

1.2 The research team

- Lab director 主任
  - Dr. Wilson Lu
- Full-time team members 成员
  - 1 RAP, 1 PostDoc, 1 SRA, 3 RAs, 7 PhD candidates
- Research themes 主题
  - Urban big data (BIM, GIS, IoT, …)
  - Construction project management
  - Construction waste management
  - International construction
    - Corporate social responsibility

Lunch-time gathering

1.3 About myself

- A mixed background 背景
  - BEng in Automation — 2004
  - MSc in Computer Science — 2007
  - PhD in System Engineering — 2012
  - PostDoc in Construction Management — 2016
- Research interests 兴趣
  - Computation and urban semantics in BIM
  - Applied operations research
  - Machine learning and visualization for construction
- On-going research projects 在研
  - PI: RGC (17201717), HKU (201702159013, 201711159016)
  - Co-I: NSFC (71671156), NSSFC (17ZDA062), HKU PTF

- Engineering
  - ISE, CEM, EIE
- Computer Science
  - AI, DFO, ML
- Economics
  - SCM

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1.4 Job vacancies at iLab, HKU

- Research Assistant (2~4 openings)
  - $16,575/month
- PostDoc(~1 opening) 博后
  - ~$30,000/month
- PhD (2~3/year) 博士
  - 100% funded scholarship
    - $16,330/month
  - HKU PhD Fellowship (UPF)
    - Above + $70,000 (one time)
  - HK PhD Fellowship Scheme (HKPF)
    - $20,000/month + $10,000/year conference + $42,100 (annual fee of 1st year)
- Inquiry: Dr. Wilson Lu <wilsonlu@hku.hk>

Empty seats for you

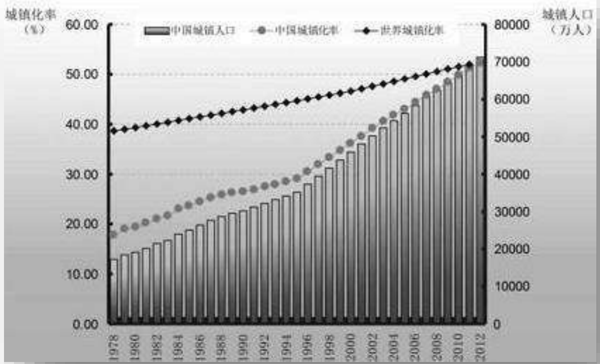
Section 2

BACKGROUND & OPPORTUNITIES

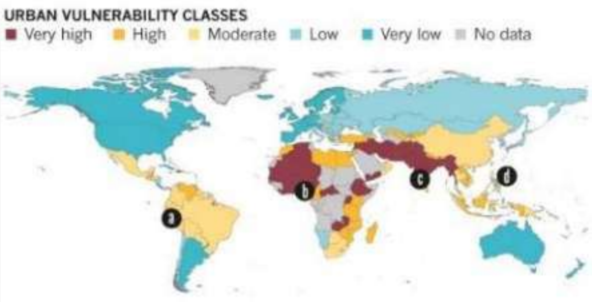
背景和机遇 — “时势造英雄”

2.1 BIM, GIS, and humanity's future

- Global urbanization 全球城市化
  - By 2050, 65% world's population will live in cities (WHO, 2015)
  - Irreversible; Even faster in China
- Leads to urban vulnerability (a.k.a. 'urban diseases')
  - Poor resource (water, power) management, inefficient traffic,
  - Poor waste treatment, environment (air, water) pollution,
  - Disasters (earthquake, storm, climate change),
  - Heritage destruction, …
- For the future of humanity 为了明天
  - Smart, sustainable, and resilient city development
    - On decision support platforms like BIM & GIS



China's and global urbanization rates
source: gov.cn 国家新型城镇化规划（2014—2020年）



Global urban vulnerability level (Birkmann et al, 2016) *source: nature.com*

2.1 BIM, GIS, and the construction industry

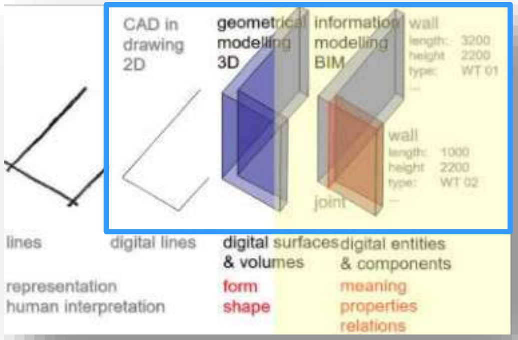
- Construction is known as a “backward industry” 现状
  - Low productivity, labor-intensive (*v.s.* aging workers)
  - Fatality, occupational hazards, management (*e.g.*, cost overrun)
- Meets new *information communication tech.* (ICT) 机遇
  - To fuse as *urban big data*
    - BIM, RFID, LiDAR, GPS, UAV, CV, VR/AR, smart phones…
  - To extract *urban semantic information*
- Is now adopting 为了今日
  - BIM and GIS models
  - For effective (productive, automatic, age friendly) and efficient (safer, profitable, on-time, sustainable) AECO industry
  - A consensus of global research institutes (e.g., Harty et al., 2007)

USA’s gross value-added by sectors
source: economist.com Efficiency eludes the construction industry

Recent advances in ICT

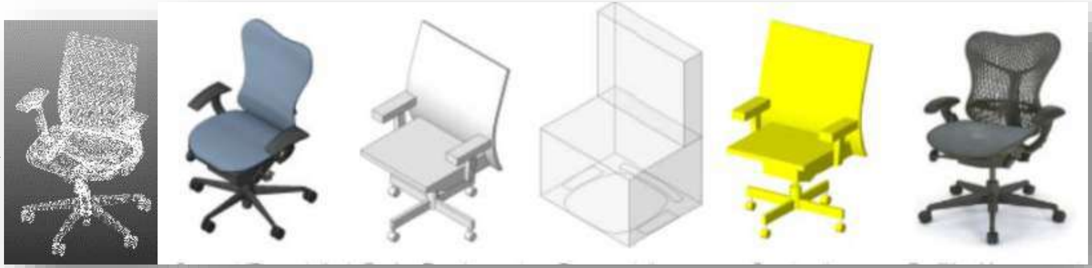
2.2 Concepts – BIM

- BIM (building information model/modeling) 概念
  - *A digital representation of physical & functional characteristics of a facility.* (NIBS, 2015) “M” “I” “B”
  - *A shared … resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward.* (NIBS, 2015)
  - Evolved from CAD (computer-aided design) (Penttilä, 2007)



An evolution view of CAD/BIM (Penttilä, 2007)

- Essence 本质
  - Urban information database
  - Component (unit facility) based
- A quiz: *BIM or not*? 练习
  - How to measure the info.?

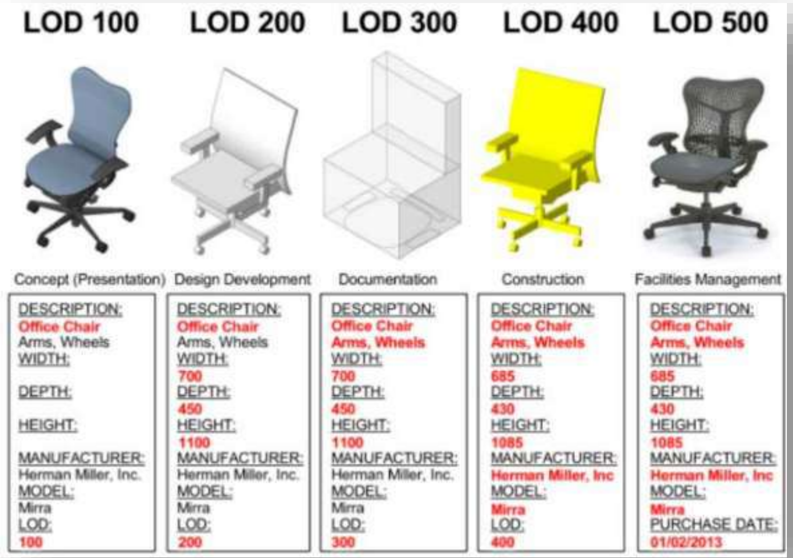


A B C D E F

2.2 Level of Development (LOD) of BIM

- BIM LOD 发展指数
  - Previously "Level of Detail"
  - Information metric by *temporal* stages
- Levels* 分级
  - LOD 100： For concept presentation
  - LOD 200： For design development
  - LOD 300： For 2D documentation
    - LOD 350 construction 3D documents
  - LOD 400： For construction stage
  - LOD 500： For facilities management
  - * *Still not accepted universally*

Arch.
↓
Eng.
↓
Const.
↓
O&M
↓
Demo.

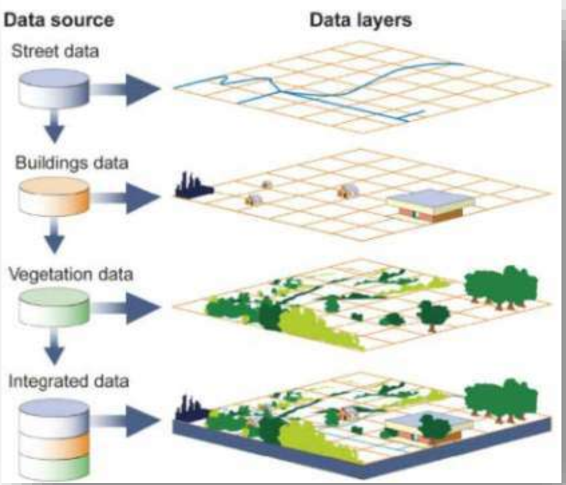


What is called LOD
Source: PracticalBIM.net

No LOD
data, needs processing to info., then to BIM

2.3 Concepts – GIS

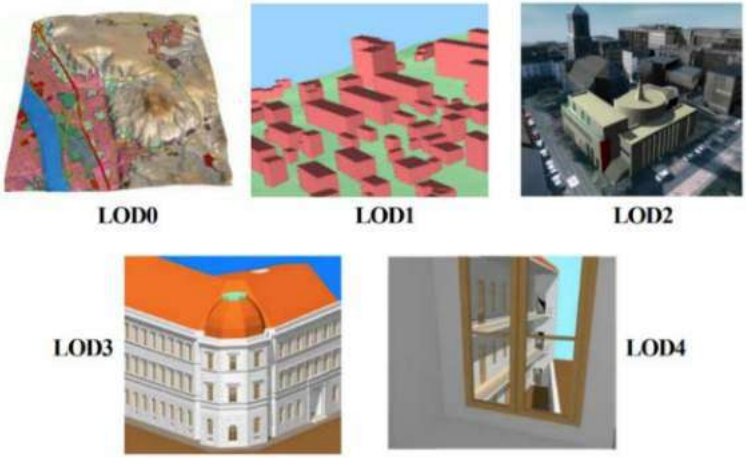
- GIS (geographic information system) 概念
  - *A computer system for capturing, storing, checking, and displaying data related to <u>positions</u> on <u>Earth's surface</u>* (NGS, 2012)
    "I" "G"
  - Evolved from DBMS (database management system)
- Essence 本质
  - Urban information database
  - Data tables (layer) based
- A quiz: *GIS or not?* 练习



GIS interpretation
Source: US Government Accountability Office

2.3 Level of Detailing (LOD) of GIS

- GIS LOD 细节指数
  - Defined in CityGML (by open GIS consortium)
  - Information metric by *spatial* details
- Levels* 分级
  - LOD0 : Region and landscape
  - LOD1 : + Prismatic buildings model (flat roof)
  - LOD2 : + Roof and thematic surfaces
  - LOD3 : + Detailed exterior (wall and roof)
  - LOD4 : + Interior (indoor)
  - * *Still not accepted universally, neither*
- But, what is <u>*information*</u> after all, behind these metrics?

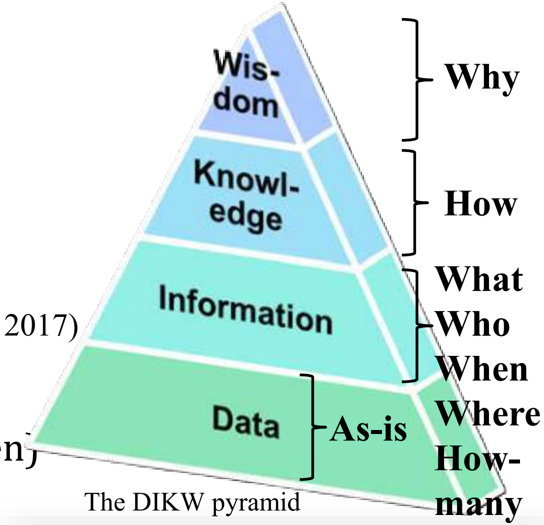


GIS Level of Detailing (Gröger et al., 2007)

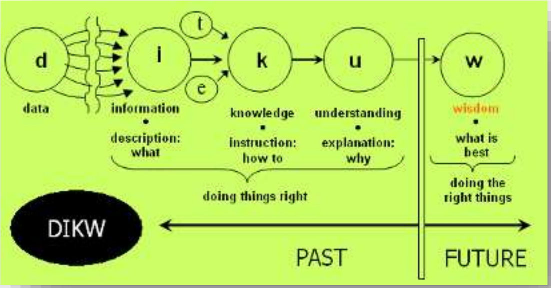
Google Map/Earth? ~*LOD2*

2.4 Concepts – information 信息

- Information 概念
  - Many definitions in different fields (*e.g.*, philosophy; comm.)
- The DIKW pyramid 相关概念
  - *Data* is sensory stimuli (Rowley, 2007) (or signals; Zins, 2007)
  - *Information* is the description, meaning of data (Rowley & Hartley, 2017)
    - Abstracted, inferred from data
    - Answering interrogative questions (what, who, where, when)
    - For supporting decision-making
  - *Knowledge* is processed, organized or structured information
    - Reasonable
  - *Wisdom** is evaluated understanding of knowledge
    - Shared, for future



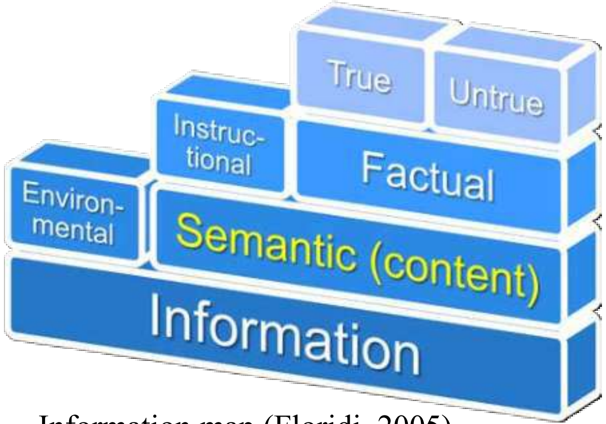
The DIKW pyramid



The DIKW flow *Source: Wikipedia*

2.4 Concepts – semantics 语义

- Semantics 概念
  - Origin in linguistics and philosophy, study of meaning
    - Opposed to syntax (e.g., SVO)
  - A subset of information (Floridi, 2005)
    - Including facts and instructions (how-to)
    - Opposed to environmental

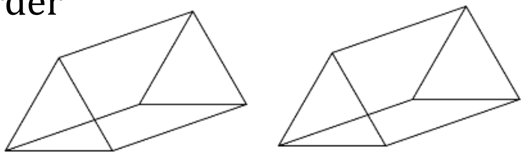


Information map (Floridi, 2005)

- In BIM/GIS, an object has (Xue et al, 2018) 分类
  - Individual's semantics
    - Geometric: *E.g.*, shape, size, position, texture
    - Non-geometric: *E.g.*, type, materials, function, assembly order
  - Relational semantics
    - E.g., dependency, topology, joints

```
for (int i = 0; i < 10; ++i)
{ sum += i; … }
```

C++



Over a box of building   On a plane of road

2.4 List of semantics of buildings (Chen et al., 2018b)

	Geometric	Non-geometric
Construction 建设	Site information (coordinate's data and layout) Building spaces (floor, zones, rooms, openings) Utility lines Dimension of building components	Construction materials (status, quality, category, manufacturer) Precast elements (quality, category, manufacturer) Equipment attributes (ID, type, status) Financial data Location of labor, materials, and machine Project performance data Construction schedule Construction activity status Site environment
Operation & maintenance (O&M) 营运	Building services (location, relationship) Building spaces (floor, zones, rooms, openings) Utility lines Specification of exterior enclosure products Furnishing	Building services (identification number, manufacturer) Status of mechanical, electrical, & plumbing equipment Maintenance record Indoor environment Attributes of replaced components Maintenance status Maintenance schedule Operation records

- Required semantics 对比
  - So many
  - Both geometric and non-geometric
  - Changing over time

2.4 List of semantics standards (Wang et al., 2018)

iLab

Research/ industry	Application Scenario	Object Parameters
Pratt (2004)	BIM object contents exchange	Functional type; Geometry; Attributes; Relations between objects; Behavioural rules.
Belsky et al. (2016)	Semantic enrichment for BIM objects	Function; Geometry; Material; Identity; Aggregation relationships; Composition relationships.
Chen and Wu (2013)	Parametric BIM object modelling	Basic Object Data (Identification, Classification, Geometry, Quantities, and Phasing); Representation data (Material)
GIS **Open Geospatial Consortium (OGC, 2007)**	Object data description in CityGML for virtual 3D city and landscape	Geometrical, Topological, Semantic, and Appearance properties.
Autodesk Revit (2017)	Modelling and professional analysis (e.g. thermal)	Identification (number, name, type, description); Classification (OmniClass code and description); Geometry; Material; Quantities; Manufacturer; Cost; Phasing; LEED, Thermal and Structural Properties, etc.
RIBA, UK (2014)	Object data description defined in NBS BIM Object Standard	Authorship, Identification (name, Uniclass code, and product link), Manufacturer, NBS description, and reference, etc.
NIBS, USA (2012)	Information Collection via Cobie to improve handover to owner-operator	Authorship, Identification (created by, category, Description, type, code, etc.) Manufacturer, Warranty, Geometry, Material
CIBSE, UK (2016)	Product description for manufacturer defined in Product Data Templates(PDTs)	Manufacturer, Construction, Application, Dimension, Performance, Electrical, Controls, Sustainability, Operations and Maintenance

- BIM vs GIS 对比
  - Seems that BIM community cares more than GIS
  - App-oriented
  - Implemented as
    - **BIM** Parameters of comp.
    - **GIS** Map layers (data tables)

2.4 Status quo of urban semantics in BIM/GIS

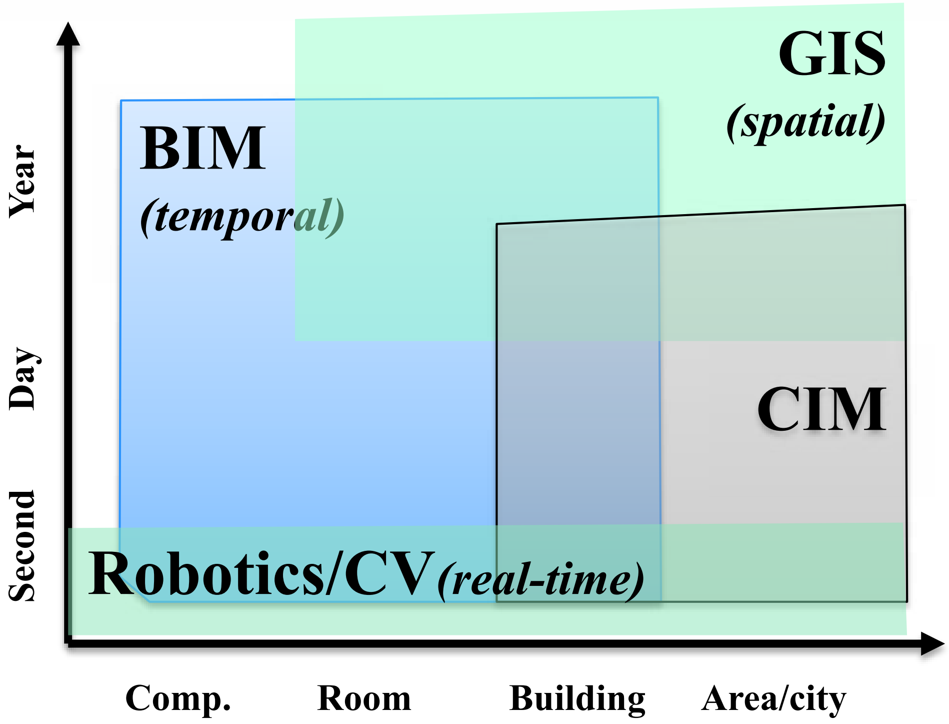
- Lacking in semantics in general 普遍缺乏
  - GIS
    - Rich (up to LOD3/300) for iconic buildings
    - Poor (LOD1/100) for most buildings
  - BIM
    - Rich (up to LOD4/400) for new buildings
    - Poor (LOD1/100) (copy-and-paste from GIS)
  - Failed to enable smart, sustainable, and resilient city apps.
    - Often requires LOD4/500
    - Plus many semantic objects in environments

      E.g., walkable 3D network, for baby strollers, lifts, …
- Any integration? 整合?

Hong Kong 3D map (95%: LOD1, 5%: LOD2~3) *Source: LandsD*

Berlin buildings 3D map (>95%: LOD1, <5%: LOD2) *Source: osmbuildings.org*

2.4 Integrating BIM and GIS with urban semantics

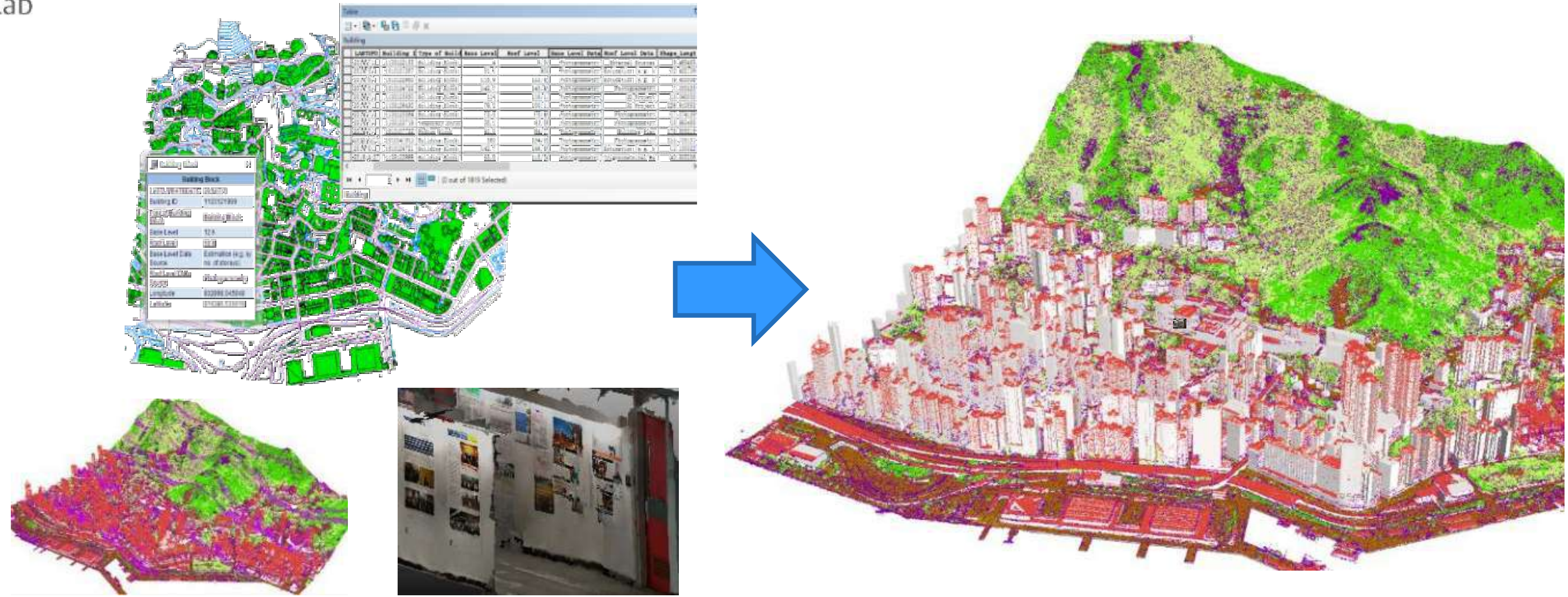


The spatial-temporal matrix of the interests of BIM, GIS, CIM. CV

- BIM, GIS, CIM, Robotics/CV
  - Complementary and overlapping
  - On the same urban objects
    - With emphasized semantic info.
- Integration is feasible
  - Via urban objects (BIM-centric)
  - Via locations (GIS-centric)
  - Enriching each other
  - Barriers by commercial companies (say, ESRI vs Autodesk)
- Is semantic enrichment possible?

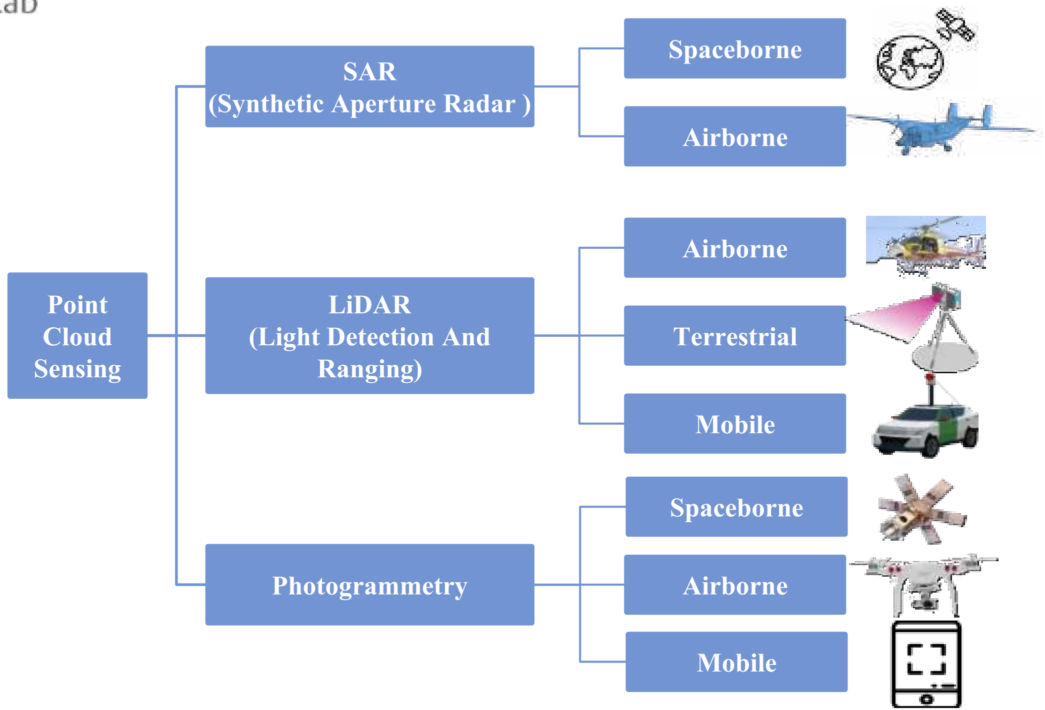
2.4 Semantic enrichment: Potentials (Chen et al., 2018a)

- Shared urban semantics in GIS, BIM, RS, AR, *etc*.



2.4 Semantic enrichment: Data & parts (Xu et al., 2018)

- Increasingly available data and components 数据越来越多



- BIM models and objects (Xue et al., 2018a)
  - BIMobject.com
    - >300,000
  - 3DWarehouse
    - >3,000,000
- Possible to enrich semantics 可能的
  - What is …?
  - When?
  - How?

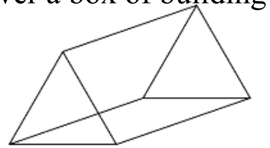
2.5 Concepts – semantic enrichment 语义充实

- An example in linguistics 语言学例子
  - Bob: *I bet my dog would like you.* 
  - Alice: *Sorry, I have a pet allergy.* 
- For BIM/GIS/CV, semantic enrichment 本研究中
  - The process of adding new semantics to existing objects
    - For *as-designed, as-altered, as-built, as-demolished* BIM (GIS)
    - On abstract meanings

      Of pixels (3D points), geometric primitives, and components
  - *E.g.*, as-designed → as-built (LOD 3/300 → LOD 4/500)
  - Prevail in BIM/GIS manual modeling/ automatic processing
    - A.k.a. annotation, labeling, scene understanding (+*relational*)
    - The core of modeling, in fact

- 另一个例子
  - 篮球裁判说：这是个好球
  - 看台观众说：这是个好球
  - 篮球售货员说：这是个好球
- BIM/GIS

Over a box of building



On a plane of road

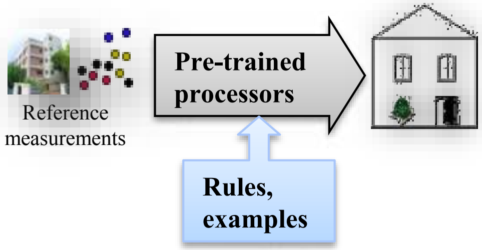
2.5 When to enrich semantics? 需求

- To meet *temporal* requirements 为不同时间
  - As-built (as-is) BIM
    - LOD 350 → 400 to enable (real-time) CEM (smart const.)
    - LOD 400 → 500 to enable O&M (disaster, smart city)
- To meet *spatial* requirements 为不同空间
  - 3D GIS
    - LOD3 for 3D map (e.g., VR flight simulation)
    - LOD4 for indoor-outdoor navigation
- To meet multi-disciplinary requirements 为不同领域
  - Scene understanding for CV (e.g., CEM, smart city)
  - Smart/rational decision making for robotics (e.g., construction industrialization)

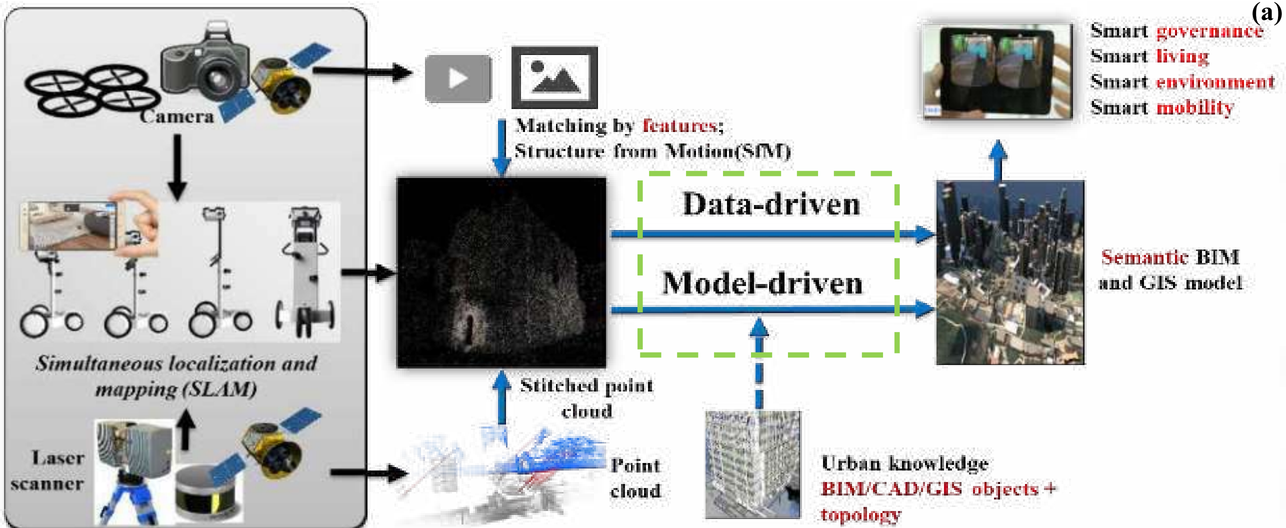
2.5 How to enrich semantics? 方法

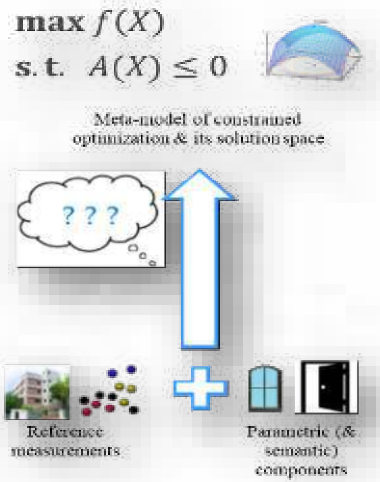
◇ Two subclasses in computational perspective 两大类

- ▣ Data-driven (scan-to-BIM): From data, processing to semantics
- ▣ Model-driven (scan-vs-BIM): From other models, copy-and-edit
- ▣ *Same as automatic/semi-automatic BIM modeling*



(a) Data-driven: A computational perspective



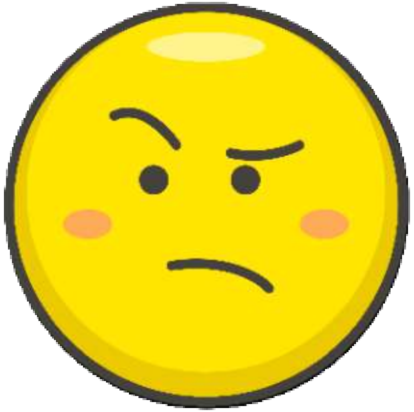


(b) Model-driven: A computational perspective

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

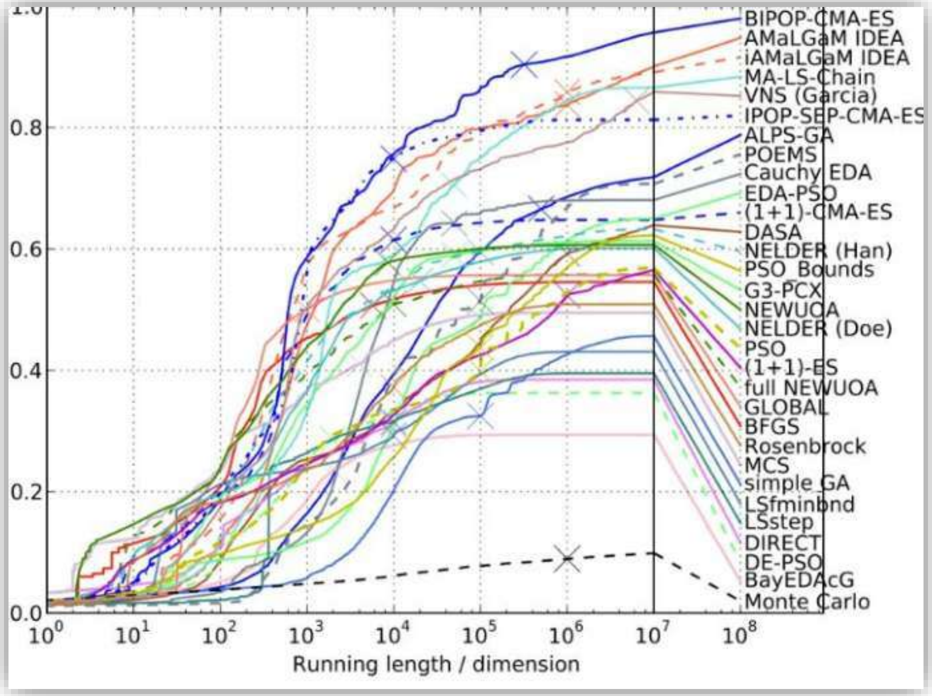
2.5 Challenges 难点

- Inputs 输入
  - Data-driven: Noise, huge amount in point clouds, uncontrolled real-world scenes
  - Model-driven: Availability of standard components
- Processing of semantic enrichment 处理
  - Rule-based data-driven
    - Fails on complex/irregular objects
  - Machine learning-based data-driven
    - Fails without big data training examples
    - Fails with biased training examples
  - Model-driven
    - Computational complexity due to huge search space



2.5 Opportunity of adopting DFO 新机遇

- Brutal-force search is impractical
- Thanks to off-the-peg *derivative-free optimization* (DFO) algorithms for solving such black-box problems
  - Surrogate methods
    - CMA-ES (Covariance matrix adap-tation with evolution strategy) and its variants are competitive
  - Trust-region methods
  - Metaheuristics (GA, PSO, VNS, *etc.*)
  - Hyper-heuristics, data mining
  - … and Monte Carlo



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

Section 3

SEMANTIC ENRICHMENT FOR BIM & GIS

BIM和GIS的语义充实 — “*热腾腾新鲜出炉*”

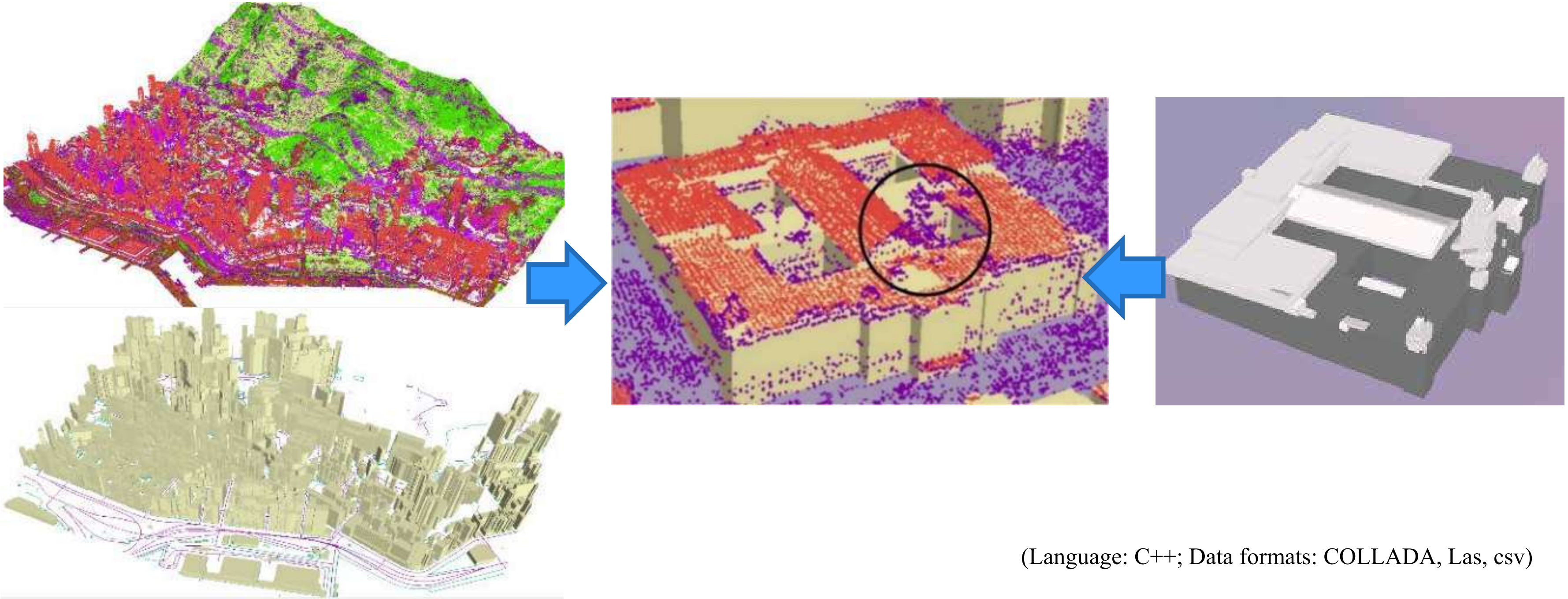
3.1 Semantic enrichment in recent papers 近期成果

- List of six automatic cases 六个
  - LOD1/100 + LiDAR →LOD2/200
    - Rule-based data-driven (Chen et al., 2018a)
  - LOD1/100 + LiDAR →LOD2+/200+
    - Machine learning-based data-driven (Xue et al., 2018e)
  - 2D photo + BIM components (LOD3/300) → LOD3/300
    - DFO-based model-driven (Xue et al., 2018a)
  - 2D photo/3D point cloud + BIM comp. (LOD4/500) → LOD4/500
    - DFO-based model-driven (Xue et al., 2018a; 2018b)
  - LOD4/400 + multiple real-time sensor data → real-time LOD4/400+
    - Rule (automata)-based data-driven (Niu et al., 2018)
  - Building's symmetry hierarchy in point clouds (Xue et al., 2018d)

As flexible, extensible as toy clay

3.2 Case 1: For LOD2/200 (Chen et al., 2018a) 屋顶

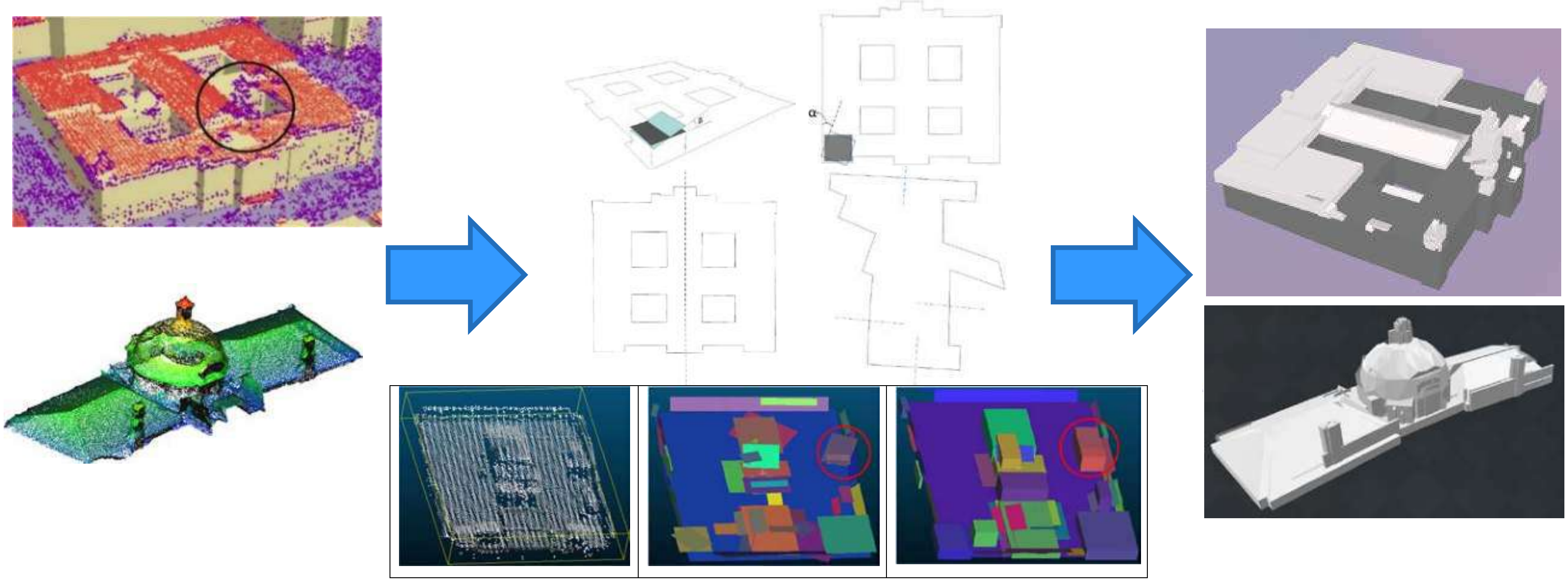
- LOD1 box models + LiDAR point cloud = LOD2 buildings
  - Data driven + architectural regularity



(Language: C++; Data formats: COLLADA, Las, csv)

3.2 Case 1: For LOD2/200 (Chen et al., 2018a) 屋顶

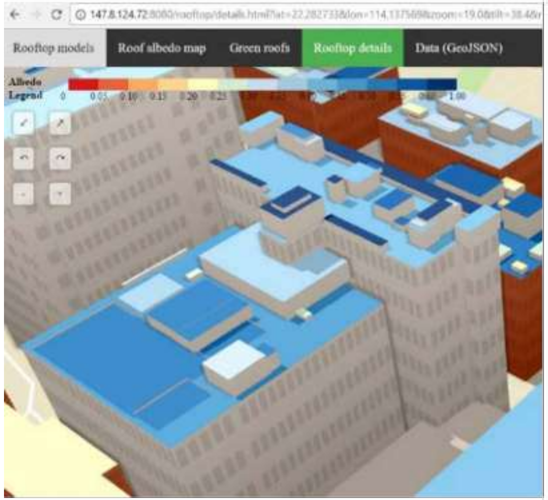
- Step 1. RANSAC; Step 2. rectification
  - A “top-down” approach, tested on over 1,300 buildings



(Language: C++; Data formats: COLLADA, Las, csv)

3.3 Case 2: Beyond LOD2/200 (Xue et al., 2018e) 非几何

- Non-geometric semantics on rooftops
  - Estimating albedo from *Intensity*, data-driven



Generated rooftop objects from point clouds

Developed albedo map

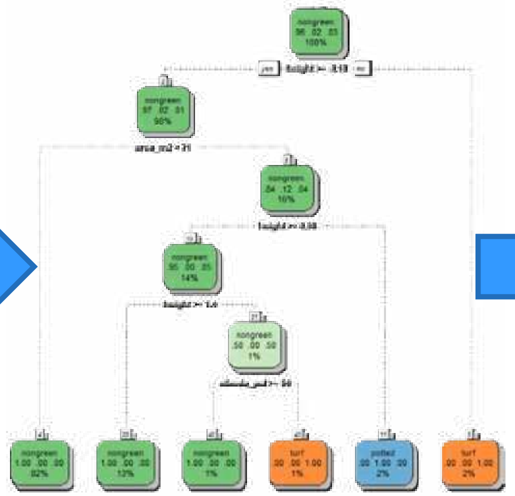
(Language: C++, R; Data formats: GeoJSON, Las, csv)

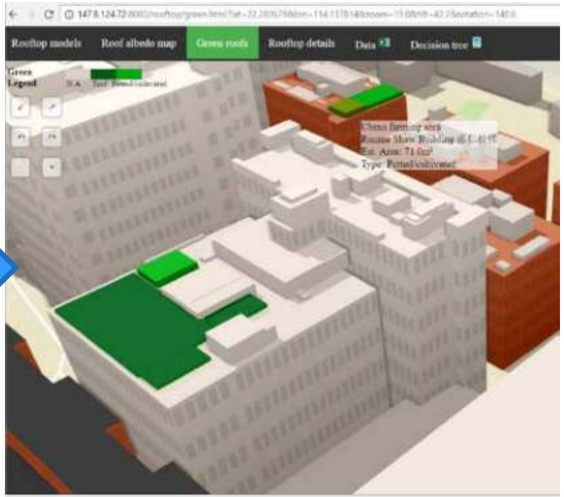
3.3 Case 2: Beyond LOD2/200 (Xue et al., 2018e) 非几何

◇ Non-geometric semantics on rooftops

▣ A preliminary decision tree model for predicting green roofs, data-driven

	A	B	C	D
1	green	albedo_p	area_m2	height
2	Non-gree	54.4978	123.5969	2.473763
3	Non-gree	53.63682	66.17113	2.386444
4	Non-gree	36.72315	400.519	3.532402
5	Non-gree	34.59036	58.62441	3.517059
6	Non-gree	50.82051	12.508	2.835854
7	Non-gree	29.5	5.046435	0.797977
8	Non-gree	30.5	9.466119	0.716205
9	Non-gree	33.47059	29.10006	0.627361
10	Non-gree	28.09091	5.260042	0.721675
11	potted	35.09589	74.02478	0.346179
12	turf	54.93458	61.92282	-0.34778
13	turf	53.72503	529.2725	-0.33987
14	turf	50.36822	74.39653	-0.39377





Identified green roof areas
by machine learning

(Language: C++, R; Data formats: GeoJSON, Las, csv)

3.4 Case 3: For LOD3/300 (Xue et al., 2018a) 外部细节

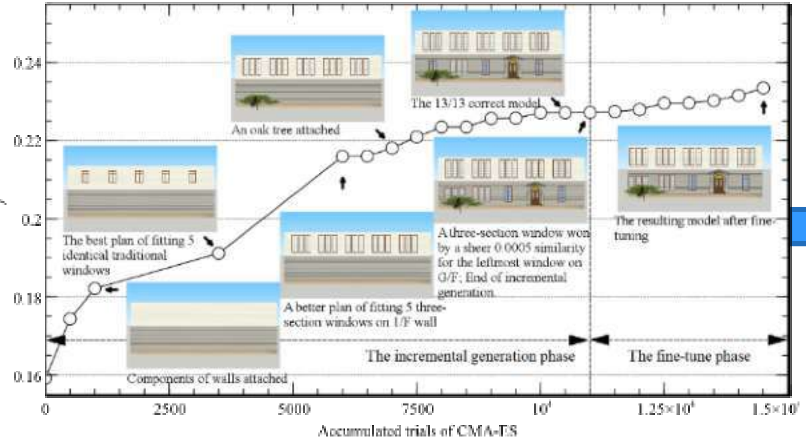
- 2D photo + free BIM objects → LOD3/300 models
  - Automatic, segmentation-free, DFO-based, model-driven
  - Recycling existing BIM/CAD resources

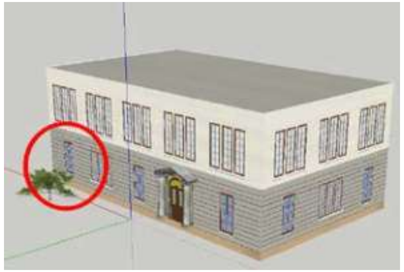
(a) A photo of a demolished building

Door portico Tree × 2

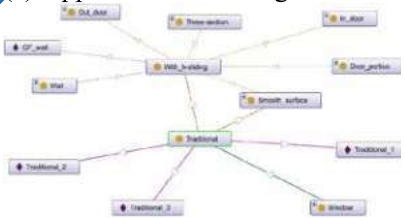
Wall × 2 Windows × 2

(b) Semantic components from web





(c) Approximate building mode



(d) Semantic/topological links

(Language: C++, Ruby; Data formats: SketchUp, Bmp, Google earth)

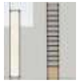
3.4 Case 3: For LOD3/300 (Xue et al., 2018a) 外部细节

- Nonlinear optimization problem formulation
  - SSIM (input 2D photos, 3D-to-2D projection of BIM)
  - Constrained by topological relationships

(a) A photo of a demolished building

Door portico

Tree × 2



Wall × 2

Windows × 2

(b) Semantic components from web

$$SSIM = structure \cdot luminance \cdot contrast$$

$$= \frac{(2\mu_{\hat{A}}\mu_{A}+c_1)(2\sigma_{\hat{A}A}+c_1)}{(\mu_{\hat{A}}^2+\mu_{A}^2+c_1)(\sigma_{\hat{A}}^2+\sigma_{A}^2+c_2)},$$

C	Example	Example value	Notes
	scaling_max	[1.5, 1.5, 1.5]	xyz coordinates
C_I	scaling_min	[0.8, 0.8, 0.8]	Ibid.
	z_rotation_max	π/2	
	z_rotation_min	0	
	on_top_of	‘Ground’	Adjacency, connectivity
C_R	contains_on	‘Wall’	Containment or intersection
	min_separation	‘0.5 m’	Separation

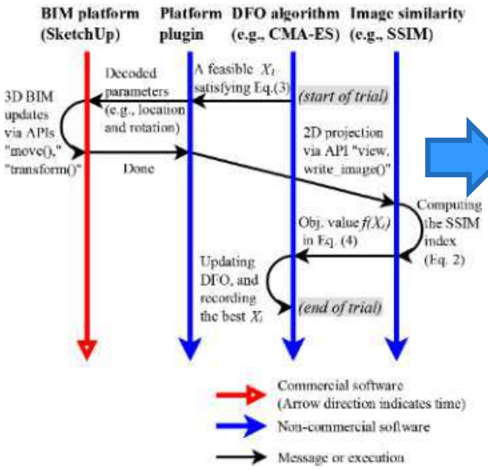
$$\text{maximize} \quad f(X) = SSIM$$
$$\text{subject to} \quad C(X) \leq 0.$$

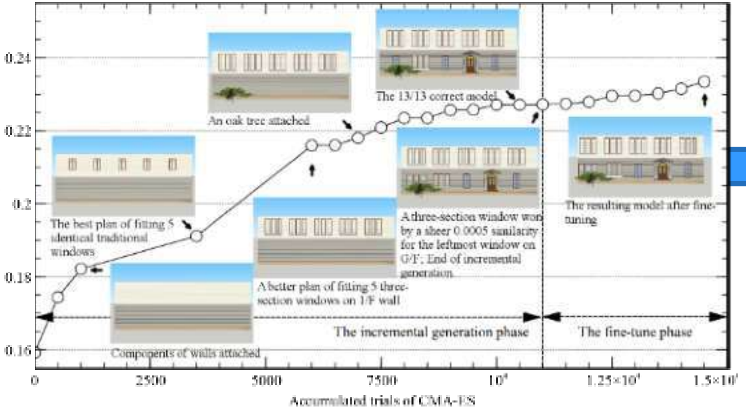
(Language: C++, Ruby; Data formats: SketchUp, Bmp, Google earth)

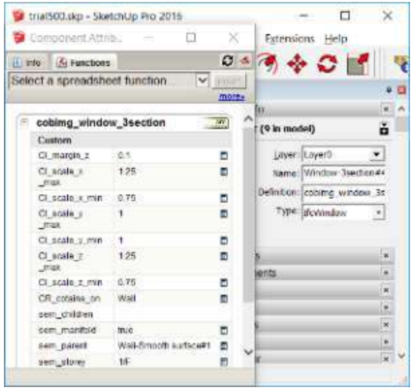
3.4 Case 3: For LOD3/300 (Xue et al., 2018a) 外部细节

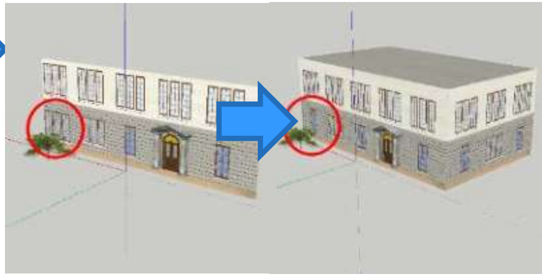
◇ Problem solving

- ▣ Fully-automatic, DFO-based, model-driven
- ▣ Rich semantics: Geometry, topology, functions, materials
- ▣ Occasional errors in recognition









(Language: C++, Ruby; Data formats: SketchUp, Bmp, Google earth)

3.5 Case 4: For LOD4/500 (Xue et al., 2018a; 2018b) 室内

- PCD/2D photos + BIM objects → Indoor (for LOD 4/500)
    - Automatic
    - Model-driven
    - Semantic
    - Accurate
    - Efficient
- COBIMG
    - DFO
- A quick demo

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

3.5 Case 4: For LOD4/500 (Xue et al., 2018b) 室内

◇ Nonlinear optimization problem formulation

- Data: PCD scanned by Google Tango phone

$$
\begin{aligned}
f(X) &= RMSE(BIM(X), P_{\text{in}}) \\
&\approx RMSE(P_X, P_{\text{in}}) \\
&\approx RMSE(P'_X, P'_{\text{in}}) \\
&= \sqrt{\Sigma_{p \in P'_{\text{in}}} nndist^2(p, P'_X)/m'} \\
&\approx RMSE(P'_{\text{in}}, P'_X) \\
&= \sqrt{\Sigma_{p \in P'_X} nndist^2(p, P'_{\text{in}})/\|P'_X\|}
\end{aligned}
$$

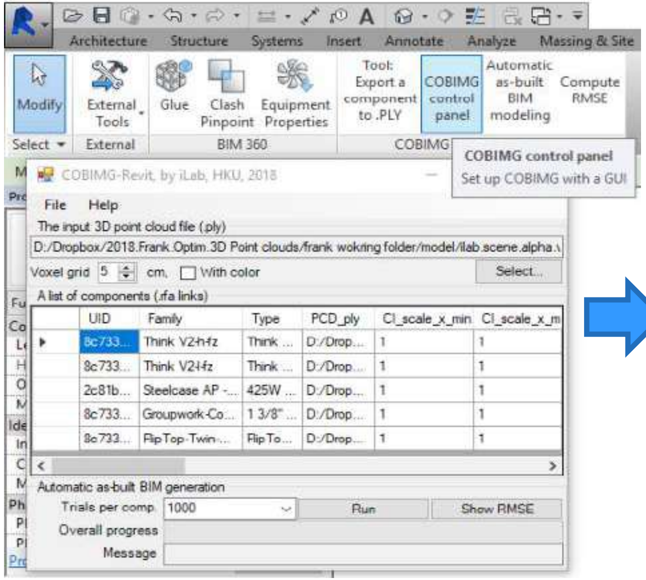
$$
\begin{aligned}
\text{minimize} \quad & f(X) = RMSE\big(BIM(X), P_{in}\big) \\
\textit{subject to} \quad & C(X) \leq 0.
\end{aligned}
$$

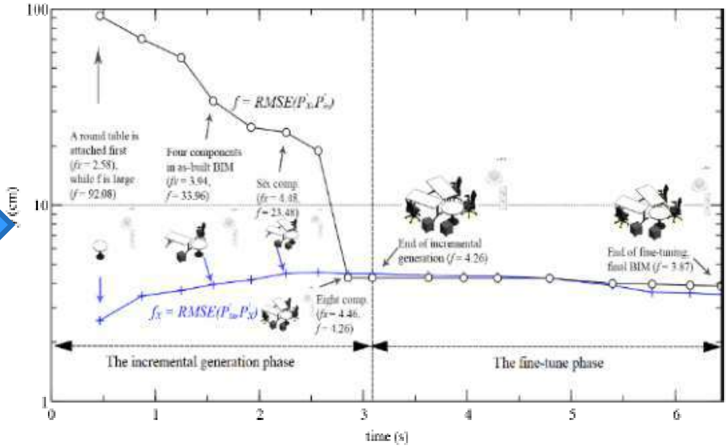
(Language: C++, CLR; Data formats: Autodesk Revit, Stanford polygon)

3.5 Case 4: For LOD4/500 (Xue et al., 2018b) 室内

◇ Problem solving

- ▣ CMA-ES-driven Autodesk Revit plugin





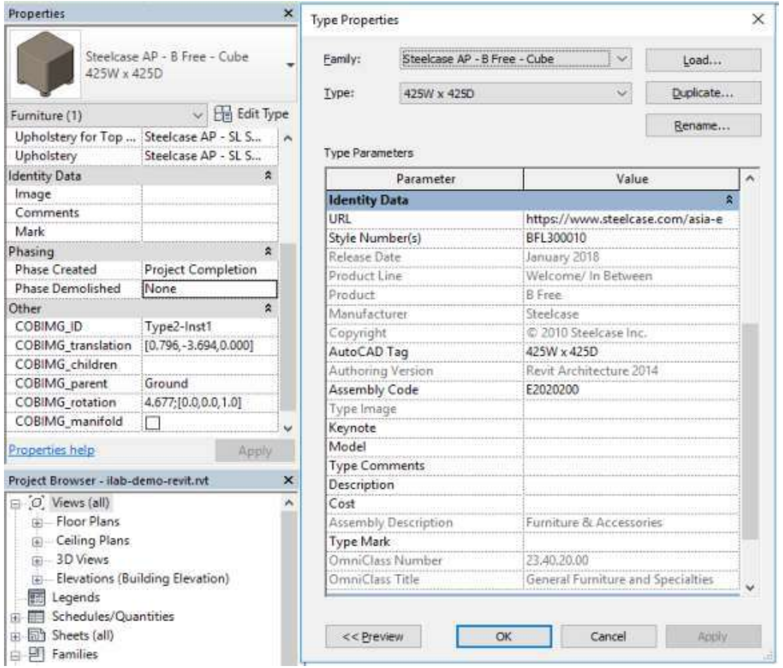
(Language: C++, CLR; Data formats: Autodesk Revit, Stanford polygon)

3.5 Case 4: For LOD4/500 (Xue et al., 2018b) 室内

Indoor modeling

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

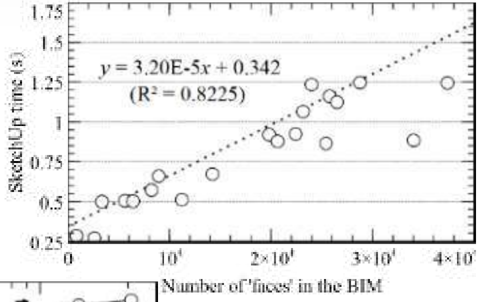
Modeler No.	Experience	Correctness (out of 8)	RMSE (cm)	Time cost (s)
1	Expert (3 years)	8	**3.79**	363.9
2	Average (1 year)	8	3.90	335.4
3	Beginner	8	4.22	691.1
COBIMG -Revit		8	3.87	**6.44**
COBIMG-Revit + annotation		8	3.87	~ 246.0



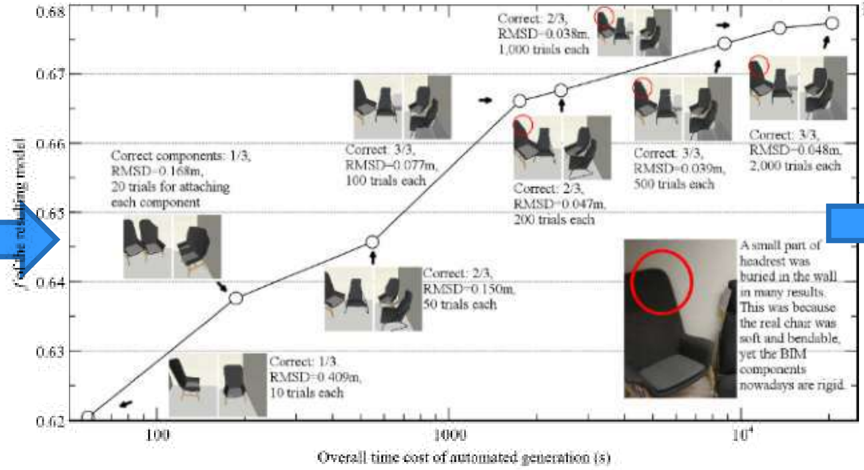
(Language: C++, CLR; Data formats: Autodesk Revit, Stanford polygon)

3.5 Case 4: For LOD4/500 (Xue et al., 2018a) 室内

- 2D photos: Two from smartphone
- Process: CMA-ES-driven SketchUp plugin
- Accurate: 3.9 cm, in 2.5 hours (97% time on projection)



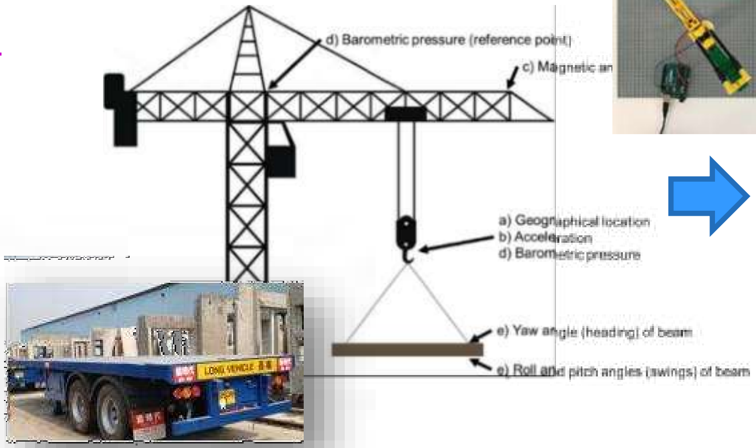
(b) Indoor case: A scene in a furniture store (384×512 pixels; taken by a smart phone camera with 28mm effective focal length; resolution down sampled)

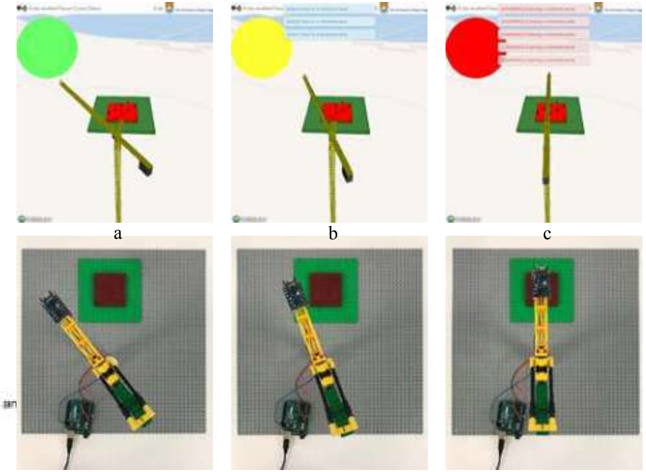


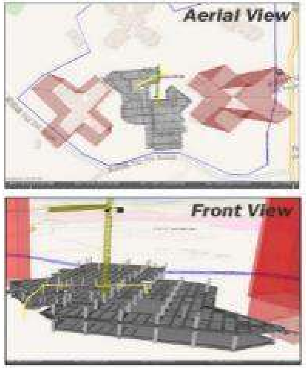
(Language: C++, Ruby; Data formats: SketchUp, BMP)

3.6 Case 5: Beyond LOD4/400 (Niu et al., 2018) 实时

- World is changing, very fast
  - BIM/GIS can be “deaf and blind” if not changes over time (Chen et al., 2015; Xue et al., 2018c)
- i-Core enabled, cloud service compatible
  - Demo1 (logistics)
  - Demo2 (Crane hoist)

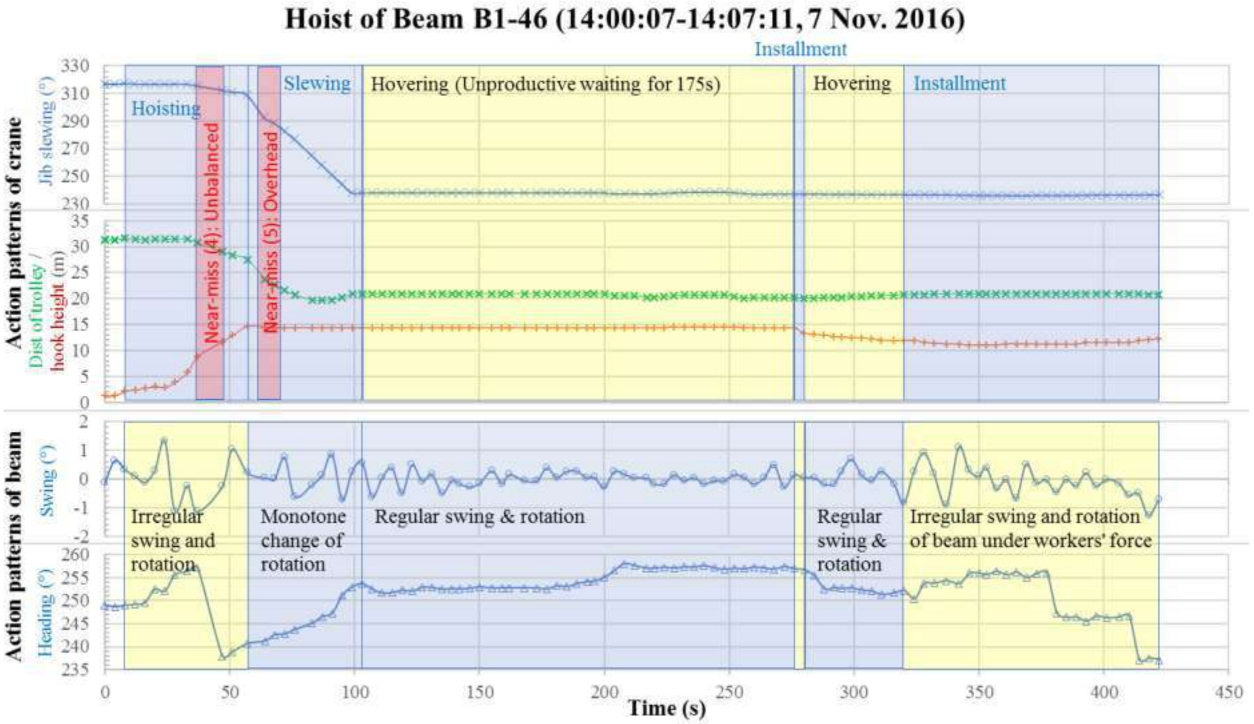






3.6 Case 5: Beyond LOD4/400 (Niu et al., 2018) 实时

- Based on IoT and rules (finite-state machine)
  - The real-time model
    - *s* accurate
  - Crane
    - Motions
    - Safety alerts
    - Efficiency
  - Beam
    - Swings
    - Rotations

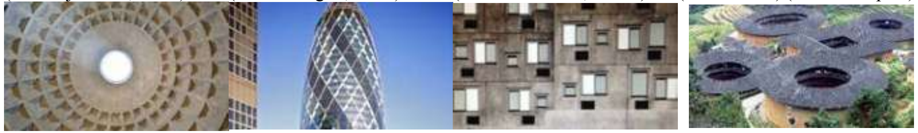


3.7 Symmetry: An on-going work (Xue et al., 2018d) 对称

◈ The universal symmetries

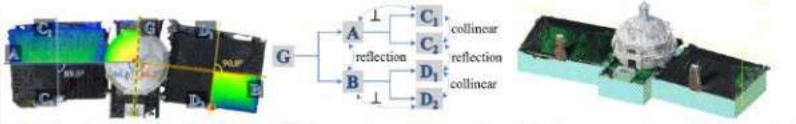
- a result of economical, manufacturing, functional, aesthetic, and mechanical considerations

(a) Reflection (Mirror) (The Taj Mahal, India)
(b) Rotation (The Pentagon, USA)
(c) Translation (The Great Wall, China)
(d) Translation × scaling (Fractal-like) (Hindu temples)

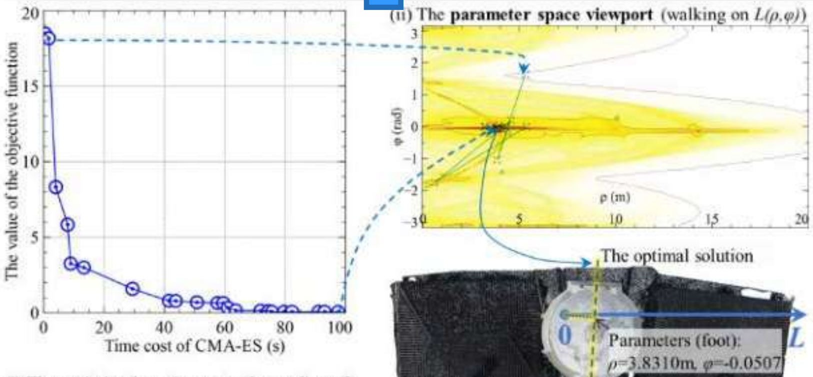


(e) Scaling × rotation (The Pantheon dome, Italy)
(f) Rotation × translation (The Gherkin, UK)
(g) Translation × reflection (Sugar Hill Project, USA)
(h) Cluster of homogeneous symmetries (Tulou, China)

(a) The building (b) Photos by a drone (c) A dense point cloud



(a) The detected reflections (b) Symmetry hierarchy (c) A symmetry-guided model



(i) The optimization viewport (descending of the objective function by CMA-ES)
(iii) The Point cloud viewport (testing a series of symmetries)

3.8 Summary of the five cases 小结

- Presented a series of semantic enrichment methods
- Accuracy up to
  - *cm* accurate (in *xyz*)
  - *s* accurate (in time)
- Automation and efficiency
  - Fully, inexpensive (e.g., saving 98% modeling time)
  - Very fast (*s* level)
- Semantics
  - Rich
- Resulting LODs
  - LOD2/200 to 4/500 and beyond

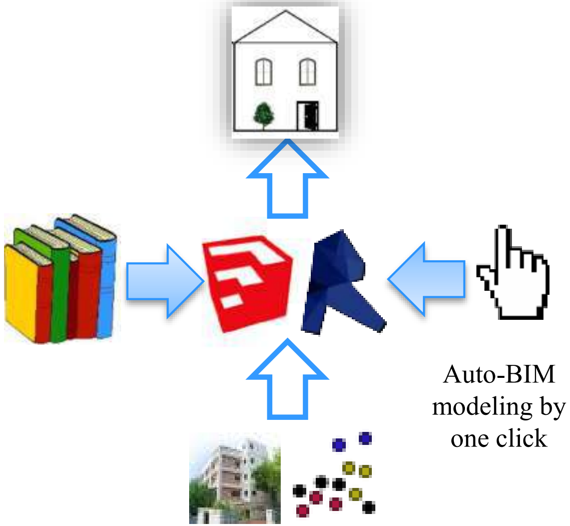
Section 4

DISCUSSION & FUTURE WORK

总结展望 — “尚未成功，仍需努力”

4.1 Discussion

- Semantic enrichment for BIM and GIS
  - Resulting in real-time, accurate, and rich urban semantics
    - Also enables fully automatic BIM modeling
  - Is highly demanded
    - In different *temporal* (BIM) and *spatial* (GIS) scales
    - In various smart city applications
  - Is feasible in different LODs
  - Can be *n*-dimensional
- Drawbacks
  - Data-driven: Limited by rules, training data
  - Model-driven: Limited by standard components
  - Killer (downstream) applications



Auto-BIM modeling by one click

4.2 On-going and future work

- Semantic prioritization
  - Identifying available urban semantic databases
  - Seeking semantics for killer applications
- Data-driven
  - Symmetry
  - Interactive machine learning
  - Improved heuristics, like multiple starts
- Model-driven
  - Algorithm benchmarking
  - Component-free
  - More than building elements

4.3 Potential collaborations

- Inter-disciplinary inter-institutional research
  - BIM, GIS, CV, RS, AR, …
- Joint research funding
  - Hong Kong
    - **HK ITF Midstream Research Fund (MRF)**

      $5~10 millions (<50% can go to Mainland)
    - HK RGC Collaborative Research Fund (CRF)
    - NSFC/RGC Joint Research Scheme

      ~$1M + RMB 0.8M
  - Shenzhen
    - Guangdong - Hong Kong Technology Cooperation Funding Scheme (TCFS)
  - Greater Bay Area
    - 重点技术联合创新基金 (still inception)

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Thank You !

谢 谢!