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

iLab @ HKURBANlab
the urban big data lab

Digital Twinning Construction Objects: Filtering, Supervised, Reinforcement, and Unsupervised Methods

6 December 2019
HKU, Hong Kong

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0.1 Aims and scope

- Goals
  - Introducing some exciting ideas
  - Streamlining my work
  - Discussion for possible opportunities
- Concepts
  - Digital twin
  - Construction objects
  - Machine learning
- My work in the past 3 years

0.2 About me

- A mixed background
  - BEng in Automation, CAUC — 2004
  - MSc in Computer Science, CAUC — 2007
  - PhD in System Engineering, HKPU — 2012
  - PDF/RAP/AP in Construction IT — 2016
- Research interests
  - Urban sensing and computing
  - Automation in construction
  - Applied operations research
  - Machine learning and data visualization

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

0.3 My research projects

- On-going
  - PI: HK RGC (17201717, 17200218), HKU-Tsinghua SPF (20300083), HKU (201811159177)
  - Co-PI: Key R&D Guangdong (2019B010151001), HKU PTF (102009741)
  - Co-I: NSFC (71671156), NSSFC (17ZDA062), HK SPPR (S2018.A8.010.18S), HK PPR (2018.A8.078.18D)
- Completed
  - PI: HKU (201702159013, 201711159016)
  - Co-I: NSFC (60472123)
- Job vacancy – Research Assistant (2~3 openings)
  - $17,000/month, transferable to PhD depends on vision, performance
  - New updates on my web page (QR code)

Outline

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1 Introduction to DTCO

2 Methods for DTCO

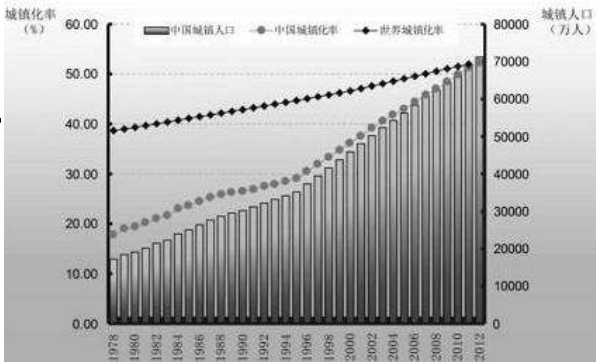
3 Discussion

Section 1

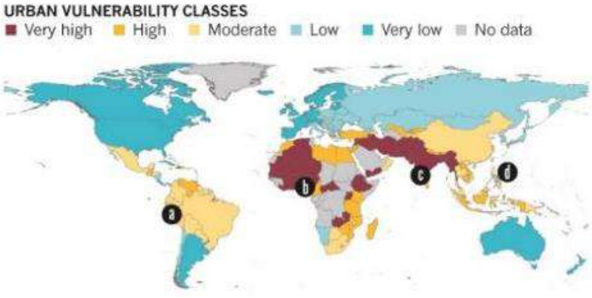
INTRODUCTION TO DTCO

1.1 Background – world

- Global urbanization
  - By 2050, 65% world’s population will live in cities (WHO, 2015)
  - Irreversible; Even faster in China
- Leads to urban vulnerability (a.k.a. ‘city diseases’)
  - ‘Dead’ space/landscape, low familiarity with surroundings,
  - Poor waste treatment, environment (air, water) pollution,
  - Heritage destruction, aging town blocks, inefficient traffic,
  - Disasters (earthquake, climate change), resource crisis, …
- Demands smarter and more resilient development
  - (a) Smarter analysis and decisions in multiple disciplines
  - (b) On basis of accurate, timely urban semantics



China’s and global urbanization rates
source: gov.cn

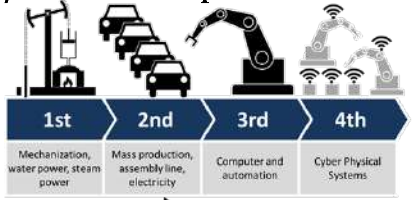


Global urban vulnerability level (Birkmann et al, 2016) *source: nature.com*

1.1 Background – the industry

- Construction is known as a "backward industry"
  - Low productivity, labor-intensive (*v.s.* aging workers)
  - Fatality, occupational hazards, management (*e.g.*, cost overrun)
- A consensus of global research institutes (e.g., Harty et al., 2007)
  - Effective (productive, automatic, age friendly) and efficient (safer, profitable, on-time, sustainable) industry
- Meets new information technology (IT / ICT)
  - Computing power
    - BIM, RFID, LiDAR, GPS, UAV, CV, VR/AR, smart phones…

USA's gross value-added by sectors
source: economist.com



Construction 2.0, to 4.0

Recent advances in ICT

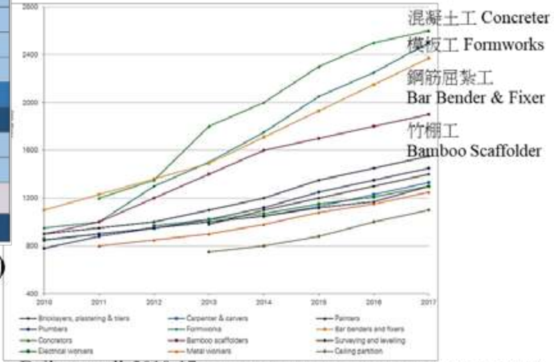
1.1 Background – the industry in Hong Kong

- Construction 2.0 (DevB 2018)
  - Innovation
    - Productivity (MiC, BIM, etc.)
  - Professionalization
    - Skilled workers
  - Revitalization
    - Young employees (see *the charming post*)

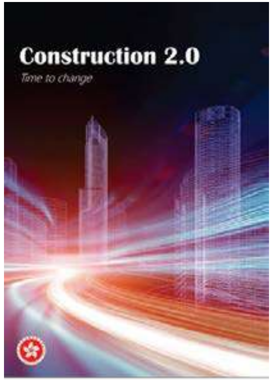
	2018	2019	2020	2021	2022
Concretor					
Plumber					
Carpenter					
General welder					
Metal worker					
Plasterer & related workers					
Electric fitter					
Ventilation mechanic					
Lift and escalator mechanic					

Number of workers in shortage: 501-1 000 | 1 001-1 500 | 1 501-2 000 | ≥2 000

Overall shortage ↓ and skilled ↑ (Source: CIC)



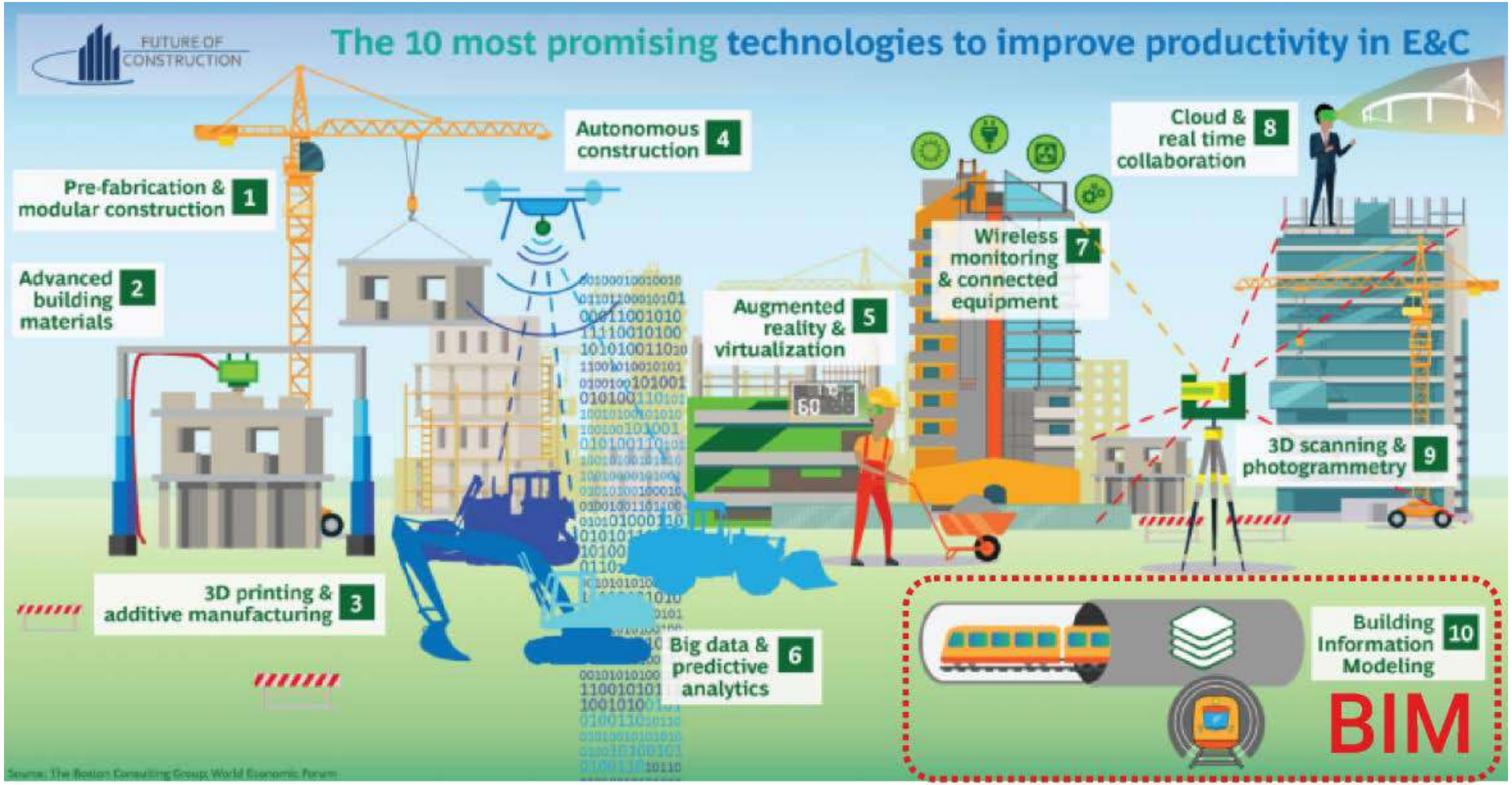
Daily payroll 2010-17 (Source: DevB, Construction Industry Employee General Union)



(Source: DevB, hkc2.hk)

(Source: CIC.hk, *Construction Power* | *Get In Gear*)

1.1 Background – new opportunities in IT

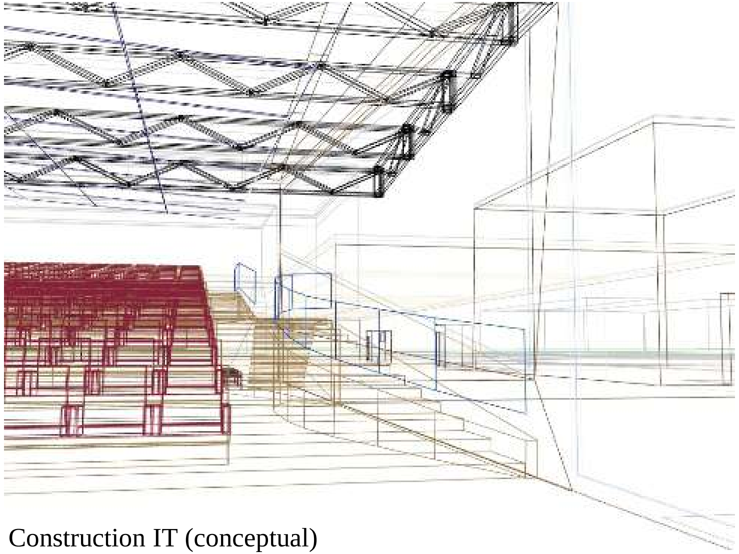


Source: The Boston Consulting Group; World Economic Forum

1.2 Construction IT

Construction IT

- A sub-field in Construction Technology + Construction Management
  - Since 1960/70s (e.g., CAD)
  - In construction (process)
  - By construction (objects)
  - For construction (targets)
- Typical research methods / -ology
  - Applying *M* (in IT) to *P* (construction)
- Aiming for
  - Automation
  - Safety
  - Productivity
  - Human/equipment/robot augment, etc.



Construction IT (conceptual)
photo source: Wiki, CC BY–SA 2.5

1.2 Construction IT

- Example journals (ranking by sub-discipline, Clarivate Analytics' JCR 2018)
  - Computer-aided Civil and Infrastructure Engineering (1/64 in Const. Bld. Tech., 1/132 in Civil Eng.)
  - Automation in Construction (8/64 in Const. Bld. Tech., 7/132 in Civil Eng.)
  - Journal of Computing in Civil Engineering (40/132 in Civil Eng.)
  - ISPRS Journal of Photogrammetry and Remote Sensing (1/50 in Geography, 3/30 Remote Sensing)
- Focused international conferences / workshops
  - CIB W78: Construction IT
  - ISARC: International Symposium on Automation and Robotics in Construction
  - CONVR: International Conference on Construction Applications of Virtual Reality
  - ICCCBE: International Conference on Computing in Civil and Building Engineering

1.3 Digital Twin (DT)

◈ Digital twin

- *A virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning*. (NIC, 2017)
- The first half of Cyber-Physical System (CPS)
  - Highlighted by U.S. NSF (2019)
  - See my top-voted answer on
  - [“What are the connections and essential differences between CPS and DT?”]
- Related
  - As-is BIM, VR, IPD, 4D city, HD GIS, …

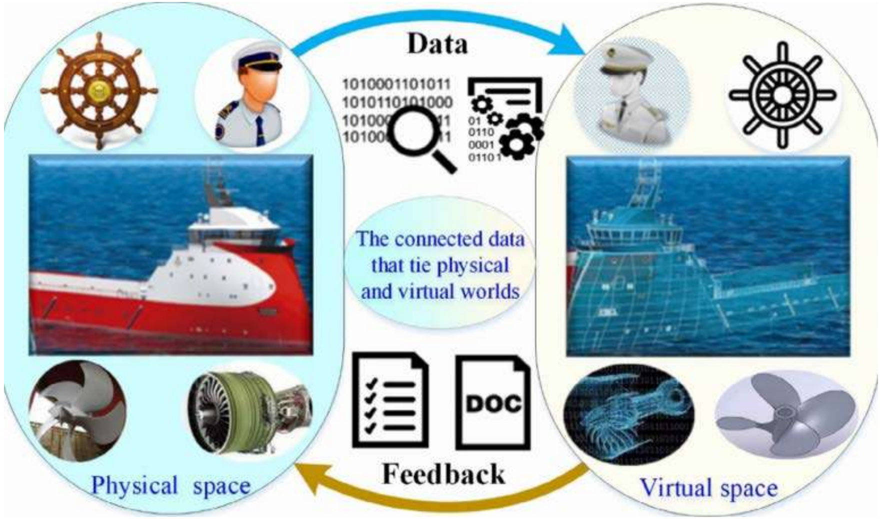
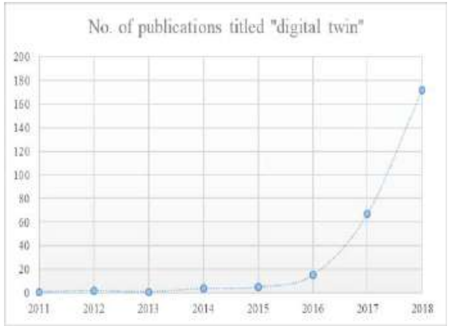
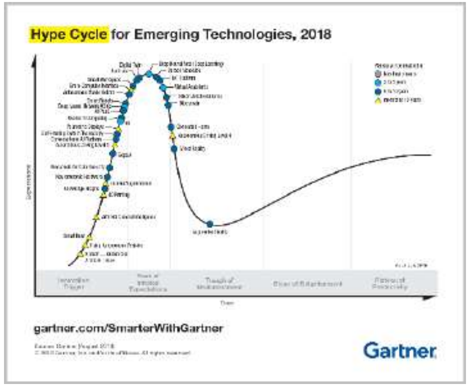


Figure 1. Example of a digital twin (Tao et al. 2018)

1.3 DT: History and examples

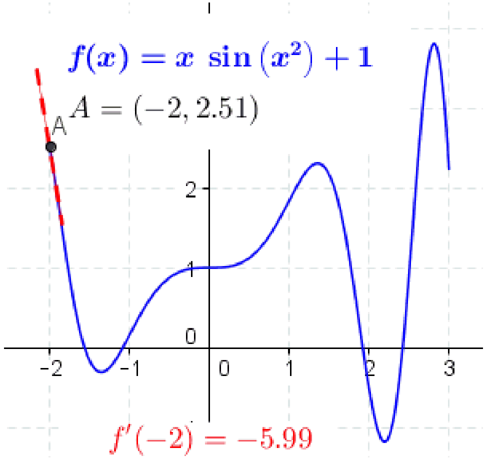
- From the CAx (CAD, CAE, CAM) waves
  - 1960s~80s: *Computer-aided design* (CAD), including 2D/3D
  - 1970s~80s: *Computer-aided engineering* (CAE), including Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), Multidisciplinary Design Optimization (MDO), Virtual prototyping
  - 1970s~80s: *Computer-aided manufacturing* (CAM), including Product data management (PDM), computational numerical control (CNC)
  - 2010s: DT for real-time CAx models
- Examples
  - Jet fighter, aircraft, wind turbine, smart train, …
  - Smart building, smart construction, smart design, …



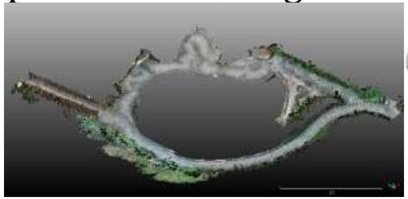


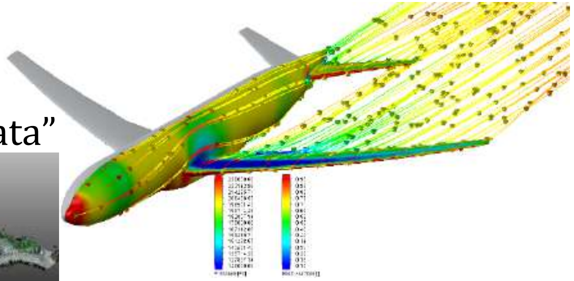
1.2 Why DT?

- Analytical models guarantee optimal analysis
  - E.g., Linear equations
  - & Gradient of a function
    - Stationary points, where the first derivative is zero
- However, DT/CAx is needed
  - For (near-)optimal analysis / control / management, when
  - Too complex to create analytical models
    - E.g., aerodynamics, aircraft device risks, concrete, ...
  - Too expensive to do so
    - E.g., construction project, massive 3D point clouds, "big data"



First derivative and stationary points




Aerodynamics simulation
Picture source: mentor.com

1.3 Objects in construction

- Construction
  - Lifecycle
    - Narrow use: Build
  - Involving three types of objects, e.g.,

	Building	Human	Equipment
Plan	Design	Designer	Ruler /BIM
Build	Window	Workers	Crane
Use	Place	Occupant	HVAC
Maintain	Service items	Engineer	Voltmeter
Repair	Facade	Workers	Scaffold
Learn	Function	Planner	Spreadsheet

1.3 Objects in construction

- Objects in construction (narrow)
  - Equipment
    - Truck, tower crane
    - Location, movement 3+ degrees of freedom (DoF)
  - Building (elements, furniture, materials, …)
    - Frame, windows, chairs
    - Location, orientation, 3+ DoF
  - Human
    - E.g., workers, site engineers
    - Complex, 10+ DoF
- Objects' properties
  - Physical (3D xyz + 3D rotation + motion + …)
  - Semantic (action, intention, utility, relations, materials, …)

Lego blocks / construction
Source: Wikipedia

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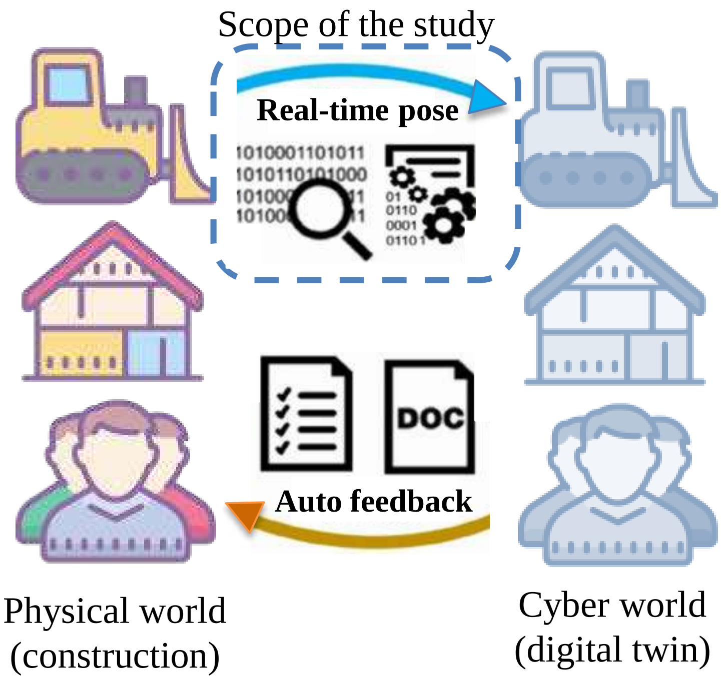
1.3 DTing construction objects (DTCO)

- The general question
  - How to DTing construction objects?
    - To reflect accurate geometry
    - To understand the semantics
  - As the diagram
    - For future construction CPS
  - A "mapping from X to Y" in essence
- Challenges
  - Various objects
  - Various data (with/without training samples)
  - Various scenarios
    - Methods: "Does one size fit all?"

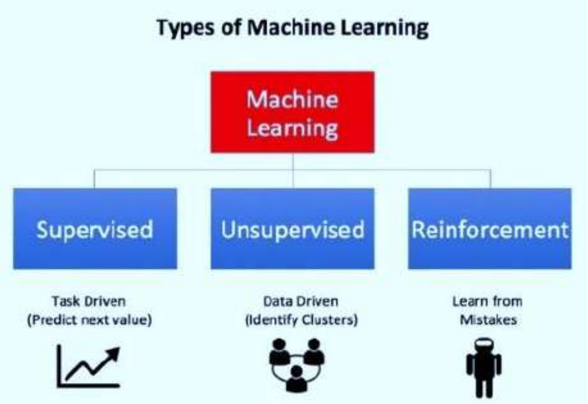


Section 2

METHODS FOR DTCO

2.1 The objects in this section

- A lot of cases to show
  - In blue are not in the narrow definition
- Grouped by the methods into
  - Machine learning (ML)
    - Algorithms & statistical models without explicit instructions, relying on patterns and inference instead



Building	Human	Equipment
Building	Worker's pose	Crane
Roofs	Indoor position	
Precast		
Furniture		
Regularity		
Street	Pedestrians	BIM
Sidewalk		

2.1 Grouping via ML paradigms

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Data & processing methods		**Machine learning paradigm**
◈ Filtering	⟷	◈ No learning
▣ IoT, Wearing		
◈ Detector, regression,	⟷	◈ Supervised learning
▣ SVM, deep learning		▣ Training examples (cost)
◈ Model tracking,	⟷	◈ Reinforcement learning
▣ RANSAC, semantic registration		▣ Finding after iterations of fitting *f*
◈ Manifold embedding	⟷	◈ Unsupervised learning
▣ PCA, LDA		▣ Feature clustering

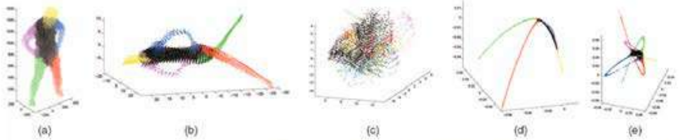
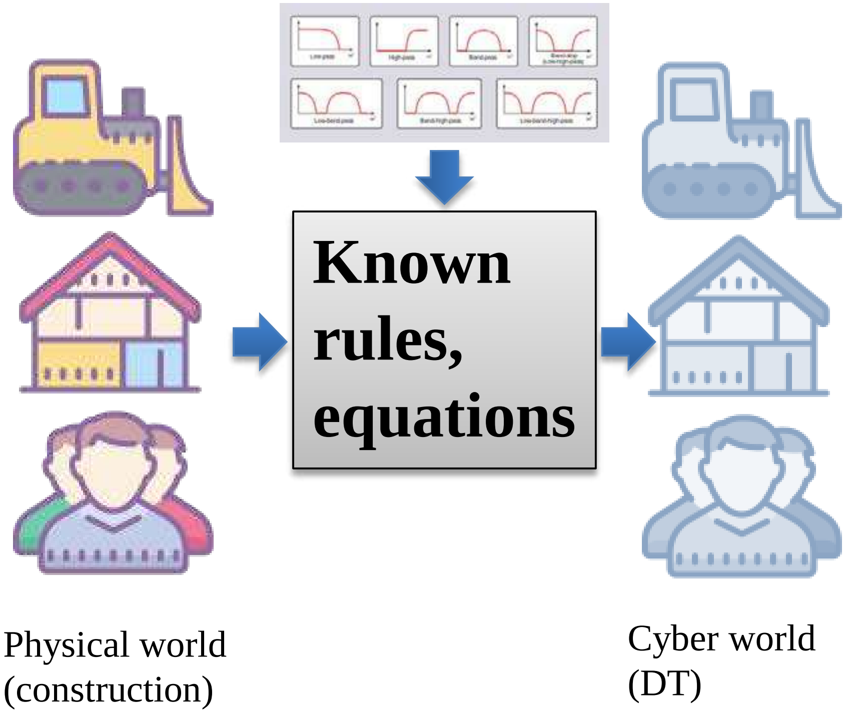


Fig. 9. Comparison of Laplacian Eigenmaps and Isomaps for a real example of the human-subject voxel reconstruction. (a) Normal. (b) Isomap: dimensions 1-3. (c) Dimensions 4-6. (d) Laplacian eigenmap: dimensions 1-3. (e) Dimensions 4-6.

(Sundaresan & Chellappa 2019)

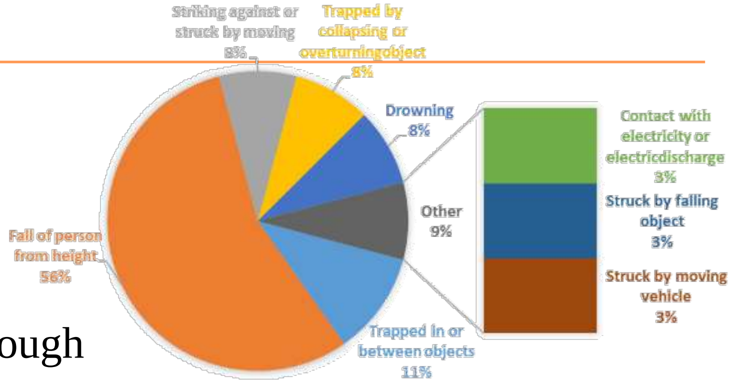
2.2 Filtering methods

- Filtering
  - Removing some unwanted components or features (noise, bias) from a signal
  - No learning involved
  - See also: *a priori*, rule-based
- Pros
  - Fast, direct, easy to interpret
- Example cases
  - Tower crane motion
  - Logistics and supply chain
  - Indoor position
  - Blockchaining BIM

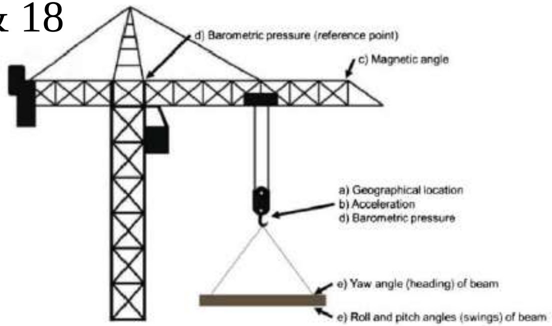


2.2.1 Case 1: Crane pose

- Productivity
  - Efficiency, seamless operation required
- Occupational health and safety (OHS)
  - To protect the safety and health of all members through prevention of work-related injury, illness and disease
  - In the US, construction accounted for ~5% workforce but 20% occupational deaths, 2003—2013 (NSC 2015)
  - In Hong Kong, construction had 36 fatal accidents in 2017 & 18
- Tower crane
  - A key equipment
  - The “bottleneck” to productivity, and
  - Related to safety issues



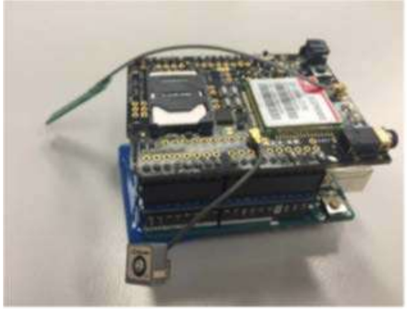
Reasons of fatality in HK’s construction (Data: Labour Dept 2019)

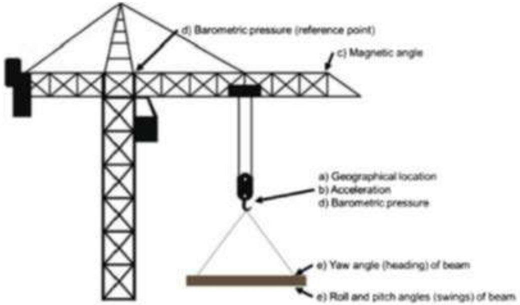


(Niu et al. 2019)

2.2.1 Case 1: Crane pose (Niu et al. 2019)

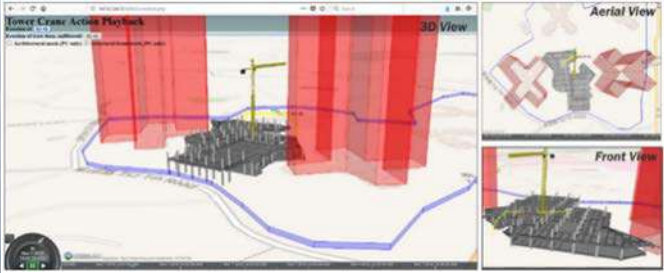
◈ (a) collection, (b) processing, (c) visualization





id	sender_name	time_sender	lat	lng	alt	alt_imu	heading_gps	heading_imu	pitch_imu	roll_imu	temp_imu
12845	c1027	2016-11-07 14:07:52	22.414655	113.97579	10.2	37.78452	150	-103.71865	0	-1.10171	41.4
12846	c1027	2016-11-07 14:07:52	22.414655	113.97579	10.2	37.61805	150	-101.14362	0	-2.1858	41.4
12847	c1027	2016-11-07 14:07:52	22.414655	113.97579	10.2	41.79813	150	-102.55789	0	-1.76239	41.3
12848	c1027	2016-11-07 14:08:10	22.414653	113.975793	10.5	43.5526	9.2	-102.5936	0.21869	-1.74893	41.2
12849	c1027	2016-11-07 14:08:12	22.414657	113.975792	10.4	48.31926	99.1	-102.92745	-0.44073	-1.76234	41.1
12850	c1027	2016-11-07 14:08:12	22.414657	113.975792	10.4	45.97821	99.1	-103.11963	-0.65854	-1.31683	41.1
12851	c1027	2016-11-07 14:08:12	22.414657	113.975792	10.4	44.47211	99.1	-102.20269	-0.43904	-2.41327	41.1
12852	c1027	2016-11-07 14:08:12	22.414657	113.975792	10.4	43.46805	99.1	-103.15113	-0.21952	-1.09748	41.2
12853	c1027	2016-11-07 14:08:12	22.414657	113.975792	10.4	39.79	99.1	-102.55152	0.44243	-1.54811	41.3
12854	c1027	2016-11-07 14:08:33	22.41468	113.975772	10.3	34.61115	285.7	-102.44339	0	-1.74895	41.4
12855	c1027	2016-11-07 14:08:37	22.41468	113.97577	10.7	29.09936	58.6	-103.28233	0	-0.43904	41.6
12856	c1027	2016-11-07 14:08:42	22.414672	113.975773	11.2	44.05463	214.8	-111.27988	0.22294	-1.11456	41.2
12857	c1027	2016-11-07 14:08:46	22.414665	113.975773	11.9	45.0587	41.7	-104.54216	0	-1.77604	41.1
12858	c1027	2016-11-07 14:08:50	22.41466	113.975775	12.3	42.46663	219.3	-105.4126	0.22037	-1.76238	41.2

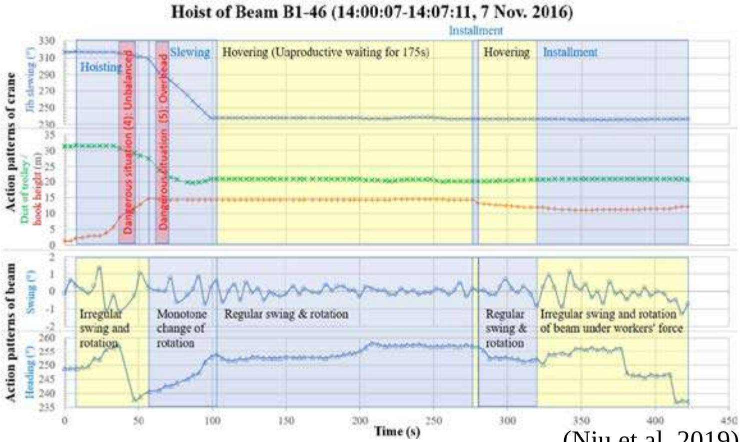
(b)



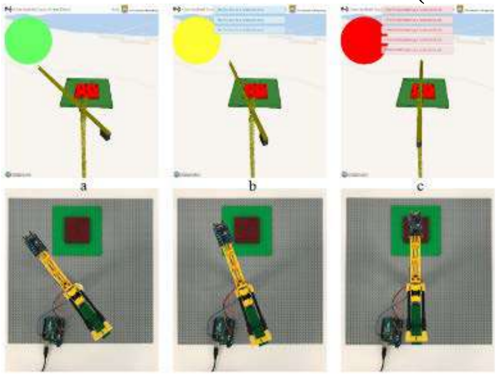
(c) [Demo (Crane hoist)]

2.2.1 Case 1: Crane pose

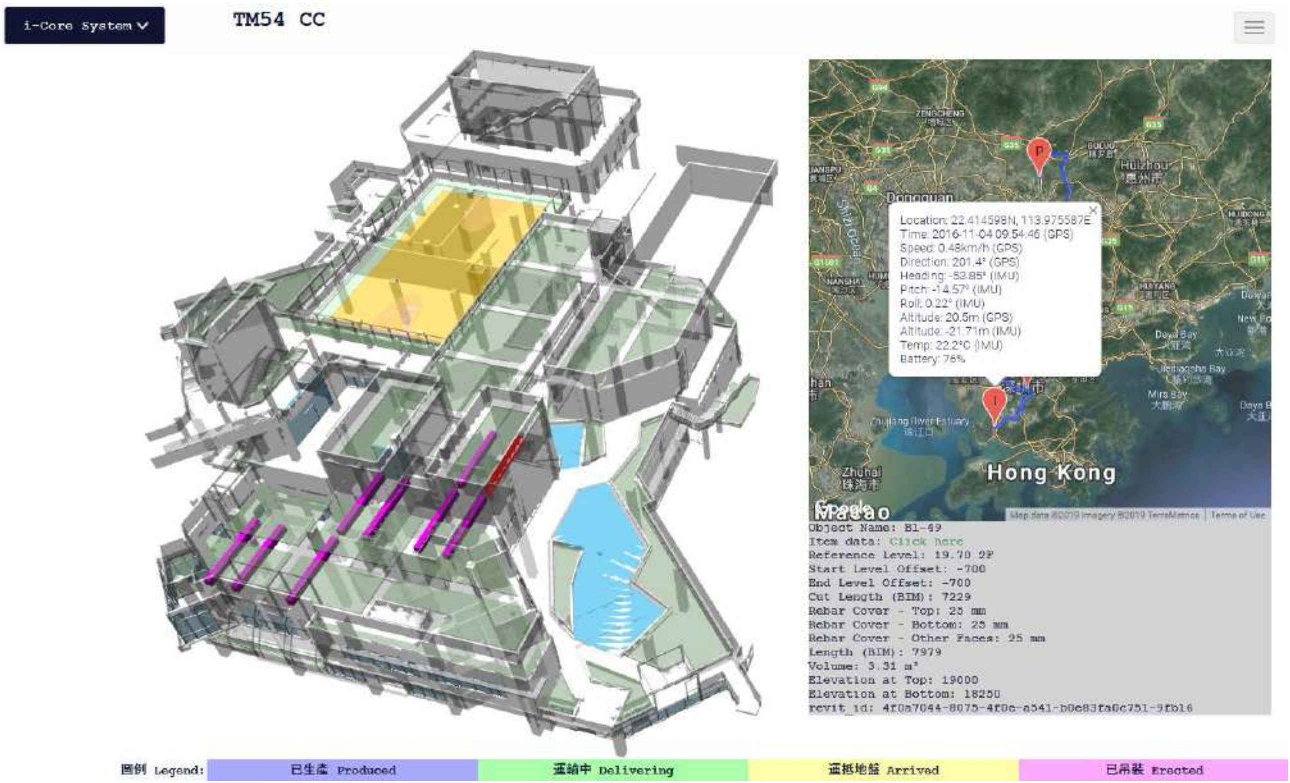
- Event analysis
  - 2 near-miss safety issues
    - 1 load above workers
    - 1 unbalanced lifting
  - 200 seconds unproductive hosting
    - Reason: Working floor preparation of locking steels for RC beam
- CPS demo (on Lego)
  - Real-time warnings to operator
  - Simplest validation
    - Worked
    - Delay < 1.0s



(Niu et al. 2019)

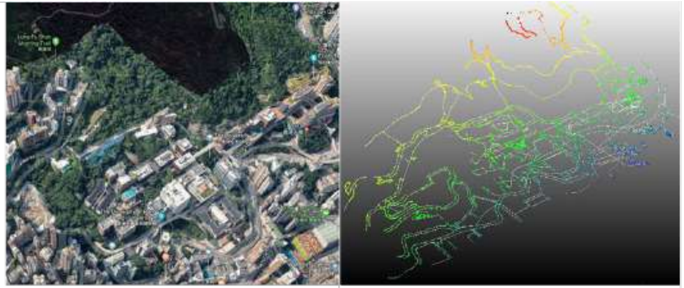


2.2.2 Case 2: Precast logistics (Liu et al. 2018)



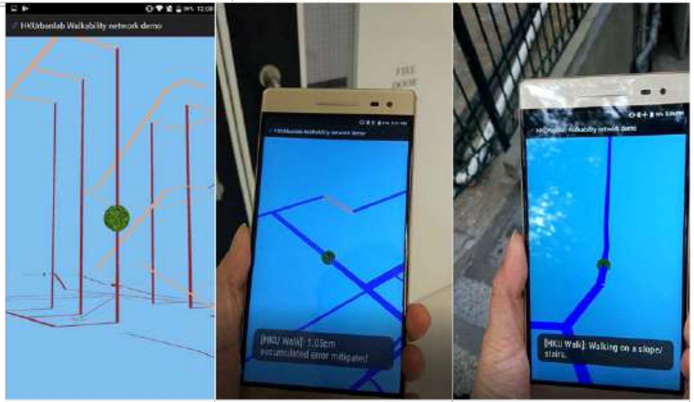
- Similar to
  - Crane pose
- [Demo]()

2.2.3 Case 3: No-RF Indoor positioning (Xu et al. 2020)



(a) The study area around HKU Main Campus

(b) The 3D walkability network, warmer color indicates higher altitude



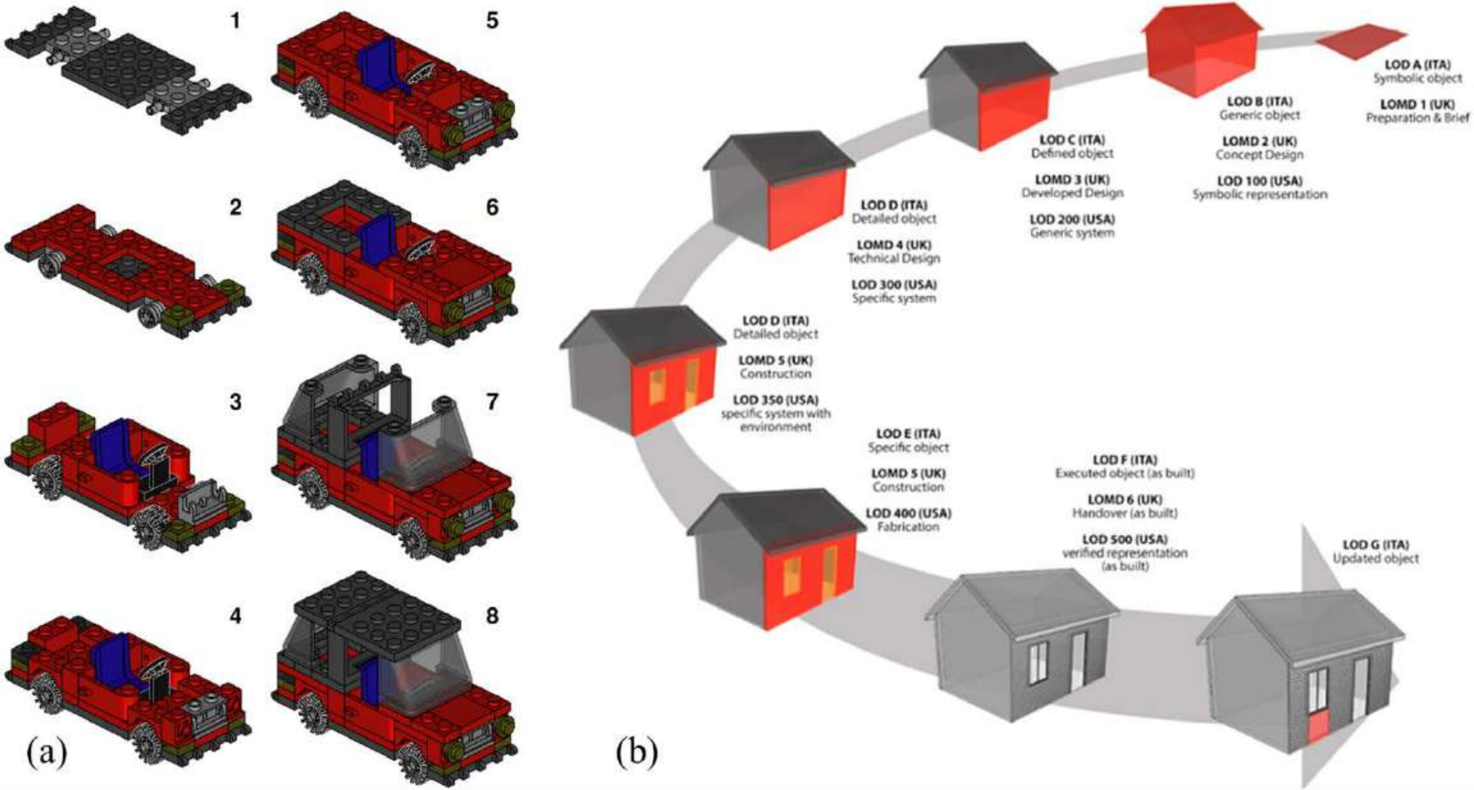
(a) Android APP

(b) Error compensation

(c) On slopes

2.2.4 Case 4: BIM versions / blockchain (working)

- Rome wasn't built in a day; so was BIM. (a) by element, (b) by lifecycle/time



(a) (b)

2.2.4 Case 4: BIM versions / blockchain

- IFC (Industry Foundation Classes)
  - The best open BIM standard
  - STEP (Standard for the Exchange of Product Data) format
  - Clear, readable
  - But massive, involving many random global IDs
- Our in-house program for the semantic difference

procedure compute_SDT

input: ifc_0, ifc_1 // IFC changed between t_0 and t_1

$\sigma_0 \leftarrow$ semantic_interoperability (ifc_0); // To call "semantic interoperability"

$\sigma_1 \leftarrow$ semantic_interoperability (ifc_1);

$\sigma^* \leftarrow \sigma_0 \cap \sigma_1$; // The intersection (unchanged) tree

$\sigma_{0c} \leftarrow \sigma_0 - \sigma^*$; // To purge the unchanged instances

$\sigma_{1c} \leftarrow \sigma_1 - \sigma^*$;

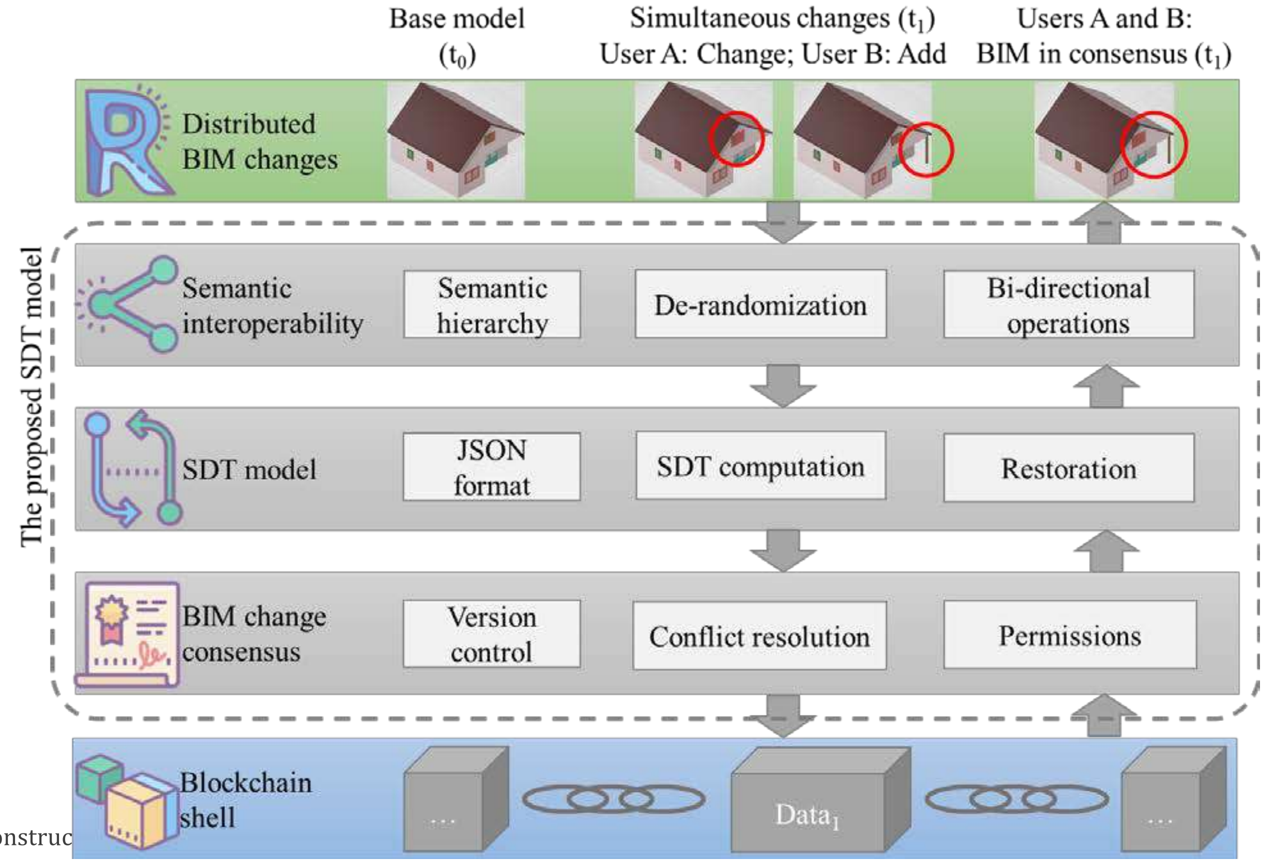
$\Delta_\sigma \leftarrow$ tree_diff (σ_{0c}, σ_{1c}); // Difference between changed objects

return Δ_σ

Example IFC

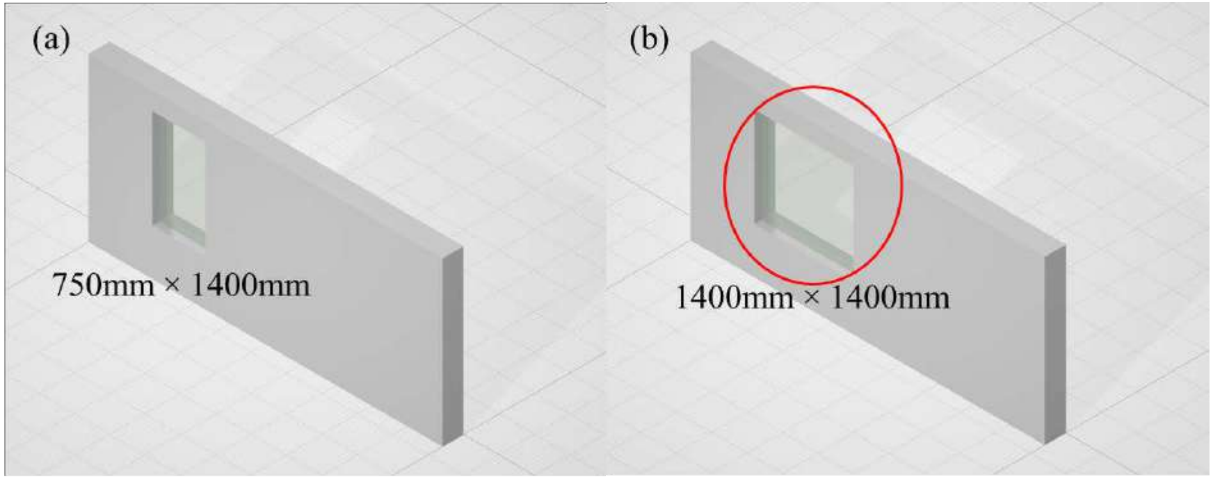
```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION(('ViewDefinition [CoordinationView, …);
FILE_NAME('example.ifc','2008-08-01T21:53:56',('Architect…);
FILE_SCHEMA(('IFC2X3'));
ENDSEC;
DATA;
#1=IFCOWNERHISTORY(#84,#71,$,.ADDED.,$,$,$,1217620436);
#2=IFCAXIS2PLACEMENT3D(#11,#4,#8);
#3=IFCCARTESIANPOINT((0.0,0.0));
#4=IFCDIRECTION((0.0,0.0,1.0));
#5=IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,1.0E-5,#75,$);
#6=IFCWALLSTANDARDCASE('3vB2YO$MX4xv5uCqZZG05x',#1,'Wall …);
#7=IFCWINDOW('0LV8Pid0X3IA3jJLVDPidY',#1,'Window xyz','…);
#8=IFCDIRECTION((1.0,0.0,0.0));
#9=IFCOPENINGELEMENT('2LcE70iQb51PEZynawyvuT',#1,'Opening …);
#10=IFCCARTESIANPOINT((0.75,0.0));
# 11 =IFCCARTESIANPOINT((0.0,0.0,0.0));
#12=IFCCARTESIANPOINT((0.0,0.3));
#13=IFCORGANIZATION($,'TNO','TNO Building Innovation',$,$);
#14=IFCPROPERTYSINGLEVALUE('AcousticRating','AcousticRating',…);
#15=IFCPROPERTYSINGLEVALUE('Reference','Reference',IFCTEXT(''),$);
#16=IFCPROPERTYSINGLEVALUE('FireRating','FireRating',IFCTEXT(''),$);
#17=IFCPROPERTYSINGLEVALUE('IsExternal','IsExternal',IFCBOOLEAN(.T.),$);
#18=IFCPROPERTYSINGLEVALUE('ThermalTransmittance',…);
#19=IFCQUANTITYLENGTH('Height','Height',$,1.4);
#20=IFCQUANTITYLENGTH('Width','Width',$,0.75);
#21=IFCLOCALPLACEMENT($,#2);
#22=IFCBUILDING('0yf_M5JZv9QQXly4dq_zvI',#1,'Sample Building',…);
#23=IFCBUILDINGSTOREY('0C87kaqBXF$xpGmTZ7zxN$',#1,…);
#24=IFCLOCALPLACEMENT(#21,#2);
…
END-ISO-10303-21;
```

2.2.4 Case 4: BIM versions / blockchain



2.2.4 Case 4: BIM versions / blockchain

- Result of changing a window (a) → (b); (c) the result of SDT

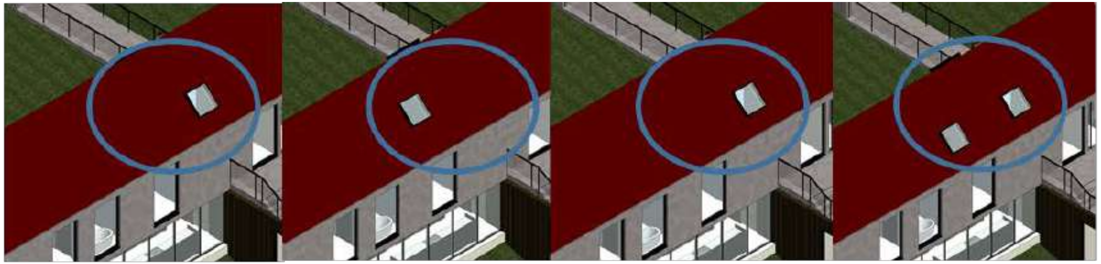


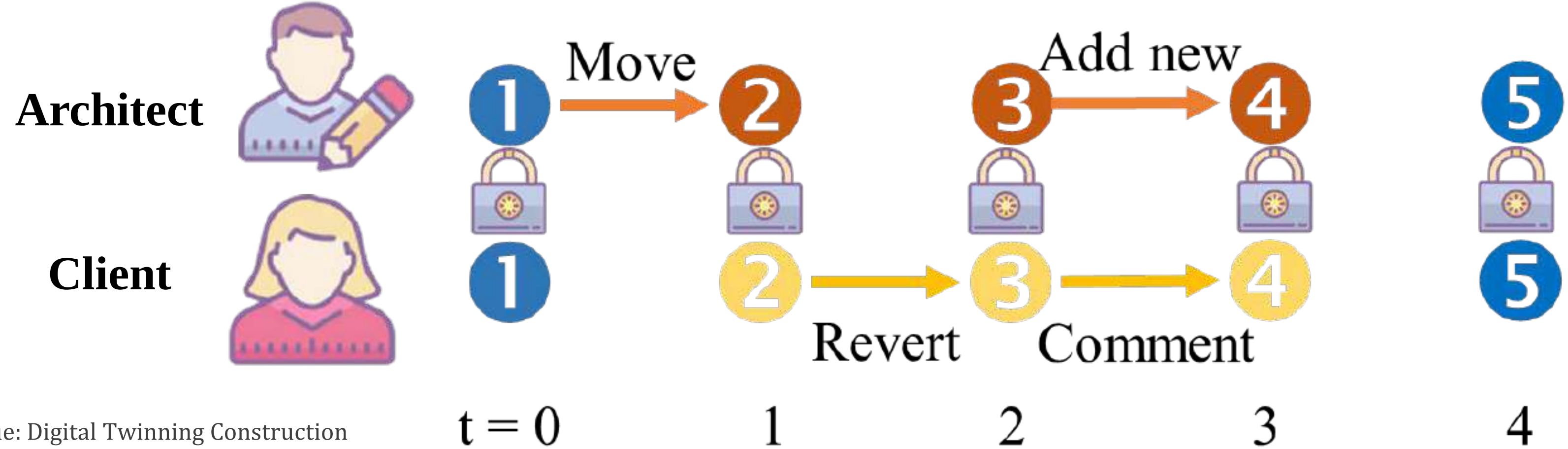
(c)


```
{
 'quantities': {
  'IfcElementQuantity': {
   '@id=0bB_7AP5v5OBZ90TDvo0Fo': {'IfcQuantityLength': {'@Name=Width': {'@LengthValue': ['0.75', → '1.4']}}},
   '@id=2yDPSWYWf319fWaWWvPxwA': {'IfcQuantityLength': {'@Name=Width': {'@LengthValue': ['0.75', → '1.4']}}}
  }
 },
 'decomposition': {
  'IfcProject': {'IfcSite': {'IfcBuilding': {'IfcBuildingStorey': {'IfcWindow': {'@OverallWidth': ['0.75', → '1.4']}}}}}
 }
}
```

2.2.4 Case 4: BIM versions / blockchain

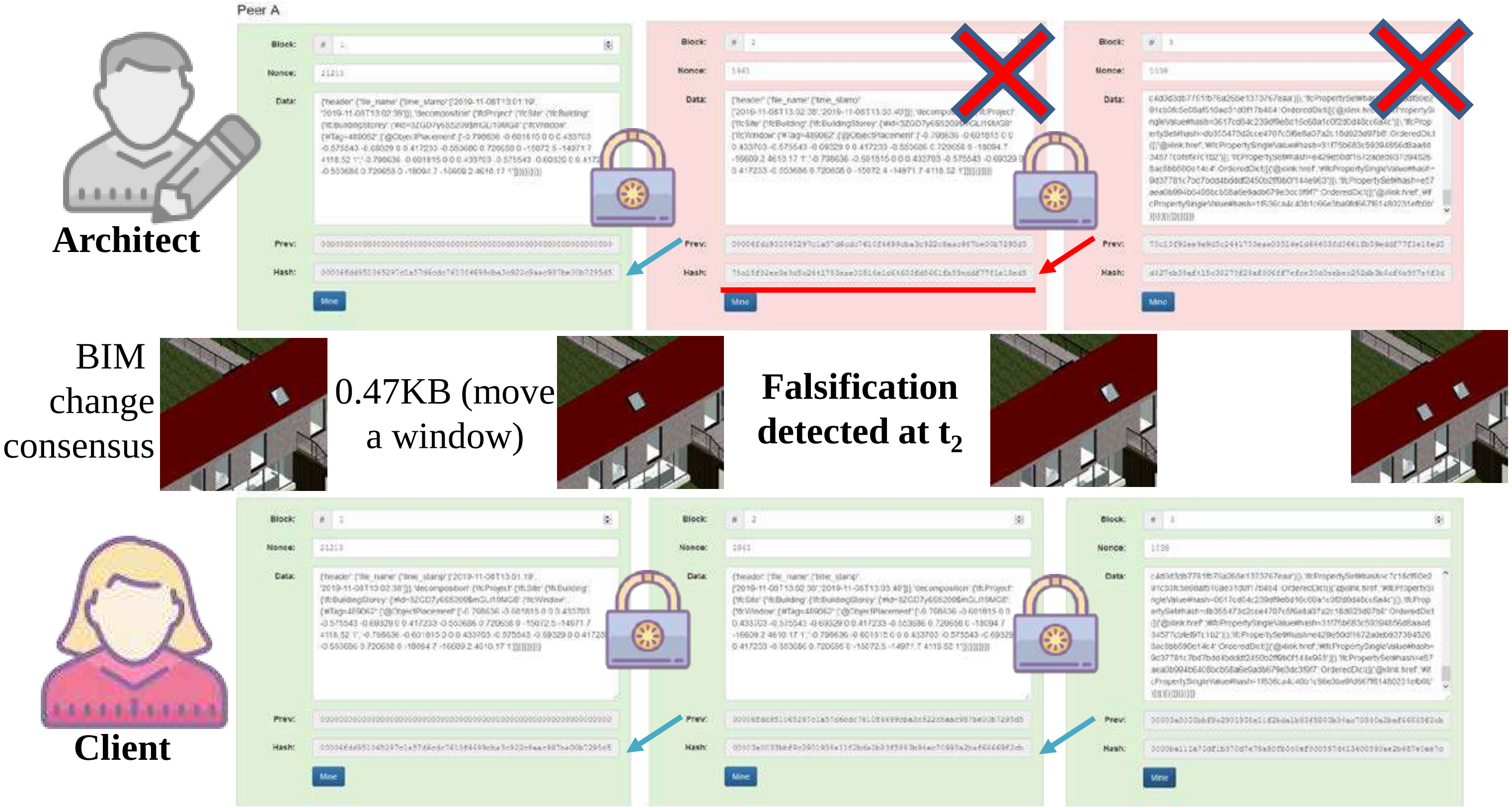
◈ A Case: Sequential / simultaneous roof window changes by two BIM users





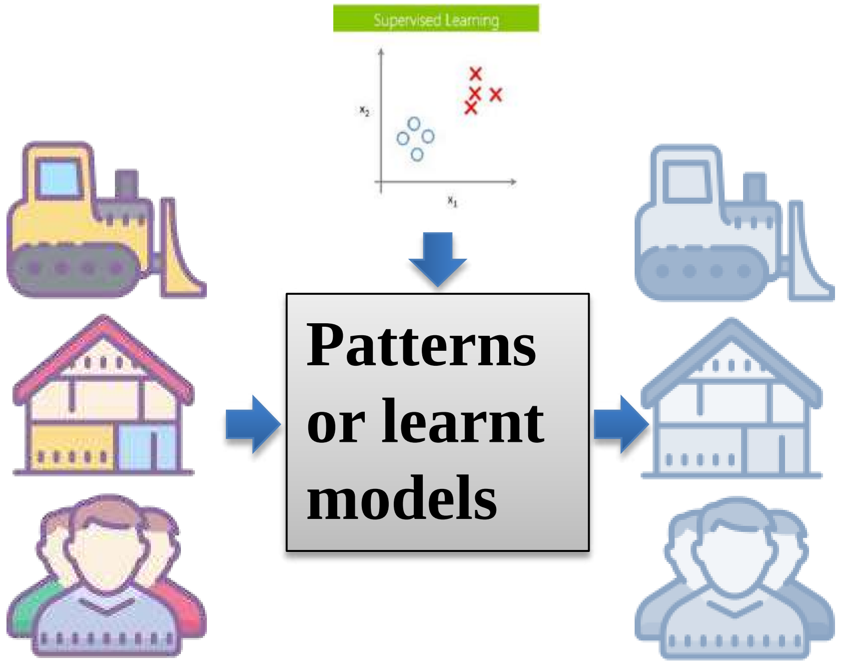
2.2.4 Case 4: BIM versions / blockchain

2.2.4 Case 4: BIM versions / blockchain



2.3 Supervised learning

- Filtering
  - “patterns” learnt from training data
  - See also: classification, regression, deep learning, prediction
- Pros
  - Generalized, many non-linear models
- Example cases
  - Pedestrian path walkability
  - Human pose and gesture
  - Street
  - Rooftop element classification

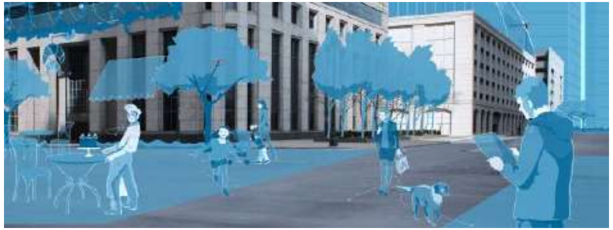


Physical world (construction)

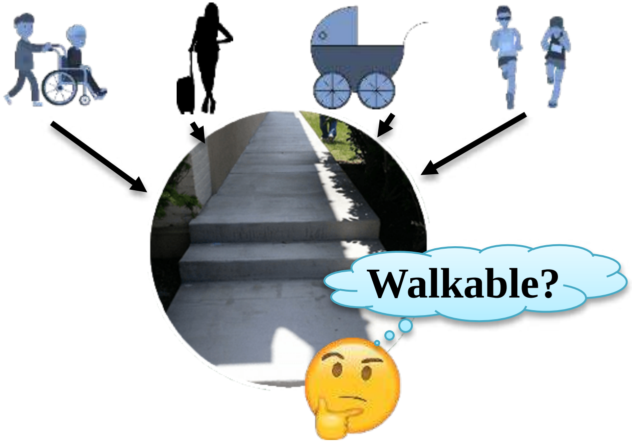
Cyber world (DT)

2.3.1 Case 1: Personalized walkability assessment

- Smart city development
  - Settled by the government of many modern cities
  - Over 200 cities in China
- Smart living/ transportation
  - *Aims at making life more efficient, more controllable, economical, productive, integrated and sustainable*
  - A pillar of smart city
- Personalized walkability
  - Meeting individual walking requirements of residents
  - Essential for smart living in smart cities
  - Demanding automatic (real-time, cheap) assessment
    - To handle the possible changes in paths

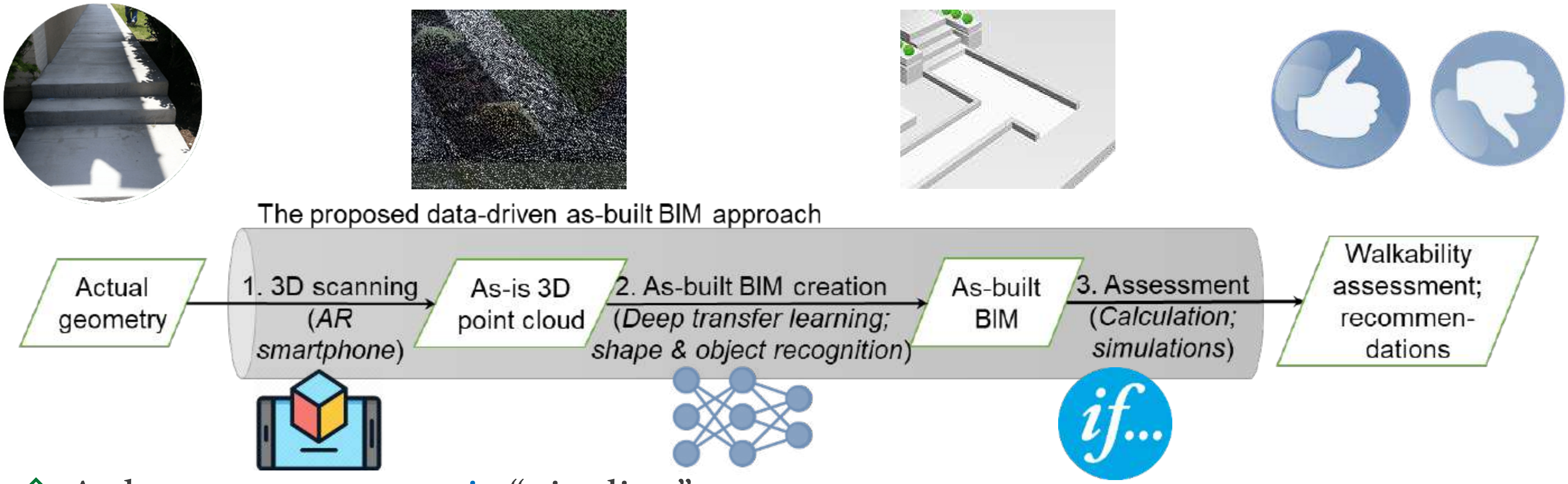


The rising of smart cities around the world
Source: siemens.com



Personalized walkability for smart living
Source: pixarba.com

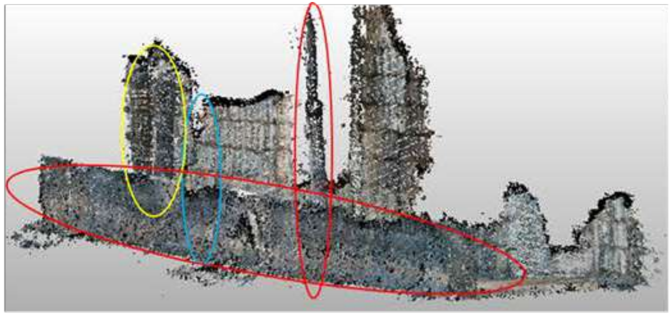
2.3.1 Case 1: Personalized walkability assessment



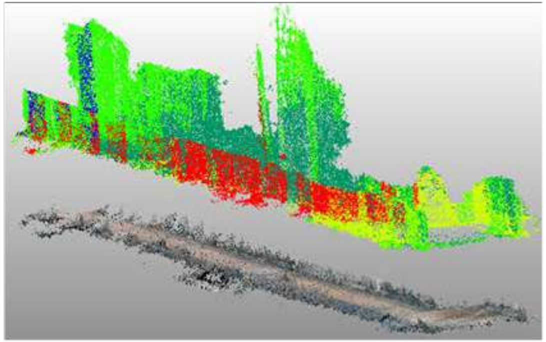
- A three-step automatic "pipeline"
  - 1. Actual path → As-is 3D point cloud
  - 2. As-is 3D point cloud → As-built BIM
  - 3. As-built BIM → PWA; recommendation

2.3.1 Case 1: Personalized walkability assessment

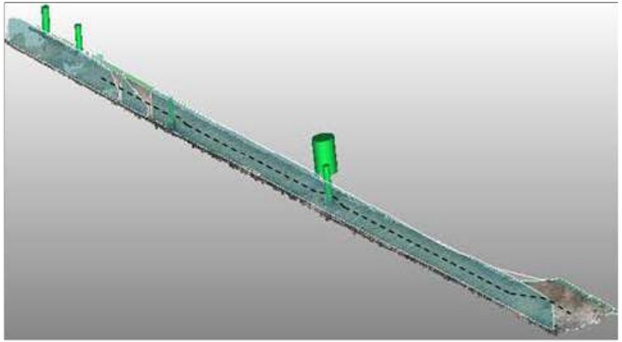
(a) A scene of Bonham Road, Hong Kong



(b) As-is cloud of 569,344 points through AR scanning



(a) 3D point classification (*e.g.*, the points labeled as "manmade terrain" were detached as the pavement)

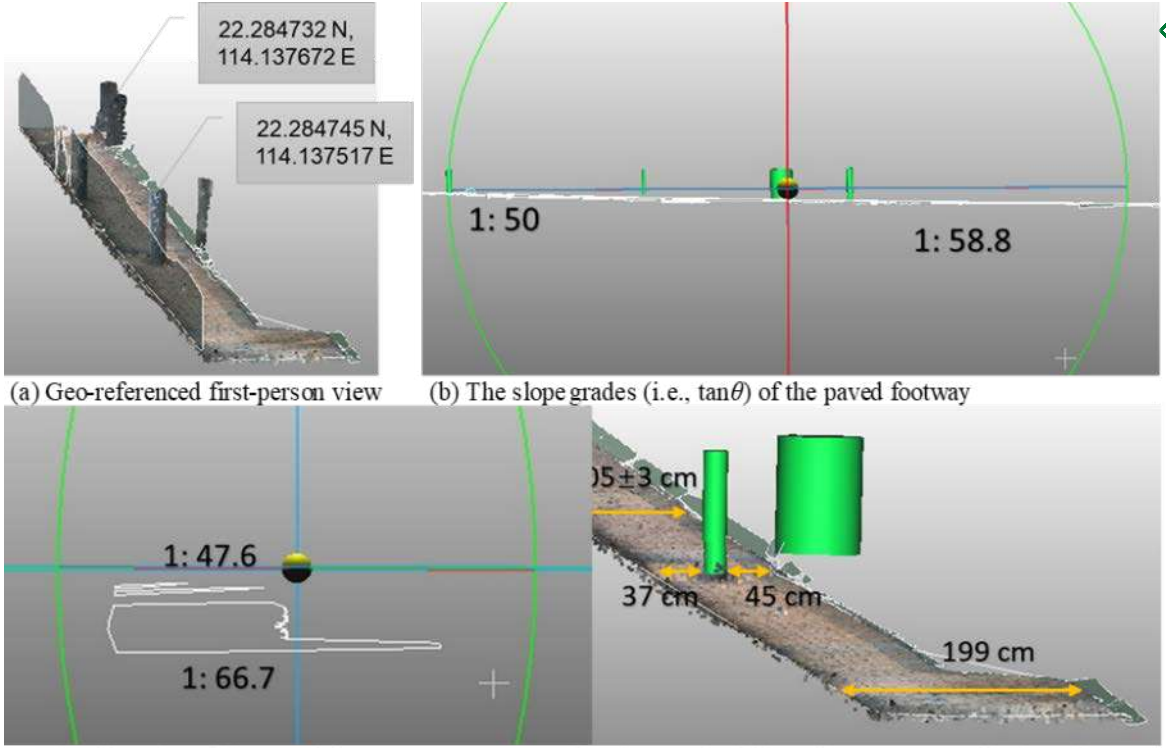


(b) As-built BIM consisting of semantic objects (walls omitted in this view)

(Xue et al. 2018)

- A narrow path
  - 1(a)
  - Guardrail
  - Obstacles
- 1: Phone scanning
  - 1(b) point cloud
- 2: As-built BIM
  - 2(a) segment
  - 2(b) modeling
  - 2(b) BIM

2.3.1 Case 1: Personalized walkability assessment



(a) Geo-referenced first-person view (b) The slope grades (i.e., $\tan\theta$) of the paved footway

(c) The tilt grades of the paved footway (d) The actual widths of the pavementwith obstacles

(Xue et al. 2018)

- 3: Assessment
  - 3(a) geo-referencing
  - 3(b) slope grade
  - 3(c) tilt grade
  - 3(d) footway width

2.3.1 Case 1: Personalized walkability assessment

Examples of five types of pedestrians

Walking characteristic	Calculated value	Type of pedestrians				
		Wheelchair	Stroller	Luggage	Senior	Exercise
No. of steps	0	OK	OK	OK	OK	OK
Slope grade*	1:50.0~58.8	OK	OK	OK	OK	OK
Tilt grade†	1:47.6~66.7	OK	OK	OK	OK	OK
Footway width‡	45~199 cm	**Failed**	Limited	Limited	OK	OK
Clearance	Good	OK	OK	OK	OK	OK
Overall walkability (the worst)		**Failed**	Limited	Limited	OK	OK

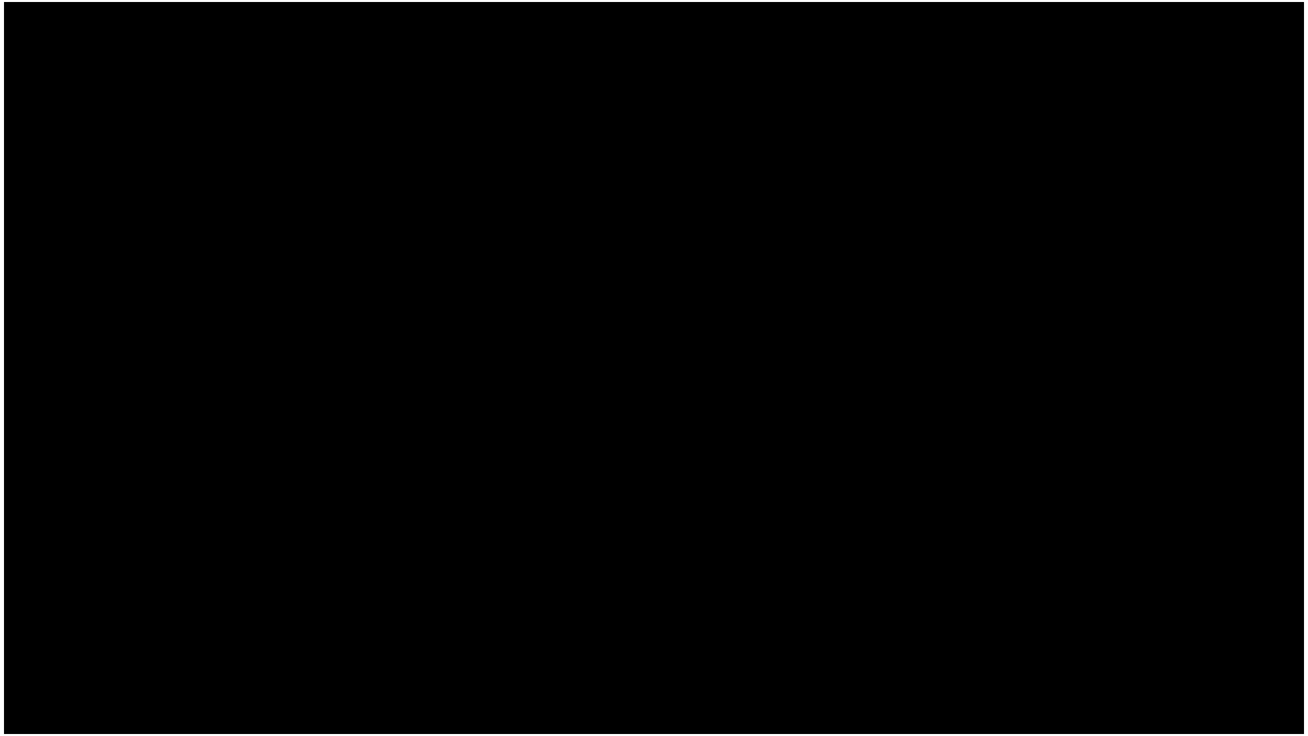
*: Reference maximum slope grade: 1:8~12 (wheelchairs);
†: Reference maximum tilt grade of pavement: 1:15 (wheelchairs);
‡: Reference minimum width: 70~90 cm (wheelchairs), 40~70 cm (strollers), and 30~60 cm (baggage).

Recommendation on possible obstacle removal

Major obstacles	Minor obstacles	Inoffensive obstacles
Light pole	(None)	Meter pole, drainage pipe #1, #2, and concrete trace on the wall

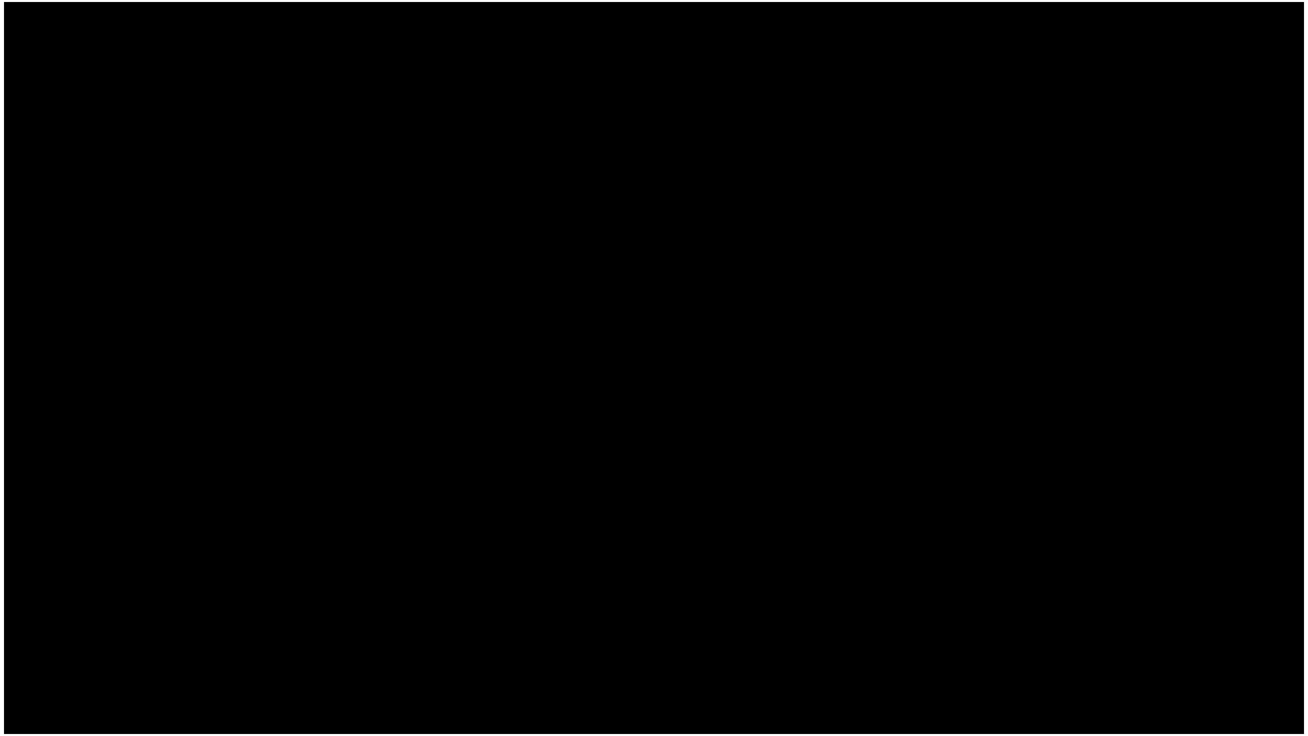
2.3.2 Case 2: Human pose and gesture (working)

- Edge AI device
  - Google Coral
  - TPU
- Unboxing test
  - PoseNet
  - Human pose
    - Multiple
    - 13 fps



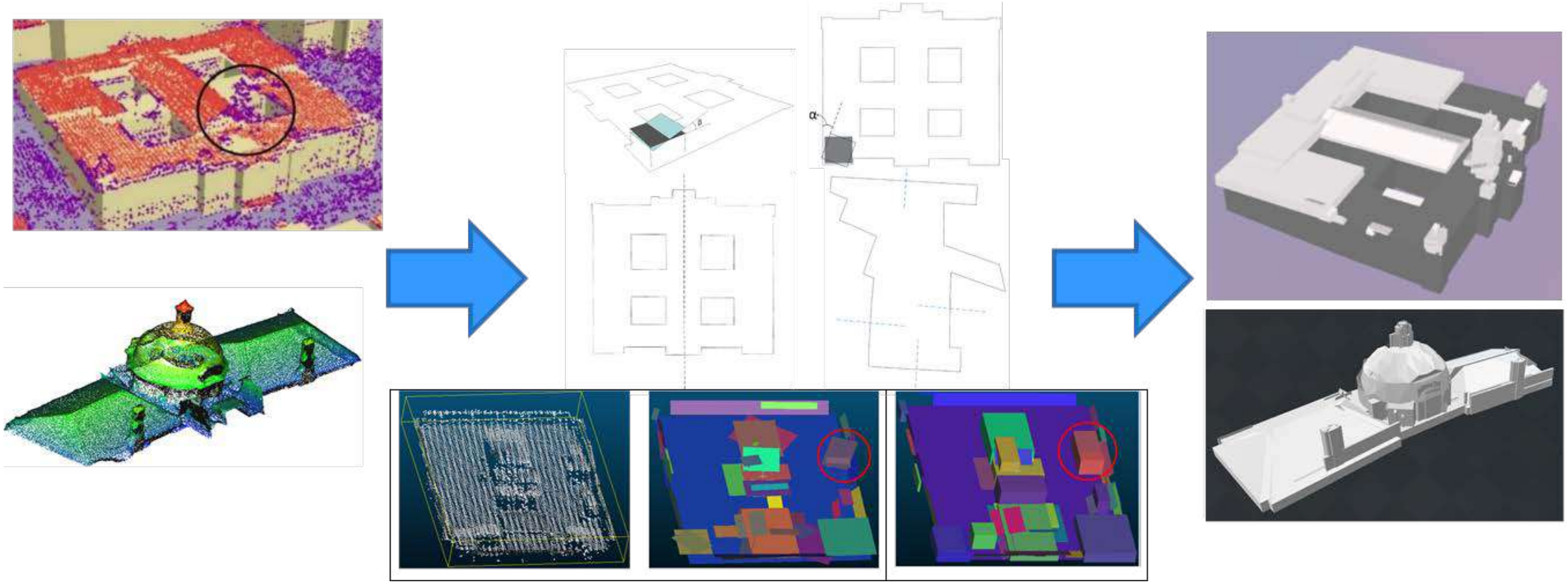
2.3.2 Case 2: Human pose and gesture

- Unboxing test
  - …
  - Looking around
    - good
    - 13 fps

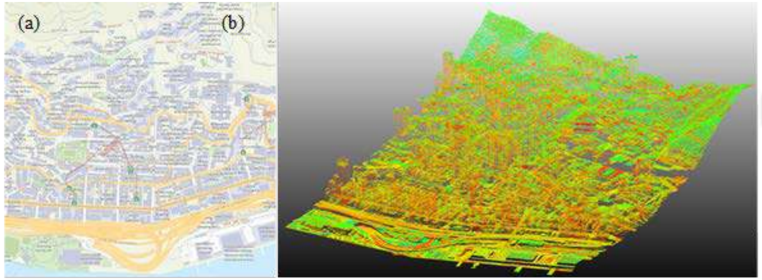


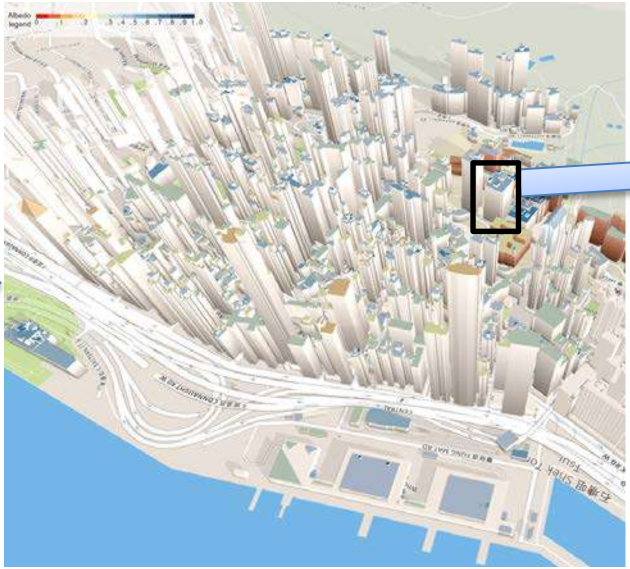
2.3.3 Case 3: Rooftop modeling (Chen et al. 2018)

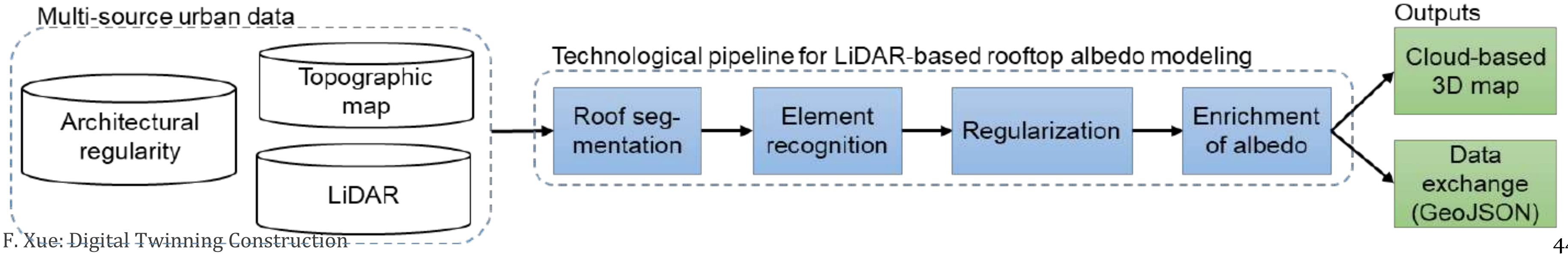
- LiDAR → RANSAC → rectification → LoD2 model



2.3.3 Case 3: Rooftop modeling (Xue et al. 2019f)

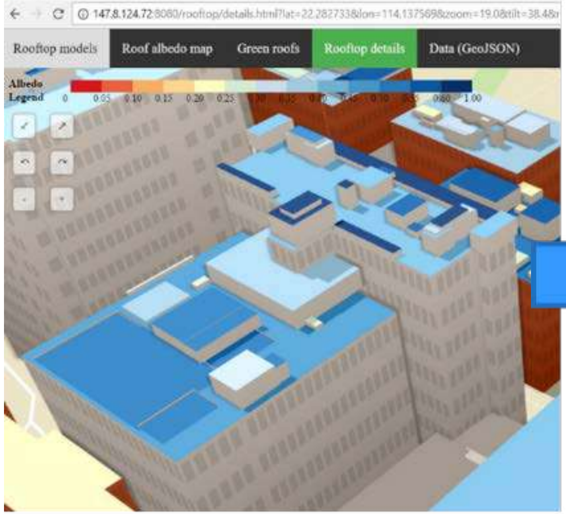




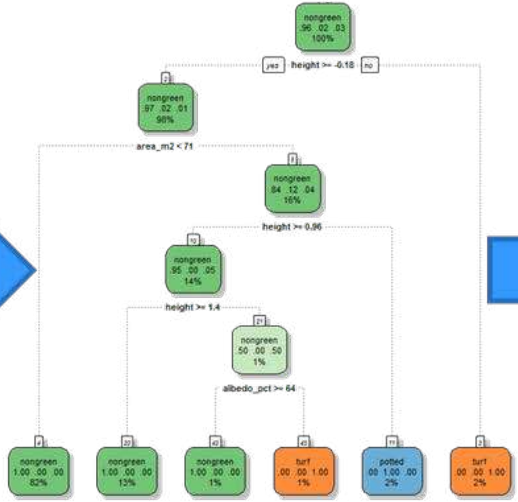


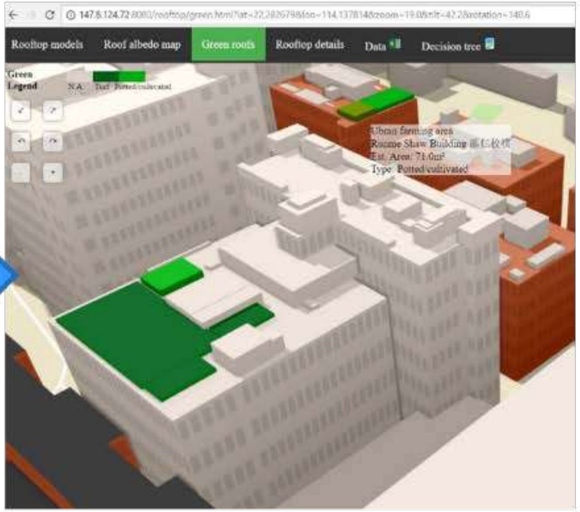
2.3.3 Case 3: Rooftop modeling (Xue et al. 2019e)

◈ Geometry + albedo → material prediction, e.g., green roofs (Tan et al. 2019)



Generated rooftop objects from point clouds

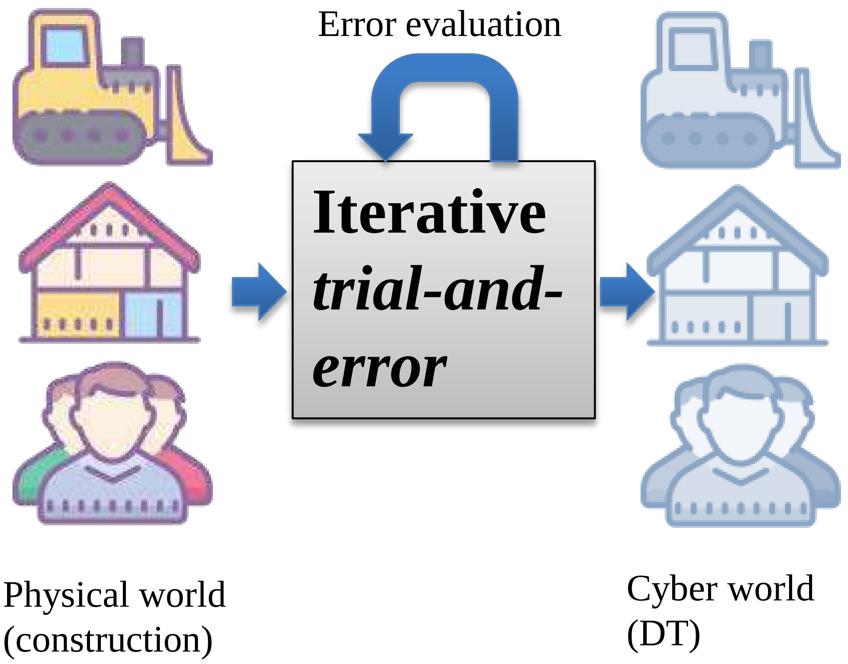




Identified green roof areas by machine learning

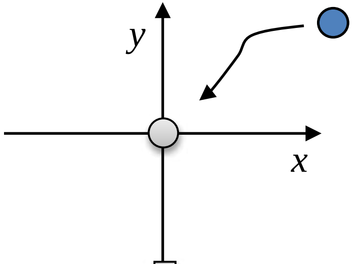
2.4 Reinforcement Methods

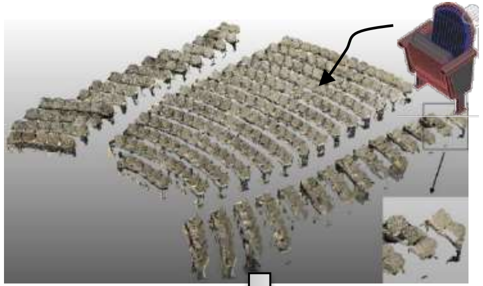
- Reinforcement learning
  - “Trial-and-error” to fit for an unknown problem
  - See also: AlphaGo, online learning,
- Pros
  - Adaptive, “white-box” style, easy to interpret
- Example cases
  - As-built BIM reconstruction
  - Furniture 3D reconstruction
  - Architectural regularity



2.4.0 Error / fitness function

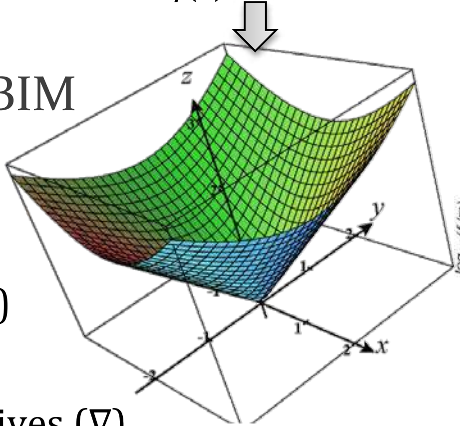
- Common in optimization problems
  - Find the best solution (e.g., min $f(x) = |\, x \,|$)
- Fitness landscape of error
  - Appearance of f
  - Peaks/valleys contain the solutions
    - Where gradient $\nabla f = 0$
- Fitness landscape for registering a BIM
  - Reflecting the geometric landscape
  - Many methods are not working
    - Up to 9 degree-of-freedoms (DoFs)
    - Continuous, jugged
    - Too expensive to calculate derivatives (∇)

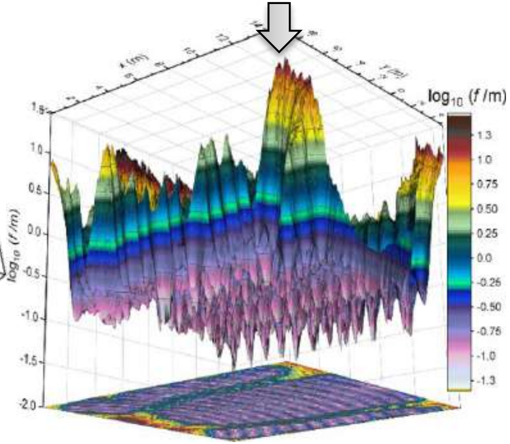




min $f(x)$ = *RMSE*

min $f(x)$ = *RMSE* …



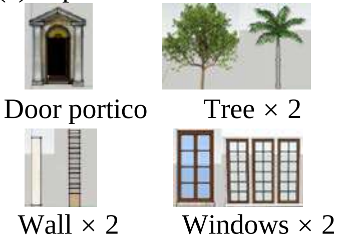


Fitness landscapes of registering BIM to 1 point (left) and real 3D point cloud (right)

3.4.1 Case 1: Building 3D reconstruction (Xue et al. 2018)

- 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



(b) Semantic components from web

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

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

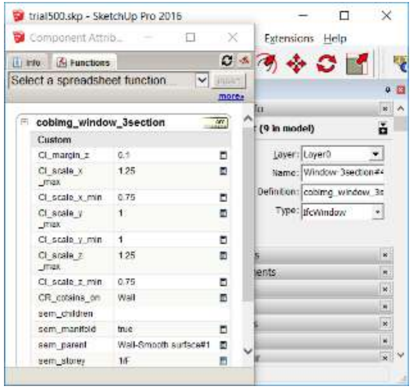
C	Example	Example value	Notes
	scaling_max	[1.5, 1.5, 1.5]	xyz coordinates
C_I	scaling_min	[0.8, 0.8, 0.8]	Ibid.
	z_rotation_max	π/2	
	z_rotation_min	0	
	on_top_of	‘Ground’	Adjacency, connectivity
C_R	contains_on	‘Wall’	Containment or intersection
	min_separation	‘0.5 m’	Separation

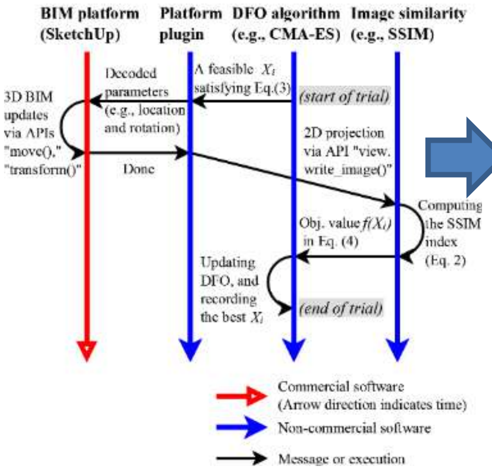
$$\text{maximize} \quad f(X) = SSIM$$
$$\text{subject to} \quad C(X) \leq 0.$$

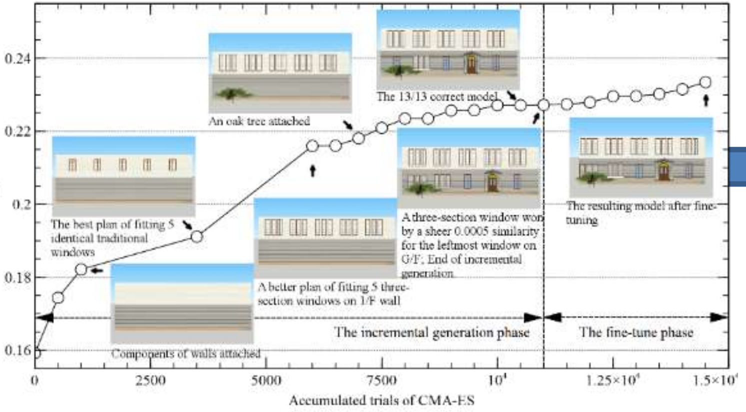
3.4.1 Case 1: Building 3D reconstruction

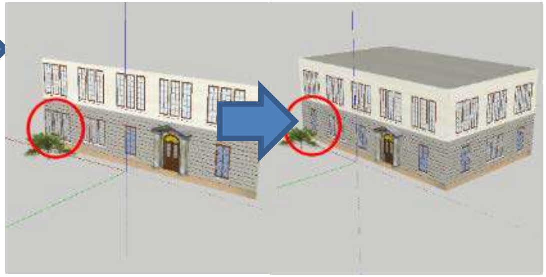
◈ Problem solving

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





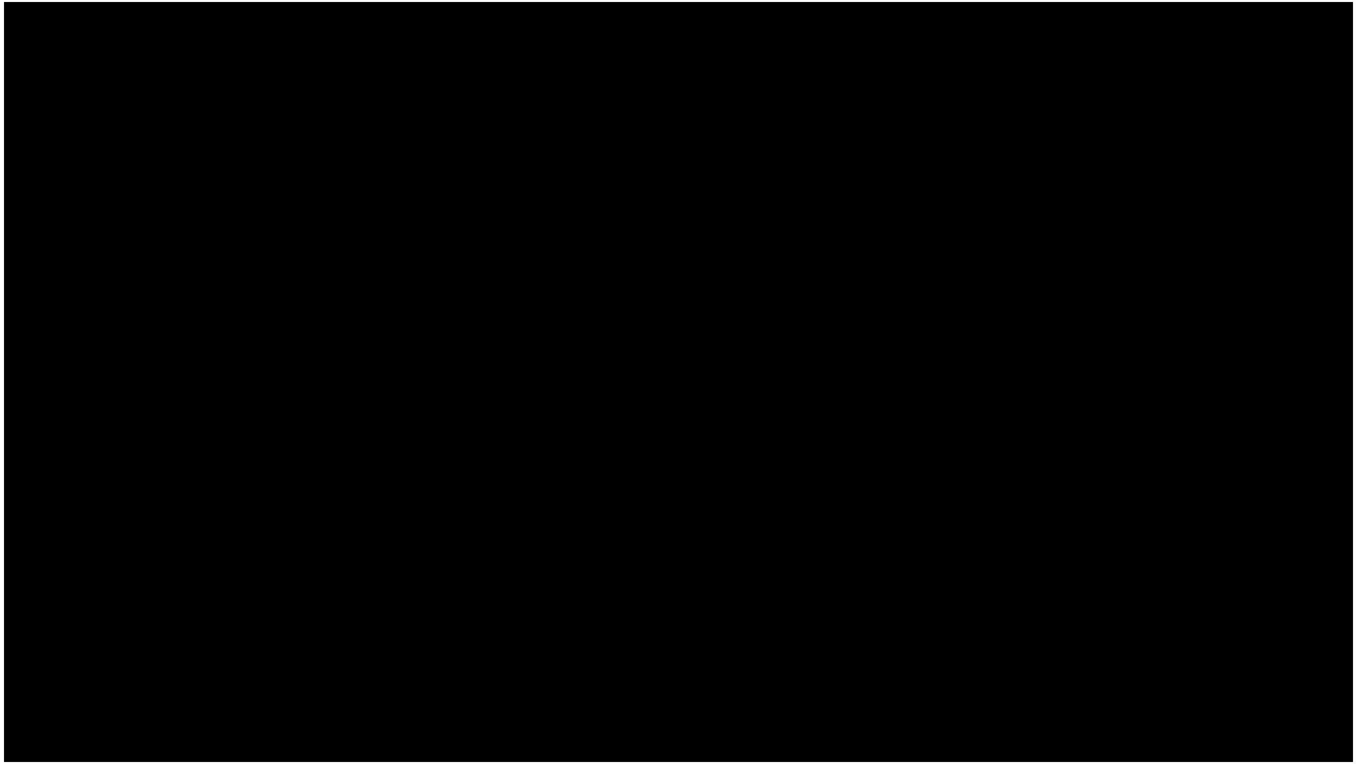




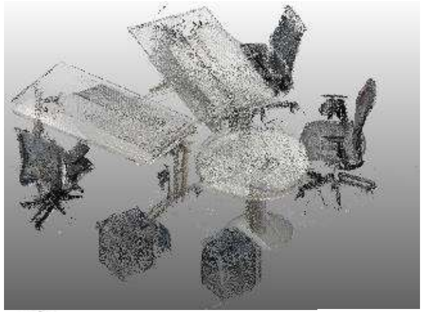
(Language: C++, Ruby; Data formats: SketchUp, Bmp, Google earth)

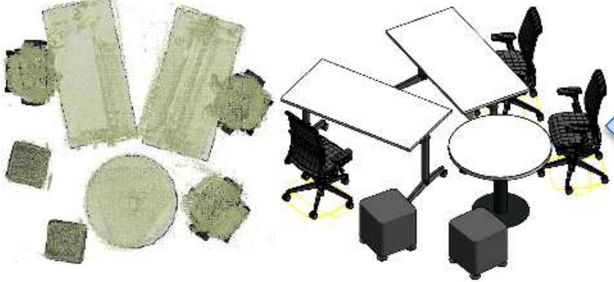
3.4.2 Case 2: Furniture modeling (Xue et al. 2019b)

- BIM from point cloud or 2D image
  - Automatic
  - Model-driven
  - Semantic
  - Accurate
  - Efficient



3.4.2 Case 2: Furniture modeling

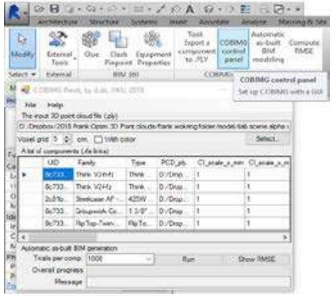


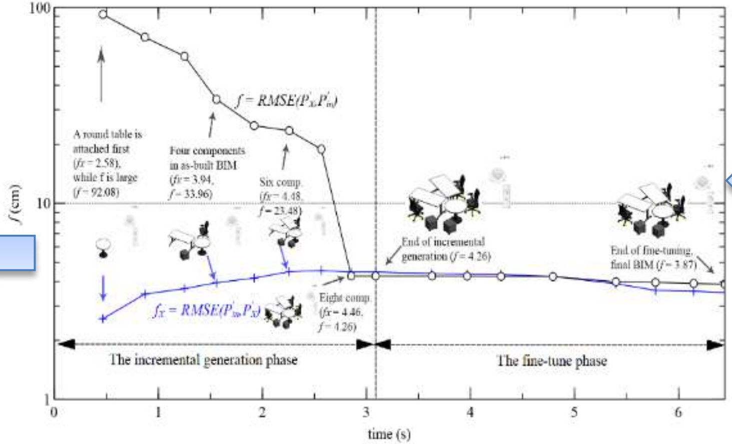


$$
\begin{aligned}
f(X) &= RMSE(BIM(X), P_{\text{in}}) \\
&\approx RMSE(P_X, P_{\text{in}}) \\
&\approx RMSE(P'_X, P'_{\text{in}}) \\
&= \sqrt{\Sigma_{p \in P'_{\text{in}}} nndist^2(p, P'_X)/m'} \\
&\approx RMSE(P'_{\text{in}}, P'_X) \\
&= \sqrt{\Sigma_{p \in P'_X} nndist^2(p, P'_{\text{in}})/\|P'_X\|}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

- t = 6.44 s
- RMSE = 3.87 cm

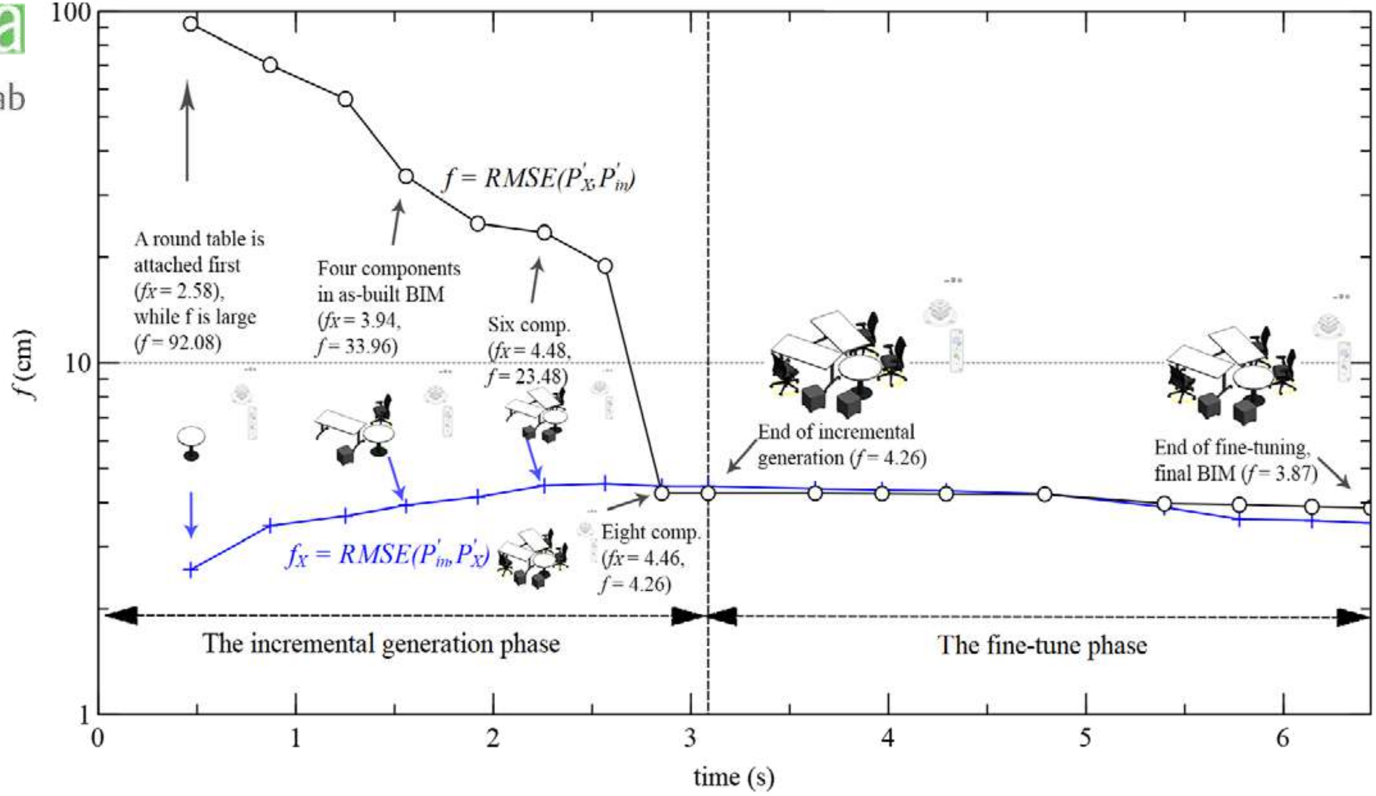
$$
\begin{aligned}
&\text{minimize} && f(X) = RMSE(BIM(X), P_{in}) \\
&\textit{subject to} && C(X) \le 0.
\end{aligned}
$$





(Xue et al. 2019)

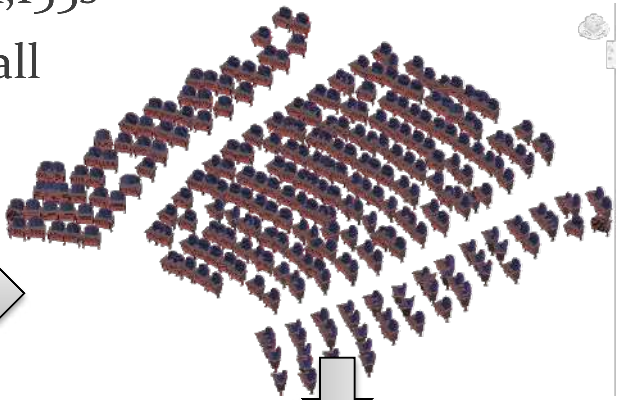
3.4.2 Case 2: Furniture modeling

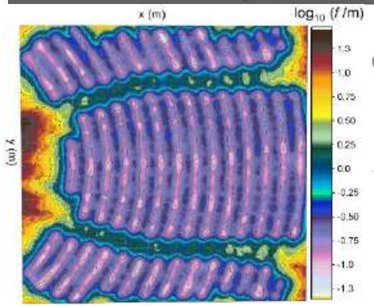


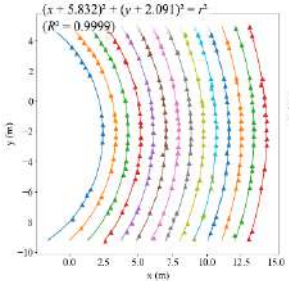
- T=6.44s
  - Manual = 330s
- Iter = 9,000
- Precision = 1.0
- Recall = 1.0

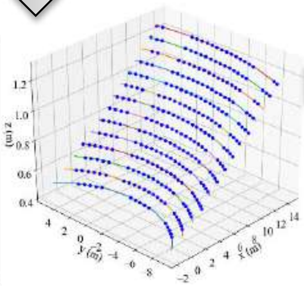
3.4.3 Case 3: Furniture modeling (more chairs) (Xue et al. 2019c)

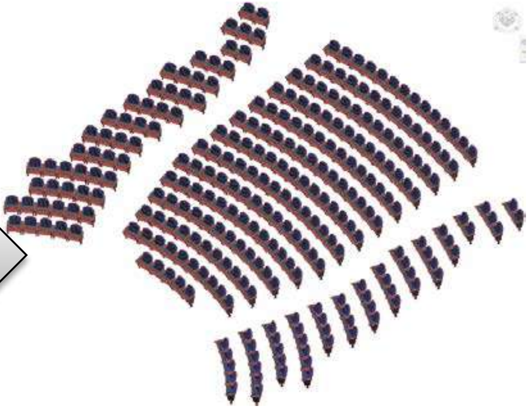
- RMSE= 8.97cm, time = 1,155s
- 99% precision, 98% recall



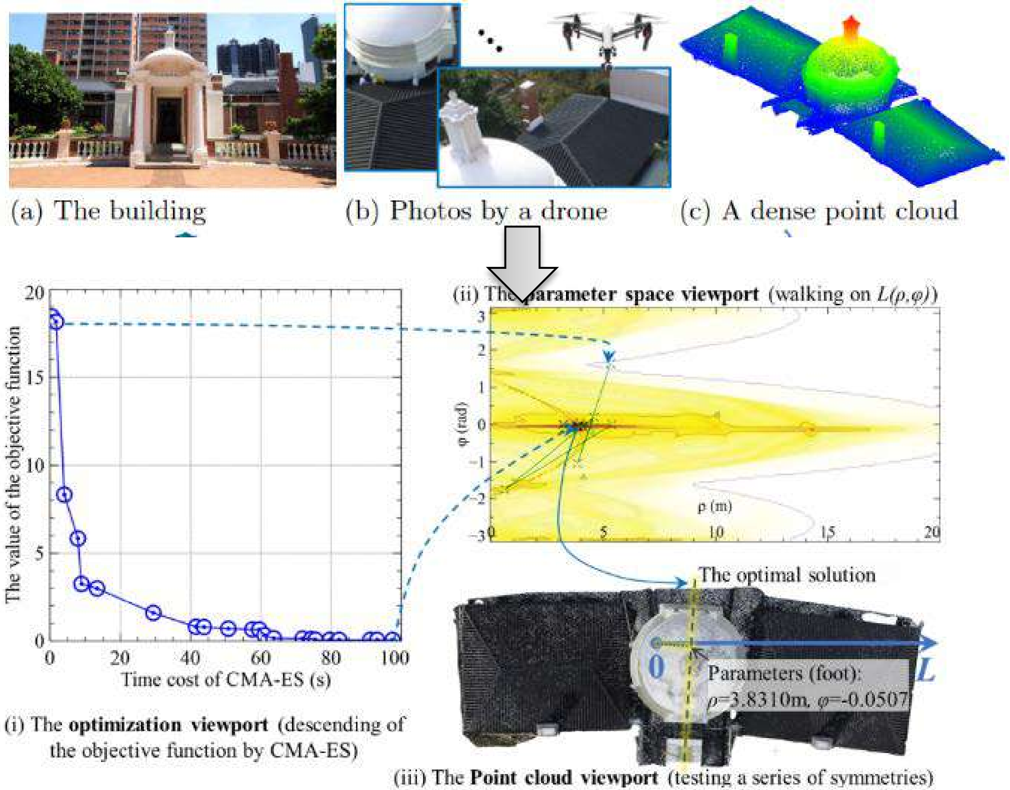


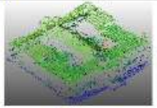
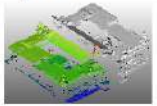
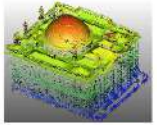
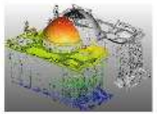
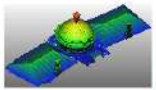
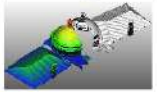
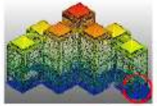
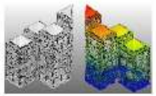
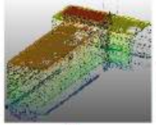
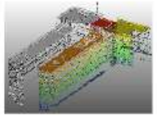
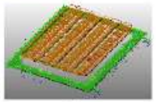
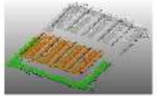
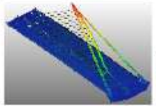
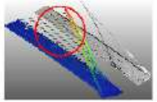






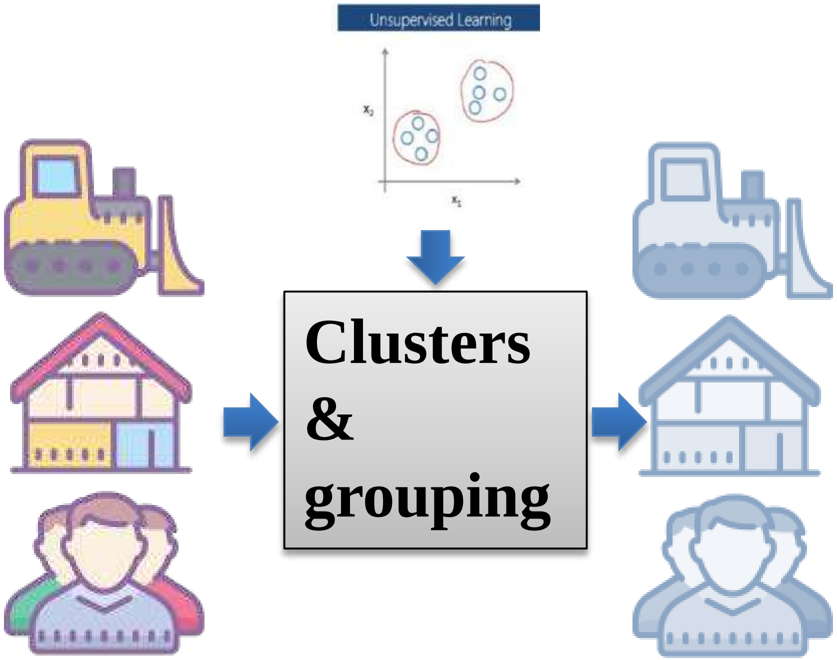
3.4.4 Case 4: Architectural Regularity (Xue et al. 2019a; 2019d)



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

2.5 Unsupervised learning

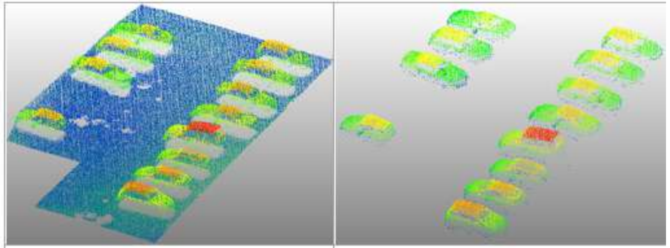
- Unsupervised learning
  - Self-organized, previously unknown patterns
  - See also: *K*-means, anomaly detection, latent variable models
- Pros
  - Inexpensive, human readable
- Examples
  - Object detection in points
  - Street clusters
  - Pedestrian clusters



Physical world (construction)

Cyber world (DT)

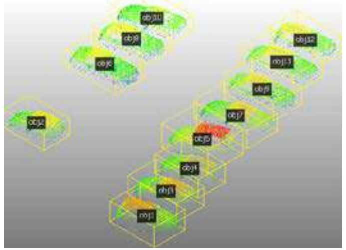
2.5.1 Case 1: Object detection in points (Xue et al. 2019)



(a) A point cloud of car park scene (112,999 points, 6.78MB) (color indicates height)

(b) The cloud (24,126 points, 1.31MB) after a preprocess of ground (planar) removal

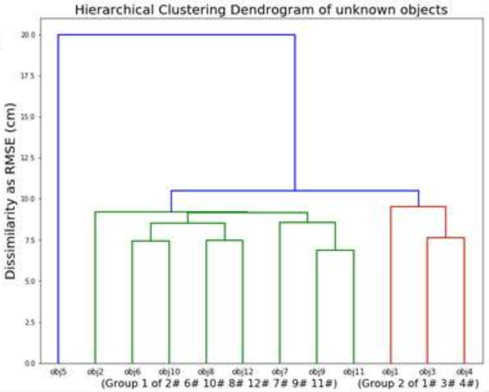
(a) 368 small patches (by color) and the connectivity (lines) detected in 1.3s



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

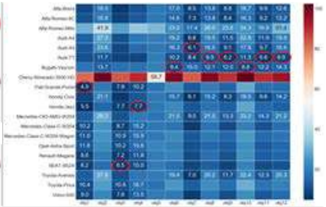
	obj1	obj2	obj3	obj4	obj5	obj6	obj7	obj8	obj9	obj10	obj11	obj12
obj1	0.0	16.6	9.5	9.5	20.0	19.1	15.2	17.3	14.1	19.0	15.4	14.8
obj2	16.6	0.0	14.8	10.7	36.0	16.0	22.6	12.0	15.9	16.7	18.7	9.2
obj3	9.5	14.8	0.0	7.6	25.6	16.0	11.1	13.8	10.5	16.1	12.1	12.3
obj4	9.5	10.7	7.6	0.0	27.5	17.4	16.8	13.6	13.5	17.3	15.7	10.9
obj5	20.0	36.0	25.6	27.5	0.0	24.1	22.3	22.8	21.6	22.8	21.1	23.7
obj6	19.1	16.0	16.0	17.4	24.1	0.0	13.3	8.5	10.2	7.4	9.1	11.7
obj7	15.2	22.6	11.1	16.8	22.3	13.3	0.0	13.1	8.6	13.6	8.6	12.4
obj8	17.3	12.0	13.8	13.6	22.8	8.5	13.1	0.0	10.9	9.7	10.8	7.5
obj9	14.1	15.9	10.5	13.5	21.6	10.2	8.6	10.9	0.0	11.9	6.9	9.7
obj10	19.0	16.7	16.1	17.3	22.8	7.4	13.6	9.7	11.9	0.0	12.9	16.3
obj11	15.4	18.7	12.1	15.7	21.1	9.1	8.6	10.8	6.9	12.9	0.0	10.0
obj12	14.8	9.2	12.3	10.9	23.7	11.7	12.4	7.5	9.7	16.3	10.0	0.0

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

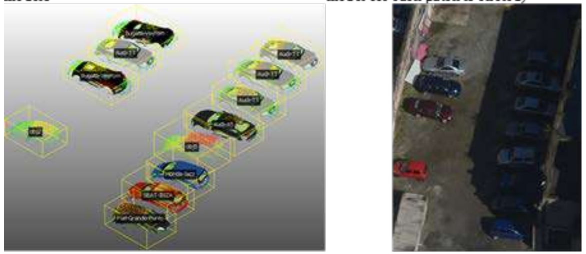


(b) Hierarchical clusters of similar patches (grouping threshold = 10cm)

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

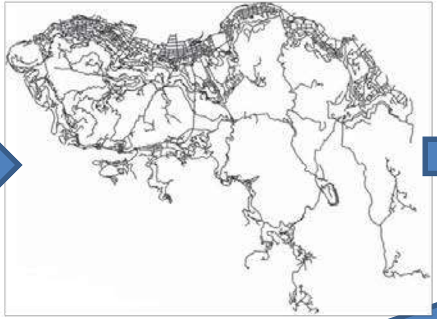


(b) The dissimilarity matrix (unit = cm, best model for each patch is circled)

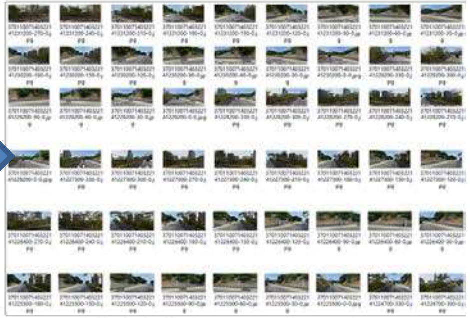


2.5.2 Case 2: Street clusters (working)

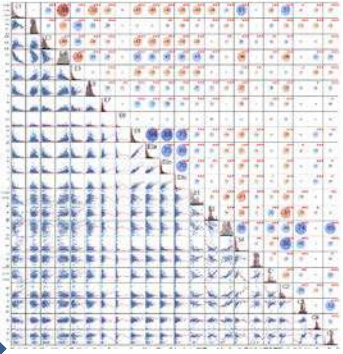
The Hong Kong Island



600 km road network



530,000 street view photos (48GB, source: Tencent)

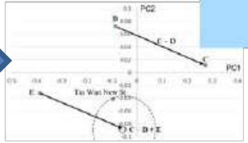


Semantic segmentation by CNN (12days)

Object recognition by RNN (11days)

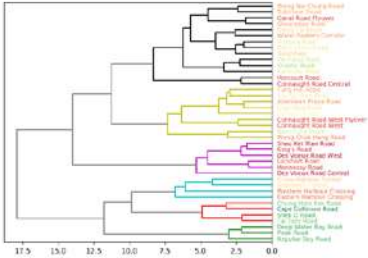
Census data (geocoded)

"Queen's Rd West – Central Western + South = ???"



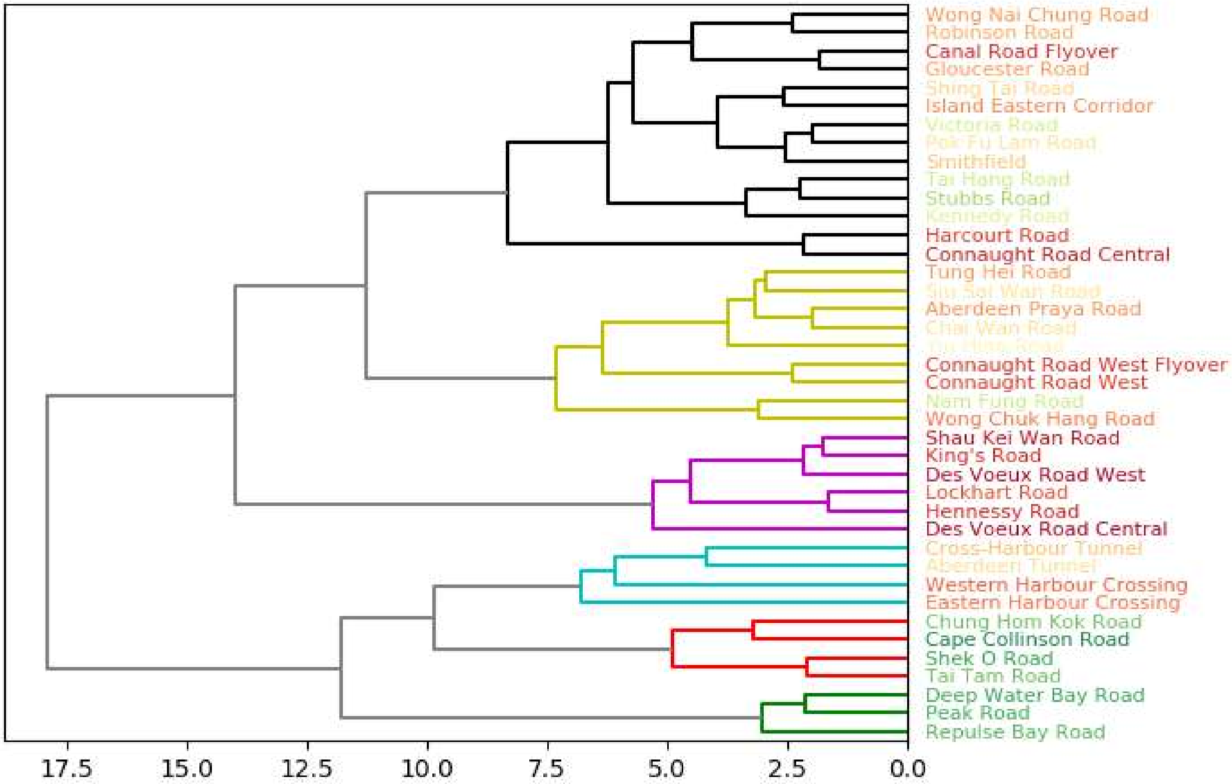
High-dimension (~17D) vector models for HK

Urban Big Data Platform (UBDP)



2.5.2 Case 2: Street clusters

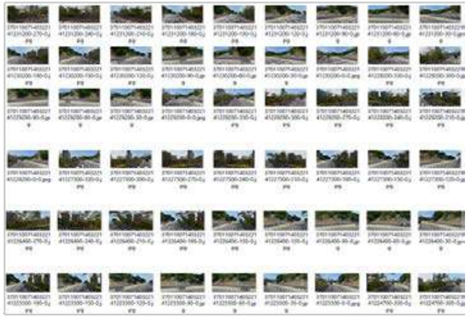
iLab



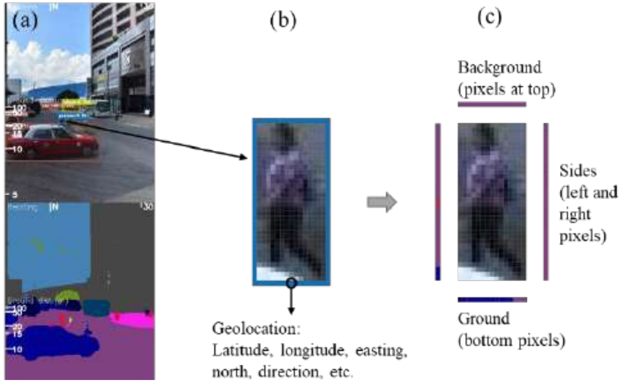
- "Closeness" between the 50 longest roads in Hong Kong
  - 21 dimensions
    - Environment
    - Economy
    - Society
  - 6 clusters
  - Text color: Green view

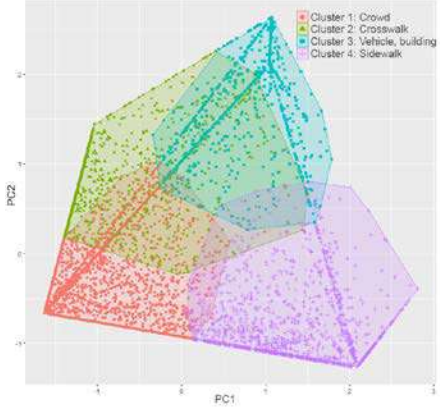
2.5.3 Case 3: Pedestrian clusters (working)

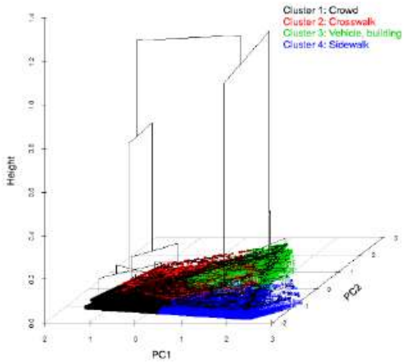
- 61,788 pedestrians
  - Seen in Hong Kong Island
- Four clusters
  - In a crowd
  - On crosswalk
  - In vehicles, buildings
  - On sidewalk



530,000 street view photos
(48GB, source: Tencent)







Section 3

DISCUSSION

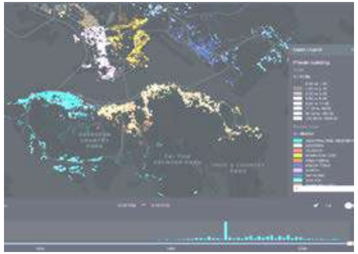
3.1 A wrap-up

- Construction IT
  - My work in recent 3 years
- DTCO = Real-time virtual replica
  - Aka. *n*D geometry modeling + semantics modeling in CAx/BIM
  - For all types of construction objects
    - Building
    - Equipment
    - Human
  - Involving various methods, as in 4 groups in ML's perspective
    - Filtering
    - Supervised
    - Reinforcement
    - Unsupervised

3.2 Possible research collaborations

- Possibility within REC's clusters
  - CLIPE
    - Conservation ✓
      - Digital conservation
    - Law
    - Innovation bld. tech. ✓ ✓
      - CAx / BIM / DT
      - IoT, AI
    - Project management ✓ ✓
      - Site safety
      - Operations management
    - Economics ✓
      - Valuation, prediction

25-year estate price "disco"

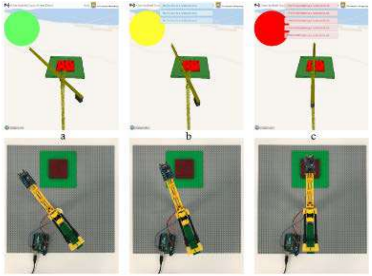


40,000 private buildings

3.3 Teaching Construction IT at REC

- My teaching
  - UG
    - RECO 3032: 1 talks
  - TPg
    - RECO 6004: 1.5 talks
- Incoming
  - TPg
    - RECO xxxx: 2-3 talks: On new advances (DT/AIR)
- Something in my mind
  - UG
    - A “Construction IT” course: On basic CAx, or playful techy

      E.g., “Introduction” (Yr2), or Elective (Yr3/4)



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    - Prof Chris Webster
    - Prof KW Chau
    - Alain, Guibo, Matthew,
- Some materials were from
  - Colleagues
  - My course materials

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Thank you!

Q&A plz