







第八届工程管理前沿与 智能建造学术夏令营

Scan-to-BIM

Reverse engineering of construction from point clouds 11 July 2022 Wuhan, China Fan Xue Dept. of Real Estate & Construction University of Hong Kong





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"大有可为"









自动化 Our automatic scan-to-BIM works "多任务"



0.1 HKU iLab: The urban big data hub

� iLab **实验**室

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- Director: Prof. Wilson Lu
- Urban big data hub at Faculty of Architecture, HKU
- multi-dimensional and multi-disciplinary *urban big data* collection, storage, analysis, and presentation to inform decisionmaking in urban development
- Focusing on Information Technology (IT)
 - 。 BIM, GIS, GNSS, Urban Remote Sensing, IoT
 - Blockchain (BC/DLT)



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0.2 About me

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♦ A mixed background 背景

BEng in Automation, CAUC

■ MSc in Computer Science, CAUC

PhD in System Engineering, HKPU PDF/RAP/AP in Construction IT ♦ Research interests 方向 Urban sensing and computing • As-built BIM and digital twin Automation/IT in construction • Applied operations research, ML Distributed (blockchain) applications to construction

Homepage (full-text PDFs)

2004

2007

2012

Engineering ■ ISE, CEM, EIE Computer Science ■ AI, OR, ML \diamond Economics ■ SCM

- \diamond Professional
 - MACM, SMCGS, MIEEE, MHKGISA
 - V.C. ACM-HK, Com. CGS-BIM

Section 1 INTRODUCTION 背景

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1.1 Introduction to smart construction

♦ Construction 建造

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- Secondary Sector, Class E 第二产业 E类 (实体经济)
- is known as a "backward industry"
 - Low productivity, labor-intensive (*v.s.* aging workers)
 - Fatality, occupational hazards, management (*e.g.*, cost overrun)
 - Facing <u>changing</u> environments, in contrast to manufacturing
- ♦ Smart construction 智能建造
 - No strict definitions yet
 - Often refers to IT applications for construction management
 - $_{\odot}~$ New sensors, such as RFID, LiDAR, GPS, UAV, smart phones
 - $_{\odot}~$ Exploiting the exponentially growing computing power
 - With responsive functions against <u>changing</u> environment





1.1 Introduction to BIM

- ◆ BIM 建筑信息模型
 - Building Information Modeling
 - Building Information Model
- ♦ Definitions 定义

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- "A <u>digital representation</u> of physical and functional <u>characteristics</u> of a <u>facility</u>." [more on design]
- "As such, it serves as a <u>shared knowledge resource</u> for information about a facility forming a reliable basis <u>for decisions</u> during its life cycle from inception onward." [more on mgmt.]
- A loose definition
- � Origin 起源

Evolved from CAD (computer-aided design) Xue: Scan-to-BIM. HUST, Wuhan, China. 2022.



An evolution view of CAD/BIM (Penttilä 2007)



Reconstructed BIM (Source: author)

1.1 Why as-designed BIM is not enough?





Src: BD



Src: Wikimedia

Aged buildings in HK (~10 K in 2019, ~30K in 2046)



Src: SCMP

HK01



BIM needs update/ extensions for smart construction

Oue to:

Real dimension*

Correct material

Real-time info. *

- Existing, aged buildings*
- Changed, altered plans*
- Current functions

*: Too tedious for BIM modelers 8

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1.2 Introduction to point clouds

� Point 点

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A location in space, 0D (no width, length, or thickness)

Structured format: {x, y, z}, [R, G, B, Nx, Ny, Nz, Cls, Int., ...]

♦ Cloud 玄

An unstructured collection [of water droplets or ice crystals]
 Dense when looking at a distance, sparse closely
 Point cloud (PC)



A point cloud of HKU Campus (Source: Author, 2019)





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1.2 Major sources of point clouds





Xue: Scan-to-BIM Building rooftop (Xue et al, 2019d), city model (Li et al. 2022)

(Xu et al, 2018)

1.2 Advantages and applications

♦ SAR 合成孔径雷达

mm-accuracyCoverage

◆ LiDAR 光达

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mm/cm/dmNo distortionIntensity

♦ Photogrammetry 摄影测量

cm-accuracyColorfulCheaper

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(c) Columnit piets crucialit on a Cougle Entit-sity model





Roof albedo (Xue et al. 2019f), indoor CFD simulation (Source: Author, 2022)



Kowloon Wall City 3D model (Source: patrick-@sketchfab.com)



HKU @MineCraft (Source: Author, 2021)

1.3 Scan-to-BIM as a reverse engineering

◆ Reverse engineering (RE) 逆向工程 (Varady et al. 1997)
 ■ Product → scan → CAD (reverse of engineering), e.g.,

- PCB → circuit design
- \circ Car part \rightarrow 3D CAD
- For quality checking, iterative improvement, etc.
 - Goal: smarter decision-making

Scan-to-BIM

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- $\blacksquare \text{ Construction} \rightarrow \text{scan} \rightarrow \text{BIM}$
- For actual geometry (quality checking), iterative improvement, etc.
 - Goal: smarter decision-making
- Comparable with RE in manufacturing





Section 2 GENERAL PROCESSING IN SCAN-TO-BIM 概述

2 Point clouds versus CAD/BIM drawings



✓Rich in details and 3D appearance (texture)
✓Consistent with the real 3D layouts (z)
X A lot of <u>defects</u>, e.g., sparse, noisy, and misaligned
X <u>Unstructured</u>, low semantic info, massive disk size



✓ Precise, compact, and parametric geometry (x, y)
X A lack of appearance
X Possibly inconsistent with the real 3D layouts



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2.2 Semi-automatic scan-to-BIM

- Manual scan-to-BIM's limitations
 - Expensive, time-consuming, limited capacity, etc.
- Semi-automation has been studied
 - Pipe (cylinder) and beam (cuboid) detection, e.g.,
 - $\circ~$ Revit addon: EdgeWise / Verity
 - Plane detection
 - RANSAC
 - 。Rules of normals 法向规则
- Unhandled cases
 - Complex objects
 - Complex scenes
 - Dynamic real-time data

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7 man-days for scan-to-BIM





2.3 Fully automatic scan-to-BIM: tasks

Automation: faster, cheaper, productive

- ◆ Tasks for (1) BIM族配准
 - 3D scene recognition
 - 3D classification
 - 3~6 DoFs pose estimation
- ◆ Tasks for (2) 识别

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- 3D object detection
- 3D semantic segmentation
- ◆ Tasks for (3) 整合
 - 3D parts and combinations
 - 3D relations/topology recognition

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2.3 Opportunity: existing methods in other fields

♦ 3D classification 分类

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- Spatial/shape features (Corner, SIFT, etc.)
- CNN deep features (e.g., PointNet++)
 - GraphNN features
- ◆ 3D object detection 目标检测
 - RANSAC (Random Sampling Consensus)
 - Perfect normals + geometric shapes (e.g., walls, ceiling)
- ◆ 3D semantic segmentation 语义分割

Sliding windows / region proposal / anchorless + 3D classification

◆ 3D scene / relationship 场景、关系

■ 3D Object/parts/topology/semantics-based

Xue: Scan-to-BIM. HUST, Wuhan ghina. 2022. , any Building/urban characteristic? 特色





(Li & Lee 2019)

Example of semantic segmentation (Qi et al. 2017)





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2.3 Symmetry and similarity as domain-specific

- ♦ Symmetry 对称
 - Reflect_x(C) $\approx C$ 镜面对称
- ♦ Similarity 相似
 - AffineTrans_r(C_1) $\approx C_2$ 仿形变换
- Guided by design laws





 Reflection (Mirror) (b) Rotation (The Taj Mahal, India) (The Pentagon, USA)

(c) Translation





(f) Rotation × translation (e) Scaling × rotation. (The Pantheon dome, Italy) (The Gherkin, UK)

(g) Translation × reflection (h) Cluster of homogeneous (Sugar Hill Project, USA) symmetries (Tulou, China)





(Xue et al, 2019d; 2020a)

Xue: Scan-to-BIM. HUST, Wuhan, China. 2022.

Section 3 OUR AUTOMATIC SCAN-TO-BIM WORKS 自动化

🧱 3.1 (1)类: Auto 3D pose estimation 工作1 (Xue et al. 2019b)



(b) A visual comparison between the input (grey points) and the output BIM

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3.1 (1)类: A demo video



Another demo of 3D pose estimation of columns (Wu et al. 2022b; https://youtu.be/kdMYD0Po7kY)

Output formatsBIMJSON



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🧔 3.1 (1)类: Sym+Sim for city objects 工作2 (1/2)

♦ Symmetry-based cross-sections 对称截面 (Xue et al. 2020)

■ 1. Ground removal

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- 2. Connectedness
- **3**. Major symmetry
- 3.1 Section #1 4. Perpendicular
 - 4.1 Section #2
- **5**. Voxelization
- For unknown objects
 - 无需语义分割
 - SymmetricAbove ground

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🧔 3.1 (1)类: Sym+Sim for city objects 工作2 (2/2)

Similarity for clustering unknown 相似聚类 Similarity to sections of known
 1. Cross-section-based registration
 3D objects 匹配已知语义模型

2. Clustering using least RMSE

■ 1. Filters (Width, Height, Depth)



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👮 3.2 (2)类: FLKPP method 工作3



3D box

🧱 3.2 (2)类: Room segmentation (1/3)

- ♦ 'FL' of FLKPP: floor layers
 - Room clustering

Room-base noise and clutter removal

- Space voxels labeling
- Region growing to segment rooms
- Clutter removal (using head levels in room







 $\langle \! \diamond \! \rangle$





(Voxels occupied

by scan data)

(Indoor

space

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🤰 3.2 (2)类: Deep learning for edge detection (2/3)

'PP' of FLKPP: Pillars of points



End-to-End Wireframe Parsing

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🔯 3.2 (2)类: Deep learning for obj. detection (3/3)

Image: Image





3.2 Results of FLKPP

In and Scan-to-BIM Challenge, CVPR2022
First Runner-up in 3D BIM track

mIoU = 0.231 (max = 1.0)
20cm's F1 = 0.584 (max = 1.0)

Second Runner-up in 2D CAD track

mIoU = 0.374
20cm's F1 = 0.173















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🦉 3.3 (3)类: Sim-guided topology of chairs (Xue et al. 2019c)





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🟮 3.3 (3)类: Texture enrichment

Wu et al. (2021)

Merit Award, Hong Kong OpenBIM / OpenGIS Award







Section 4 SUMMARY 小结



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4 A recap

Scan-to-BIM

• Vital to smart construction (including real-time, actual info.)

A reverse engineering process

◆ In general, 3D → 2D + obj. → 3D "总分总"

Automation is demanded in many cases

♦ Auto scan-to-BIM "多任务"

- ■(1) 3D family registration BIM族配准
- (2) 2D section reconstruction 剖面重建
- ■(3) BIM reconstruction 三维重建
- ♦ Yet, plenty of room to improve "大有可为"

Huge market, low costs, many tasks, unsatisfactory performances

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Keep awesome!

感谢! 欢迎提问

