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

Hong Kong Alliance of Built Asset & Environment Information Management Associations 香港建設資產及環境信息管理聯盟

buildingSMART Hong Kong

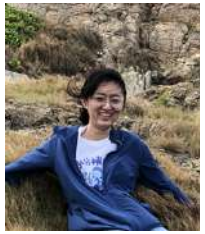
iLab @ HKURBAN lab the urban big data lab

HKABAEIMA Training Class 51

Low-cost Digital Twins of Built Assets

Automatic creation of photo-realistic openBIM by integrating ubiquitous Augmented Reality and 2D CAD drawings

12/10/2022



Yijie WU

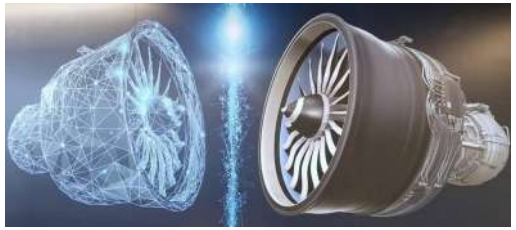
Lingming KONG

Fan (Frank) XUE

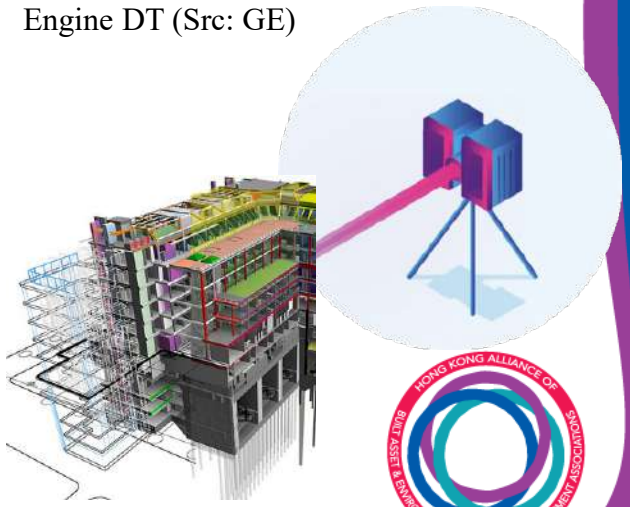
Dept. REC, Faculty of Architecture, HKU

1 Background & challenges

- Digital Twin (DT)
  - is “digital replica of a physical object”
    - Real geometry, current texture, functions (regularly updated)
    - A US$ 3 billion global market in 2020 (yearly growth at 58%)
  - Featured with 1) reality, 2) simulations, 3) optimization
  - Highly demanded for building assets in the AECO sector
- Challenges against DTs of building assets
  - Devices/data collection
    - Expensive LiDAR, drones, slow collection, incomputable data
    - As-designed BIM (no real textures)
  - Processing for reality
    - 3D Modeling: Intensive manual effort
  - Simulations & optimization: largely uncharted area

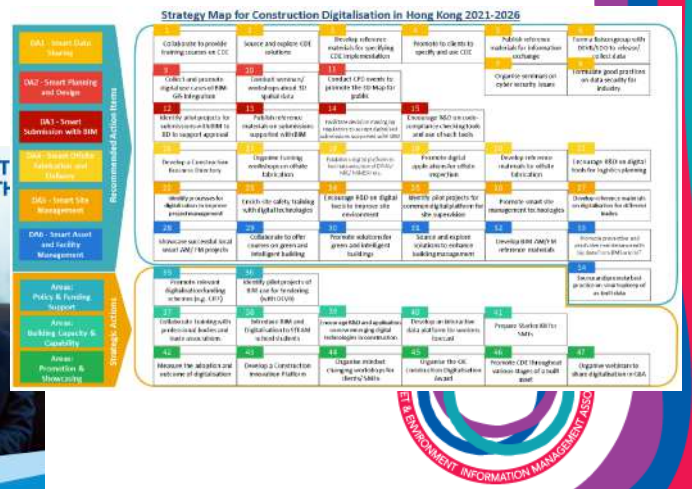


Engine DT (Src: GE)



1 DTs aspired in national and local guidelines

- 國家自然資源部 (MNR, 2022)
  - 《关于全面推进实景三维中国建设的通知》
  - ‘Real 3D China’ for all 15 sub-provincial cities by 2027/32
    - “For >80% decision making”
- CIC’s (2021) Const. Digital. Roadmap
  - DA 1/4/5/6
  - Digital scans for pre-2010 assets
  - Realtimelize as-designed BIM/CAD
- Manifesto of CE’s Election (2022)

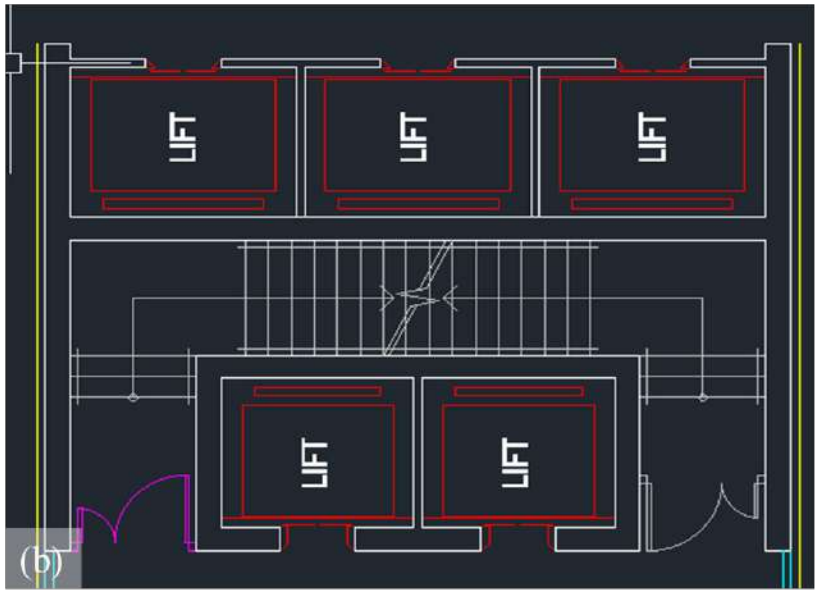


2. Opportunities: Augmented Reality (AR) and CAD

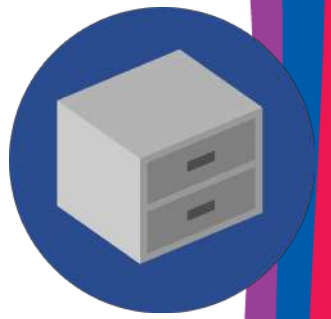
As-is AR scan data

✓Rich in details and 3D appearance (***texture***)
✓Consistent with the real 3D layouts (***z***)
✓Low-cost, ubiquitous, easy to use
✗A lot of defects, e.g., sparse, noisy, and misaligned
✗Massive size on disk

As-designed CAD drawing



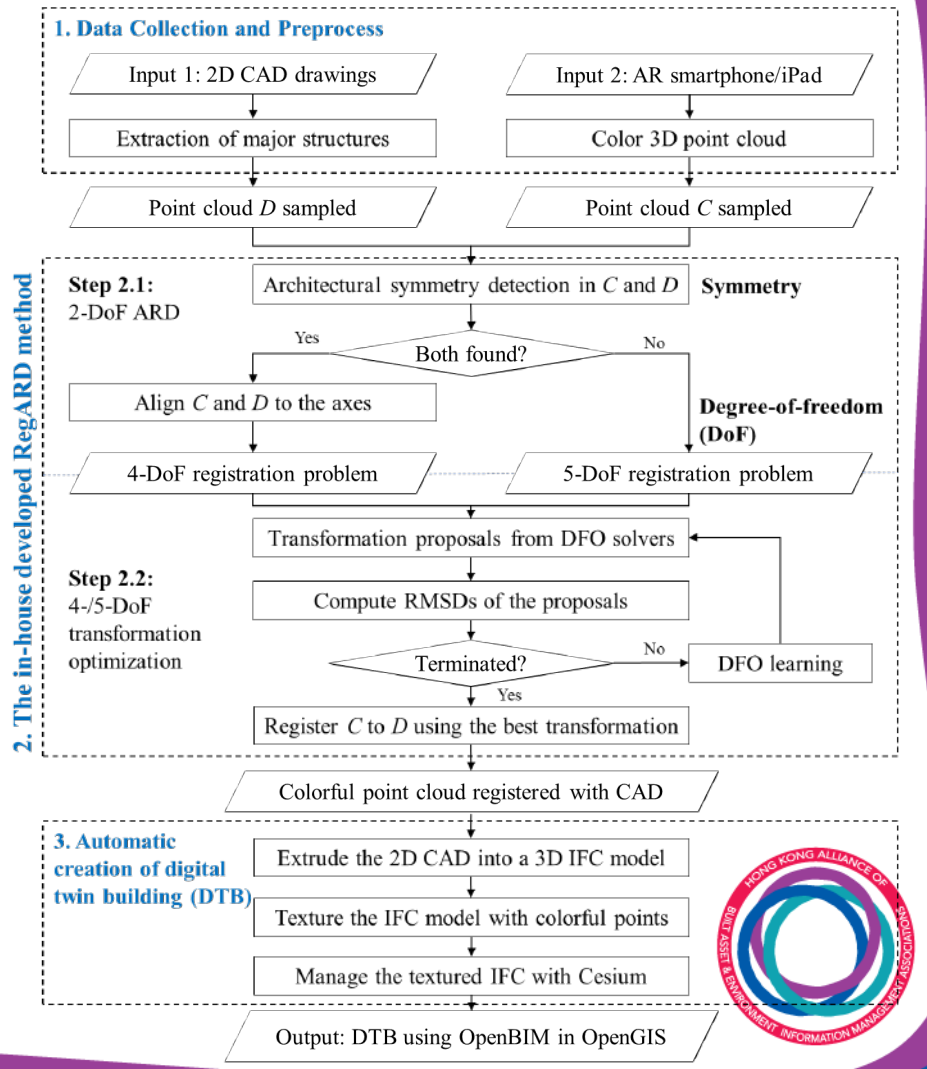
✓Precise, compact, and parametric geometry (***x, y***)
✓Low-cost, ubiquitous, easy to use
✗A lack of appearance
✗Possibly inconsistent with the real 3D layouts



- Research question: How to integrate AR and CAD effectively for DTB?

3.1 Our "AR + CAD = DT" for building assets

Conceptual map of "AR + CAD = DT"



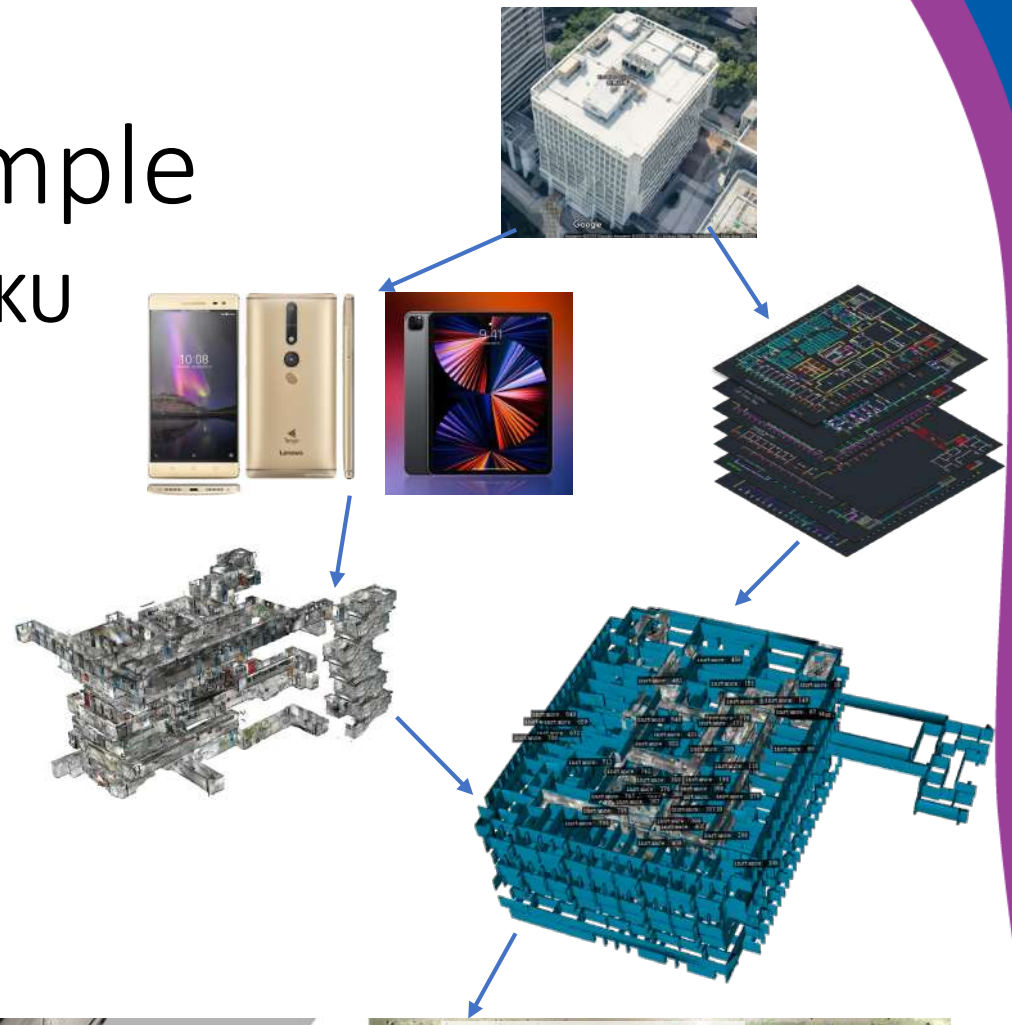
Process map

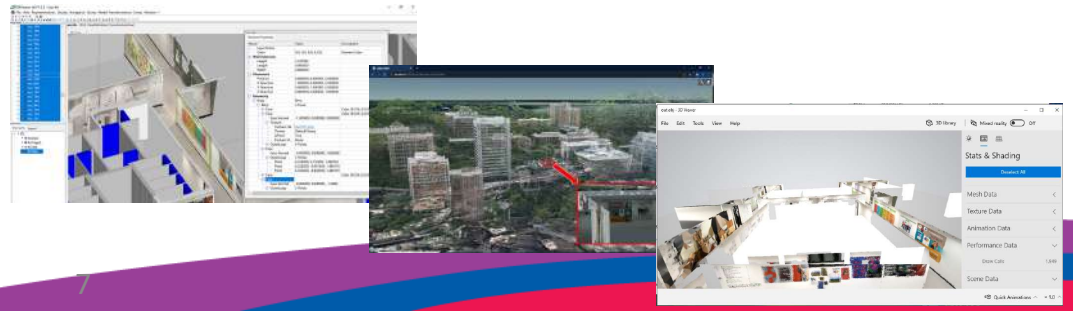
3.2 Software ecosystem

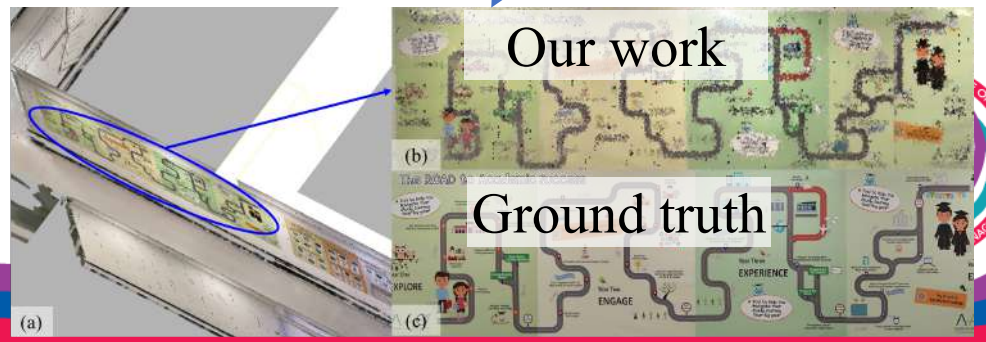
- Stands on the shoulders of OpenBIM/open GIS ecosystems
- 5 clusters
  - Data / device
  - Technologies
  - Services
  - Standards
  - User tools

4.1 Implementation – example

- Corridor networks, Knowles Building, HKU
  - From 2/F to 8/F
    - 7 largely different layouts
  - AR devices: Tango, iPad Pro →
    - 1,400 ~18,000 color points / m^2
- Results
  - Output DT with photo-realistic textures ↘
  - Accessible in BIM, webGIS, Windows
    - IFC4, glTF, OBJ formats ↓

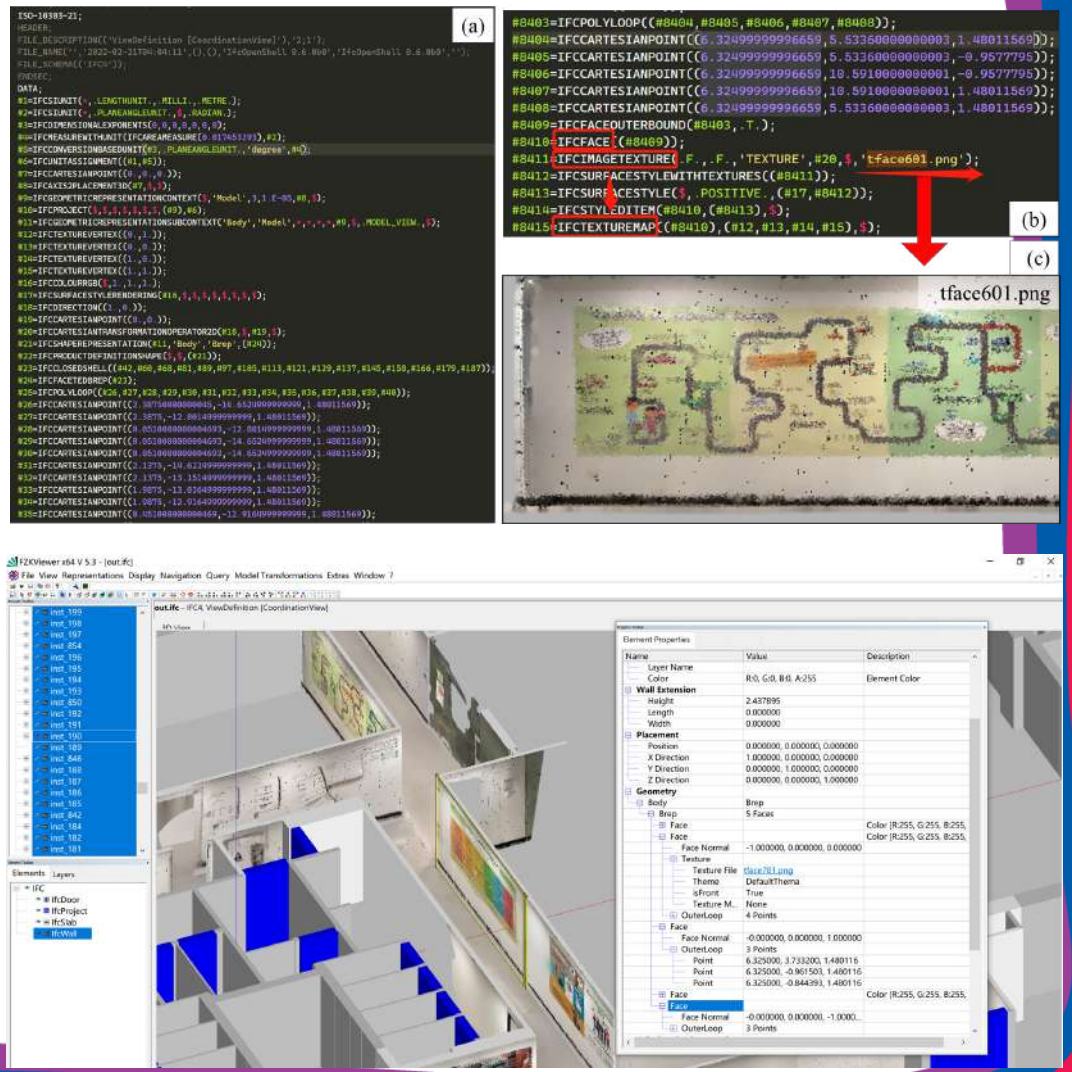






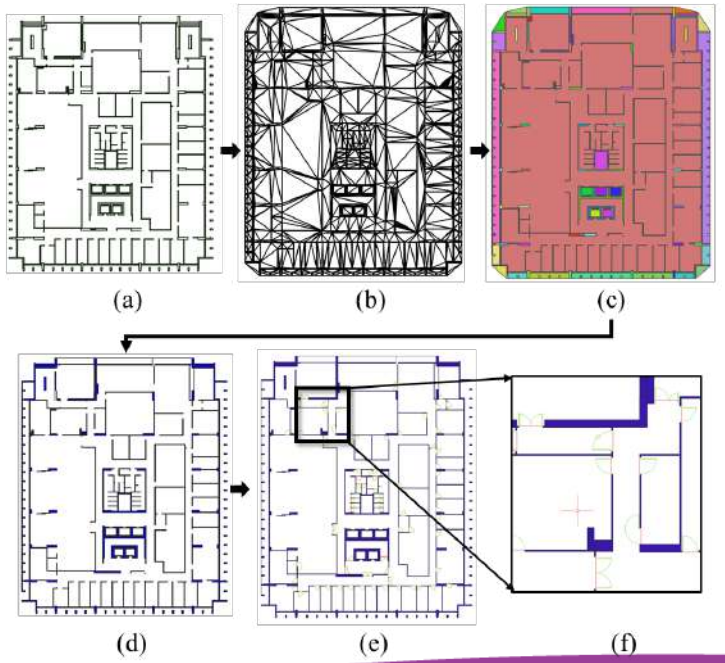
4.1 Implementation – OpenBIM

- Textured DT as OpenBIM
  - OpenBIM : IFC4 with textures →
    - Geometry in IFC4
    - “IfcFace <--> IfcTextureMap <--> IfcImageTexture” schematic pipeline
      - ***Standard IFC schema***
      - ***No extension needed***
    - Texture image
  - The computable semantics in OpenBIM →
    - Well structured semantics for building assets
      - *No add-in / extensions*
    - Software tool: FZK viewer
      - *Some IFC tools do not support PNG texture*

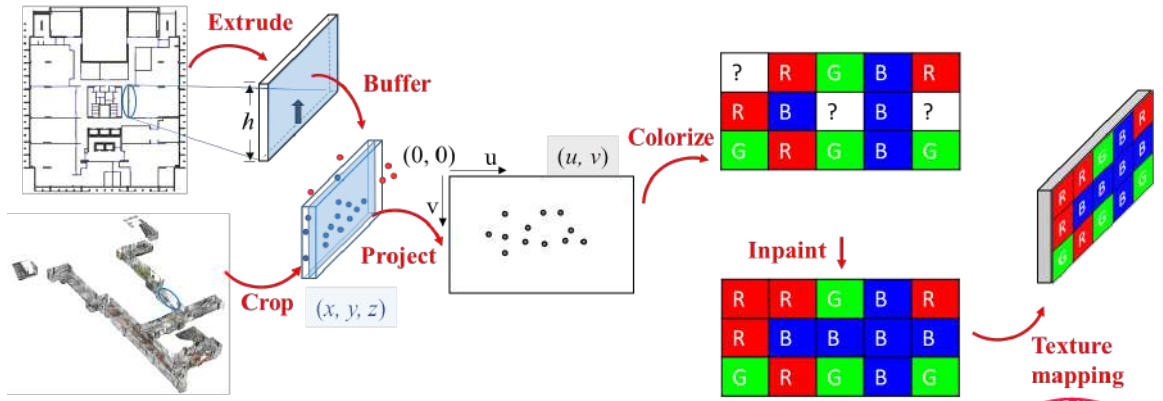


4.1 Technical details

- CAD segmentation
  - Walls, doors, columns, etc.
  - Using filters



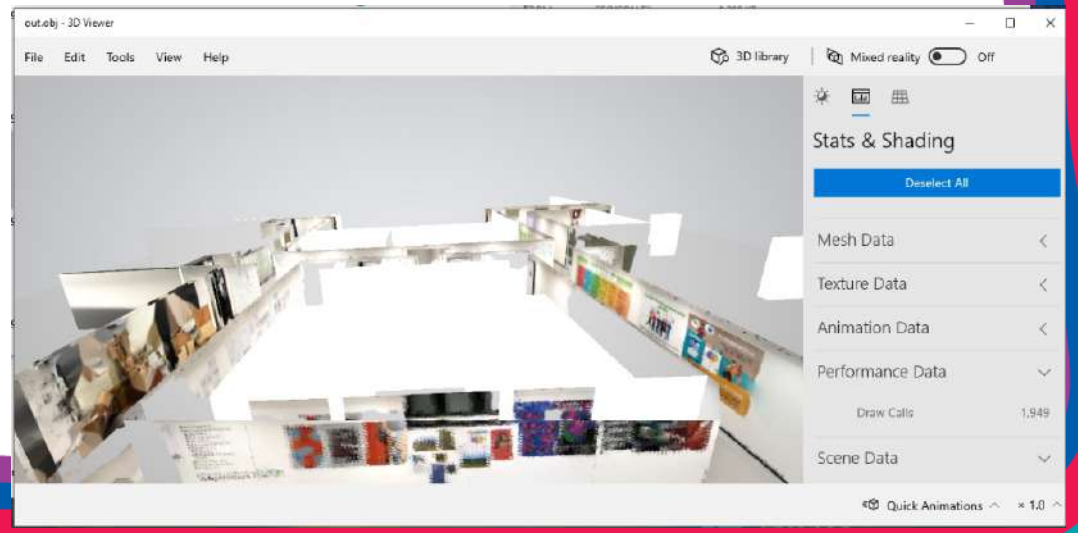
- Points to texture
  - Sampled point colors to extrusion
  - Small holes completion using neighbor colors



4.1 Implementation – OpenGIS/Win viewer

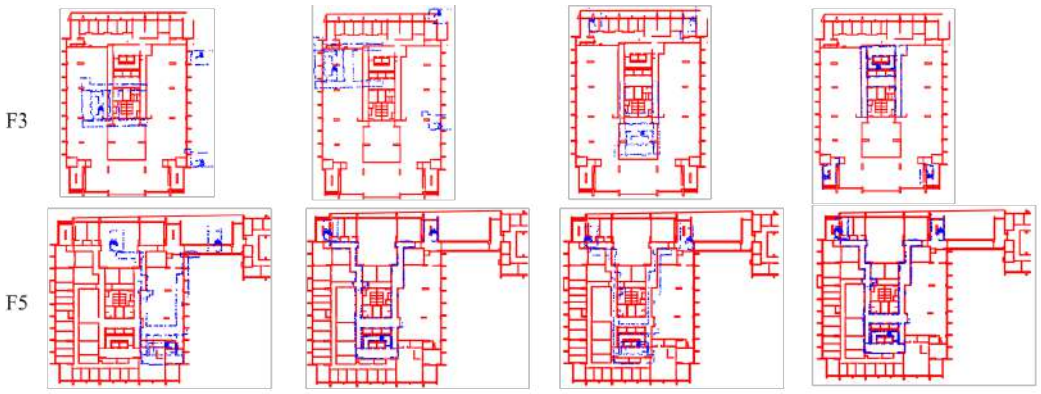
- DT in OpenGIS →
  - Cesium (a web GIS platform)
    - IFC4 → *glTF* format
    - WebGL 3D tiles (see right)
    - With a background of 3D point cloud
  - Also works with ArcGIS APIs

- DT in general viewer →
  - Windows 10/11's native 3D viewer
    - IFC4 → *OBJ* format
    - Accessible on any PC



5. Evaluation – performance

Metric	Story	Init.	CPD	Go-ICP	GMMTree	RegARD	%imp[a]
	F2	0.871	0.923	0.865	0.871	**0.345**	60.17
	F3	2.168	0.732	0.592	2.168	**0.295**	50.12
Avg.	F4	0.663	0.735	0.65	0.664	**0.29**	55.34
RMSD	F5	1.997	0.708	1.533	1.997	**0.322**	54.52
(m)	F6	0.645	1.626	0.636	0.645	**0.478**	24.87
	F7	0.667	1.148	0.651	0.664	**0.352**	45.9
	F8	1.063	2.17	0.974	1.063	**0.407**	58.21
						Avg	49.88
	F2	–	279.78	14.25	8.08	**5.17**	36.02
	F3	–	85.58	14.49	8.19	**1.67**	79.66
Avg.	F4	–	69.77	14.09	8.36	**1.42**	83.06
Time	F5	–	99.5	14.48	8.24	**2.02**	75.53
(s)	F6	–	77.5	14.03	8.48	**1.44**	83.03
	F7	–	123.98	14.04	8.6	**1.89**	78.02
	F8	–	150.82	14.06	8.73	**2.05**	76.57
						Avg	73.13



- ← Our work was ~50% more accurate and 73% faster than existing ones
- ↙ How it works
- ↓ Comparison of AR devices
  - iPad Pro was better
    - High-density points, vivid colors
    - 87~95% data compressions

AR technology	Data format	File size (MB)
Apple iPad Pro	AR 3D color point cloud	553.7
	DTB as textured OpenBIM	27.7
	Space saved	95%
Google Tango AR (7 stories)	AR 3D colorpoint cloud	1862.5
	DTB as textured OpenBIM	243.6
	Space saved	87%

5. Evaluation – costs

- Fixed cost
  - iPad Pro: HK$6,500
    - Or Google Tango/ARCore: HK$3,000
  - Easy to use, no training required
  - OpenBIM/OpenGIS: free and open
- On-cost
  - CAD: HK$42 per sheet (from BD's BRAVO)
  - Human resource: 20 mins per storey
  - Data processing (per storey):
    - Step 1: 15~20 mins
    - Step 2: 1~5 seconds
    - Step 3: 1~2 mins

6. Innovations and advantages

- Five innovations of the study
  1) Automatic creation of DT for building assets
  2) Ubiquitous AR+CAD for any existing building
  3) Information compensation between AR and CAD
  4) Utilization of architectural symmetry for DTB
  5) Photo-realistic textured OpenBIM

- Advantages
  - **Low-cost** prerequisite: AR devices and CAD
  - **Low-cost** processing: Our open-source, fast Python tool
  - **High-quality** DT: in OpenBIM/OpenGIS (~90% compression)
    - Using "IfcFace <--> IfcTextureMap <--> IfcImageTexture" pipeline

6. Limitations & to-dos

1. Noises & “Holes” in texture

2. AR Phones cannot scan building exteriors

- 1. Cause:
  - Sub-sampling (1cm or 2cm) before point-to-image projection
- 1. Future improvement:
  - Full point cloud cropping → projection textures → subsample
- 2. On-going: Drone exterior mesh texture optimization (multi-LoD)

7. Future directions

Fine-tune the technology in more projects/ types of assets

Collaborate with partners to develop a user-friendly "AR + CAD = DT (IFC4)" software pipeline

Promote 2) simulations and 3) DT optimizations of Built Assets via OpenBIM in Hong Kong and beyond

Acknowledgements

- Funding support for algorithms
  - Research Grants Council (Nos. 17200218, 27200520)

- Contact
  - Coordinator contact
    - Dr. Frank Xue, xuef@hku.hk, Asst. Prof., FoA, HKU
- Related paper, software, and resources
  - Wu, Y., Shang, J., & Xue, F. (2021). RegARD: symmetry-based coarse registration of smartphone's colorful point clouds with CAD drawings for low-cost digital twin buildings. *Remote Sensing*, *13*(10), 1882. https://doi.org/10.3390/rs13101882
  - RegARD (Python) @ GitHub, https://github.com/eiiijiiiy/RegARD
    - Shared by us under **LGPL-3.0 license**, free for non-commercial use; **limited commercial use** (open source if any modifications)
  - FZKviewer @ KIT, https://www.iai.kit.edu/english/1648.php

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OpenBIM/ OpenGIS
and our Python code are
free and open for you

Let’s join our hands for an open-minded future !