



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



iLab | @HKURBAN
the urban big data lab

Design for eXcellence (DfX) with Digital Twins: From Reality Data to Semantic Models to Optimized Design

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at Faculty of Architecture and the Built Environment, TU Delft

30 June 2023, Delft, Netherlands



Section 1

INTRODUCTION TO OUR LAB



1 Hong Kong



iLab



The only city hosting 5
of world's top 100
universities (QS2024)

- HKU
- CUHK
- HKUST
- HKPolyU
- HKCityU



1 University of Hong Kong



iLab



- ◆ Since 1912
- ◆ 10 Faculties
- ◆ China's only English language comprehensive research-based university



(Source: CPAO Multimedia, HKU)



1 Faculty of Architecture

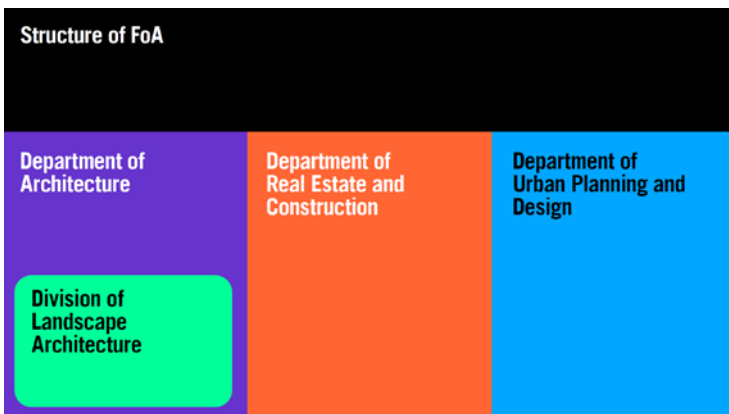


iLab




HKU Faculty of Architecture

China's only English language comprehensive Built Environment Faculty

Architecture, Urbanism, and the Humanities Initiative	iLab	HKURBAN labs
Building Simplicity Lab	Real Estate Lab	
Built Heritage Research Collaborative	Ronald Coase Centre for Property Rights Research	
Centre for Chinese Architecture and Urbanism	Rural Urban Lab	
Centre of Urban Studies and Urban Planning	Social Infrastructure for Equity and Wellbeing	
Fabrication and Material Technologies Lab	Sustainable High Density Cities Lab	
Future Urbanity & Sustainable Environment (FUSE) Lab	Urban Analytics and Interventions Research Lab	
Healthy High Density Cities Lab	Urban Ecologies Design Lab	
	Urban Environments & Human Health Lab	



FoA is closely involved with these HKU-wide research initiatives:

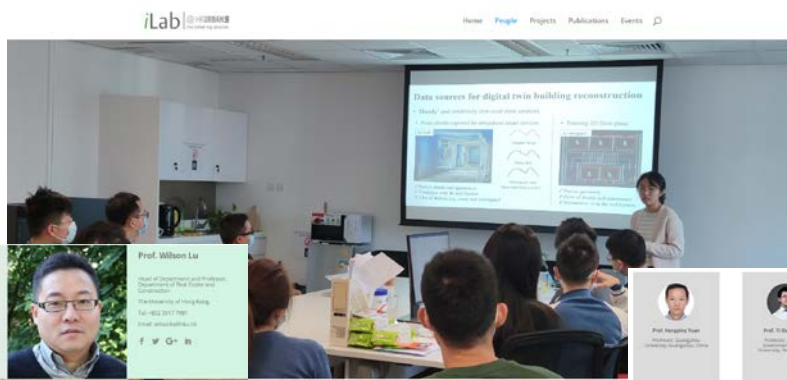
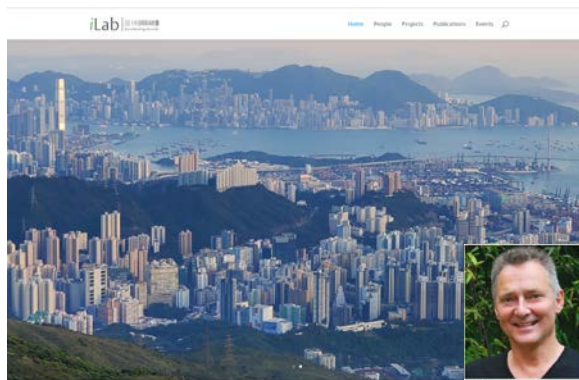
- Institute for Climate and Carbon Neutrality (ICCN)
- Urban Systems Institute (USI)
- Institute of Data Science (IDS)



1 iLab – the urban big data lab



iLab



Welcome to iLab

iLab is an urban big data lab based on the 7th Floor of the Riverside Building, the university of Hong Kong that supports the smart space of architecture, it handles multi-dimensional and multi-temporal urban big data collection, storage, analysis, and presentation to inform decision-making in urban development. iLab is a repository for urban big data from Geographic Information Systems (GIS), Public Reporting Burden (PRB), Urban Forming Strategy (UFS), Urban Form and Scheme (UFS), Building Information Modeling (BIM), Landmarking, facilities use and management, and other sources.

iLab is a forum for research across the urban design and planning with other groups in HKU, all of which handle use of big data. iLab staff is also a research hub, it is the focus of more than 10000 urban research grants related to BIM, BIMchar, construction information, construction logistics and supply chain management, and big data-enabled urban environmental management.

Contact

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Prof. Chris Webster

Associate Professor of Design, Faculty of Architecture, Urban Design, Department of Urban Planning and Design, The University of Hong Kong

f w G+ in

Prof. Wilson Lu

Head of Department and Professor, Department of Real Estate and Construction, The University of Hong Kong

f w G+ in

Dr. Fan (Frank) Xue

Visiting Director, iLab, Institute of Architecture, Department of Architecture, The University of Hong Kong, Pokfulam, Hong Kong

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Dr. Junjie Chen

Visiting Director, iLab, Research Assistant Professor, Department of Real Estate and Construction, The University of Hong Kong, Pokfulam, Hong Kong

- ◆ <https://ilab.hku.hk/>
- ◆ 30 + 11 members
 - ▣ Two interest groups
- ◆ 23 alumni



Mr. Tan Tan

Post-Doctoral Fellow, Faculty of Architecture and Built Environment, Delft University of Technology, Delft, Netherlands



1 My background and research interest



iLab

◆ Xue, Fan (Frank)

◆ Edu. background

- ▣ BEng in **Automation**
- ▣ MSc in **Computer Science**
- ▣ PhD in **System Engineering**
- ▣ PDF/RAP/AP in **Construction IT**

◆ Research interests

- ▣ Urban sensing and computing
- ▣ As-built BIM and Digital Twin
- ▣ Automation/IT in construction
- ▣ Operations research, ML
- ▣ **Blockchain applications in construction**

◆ Professional

- ▣ MACM, MHKGISA, MIEEE,
- ▣ SMC GS, MASC, MHKABAEIMA
- ▣ Vice-Chair ACM-HK, Com. CGS-BIM, Com. ASC-Smart Construction

2004

2007

2013





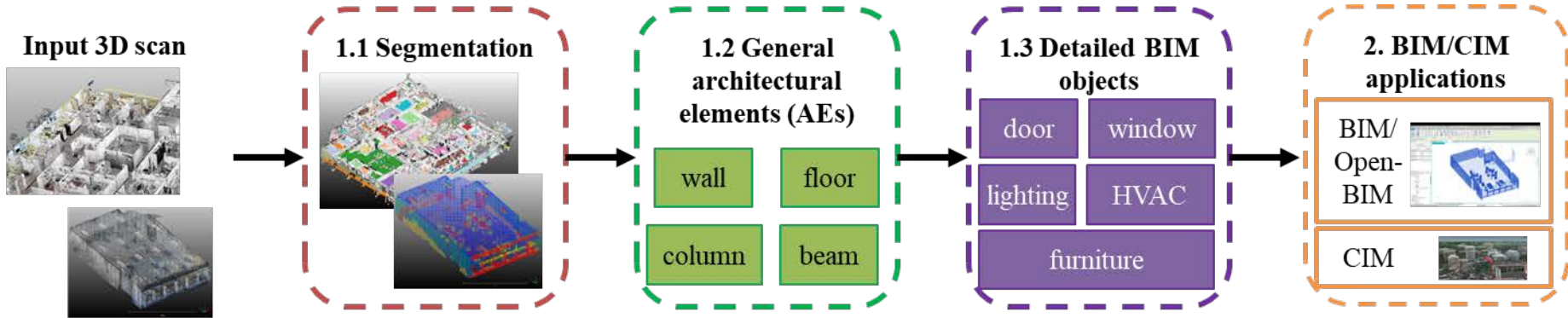
1 My recent work #1: Scan-to-BIM automation



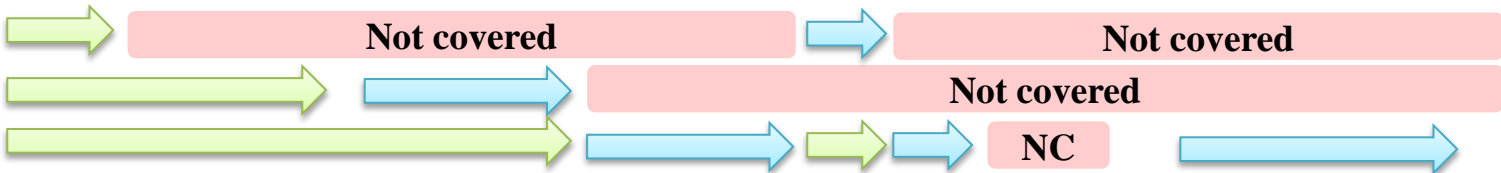
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- ◆ 1. Normal segment + mesher + ifcopenshell (10+ years)
- ◆ 2. 3D deep learning segmentation + clustering (3+ years)
- ◆ 3. Our fully auto “dream”: Automate >60% workload (1 year)

◆ Winner of Scan-to-BIM Challenge, CVPR2023



- 1. Mesher + *ifcopenshell*
- 2. 3D DL + clustering
- 3. Our fully auto dream





1 My recent work #2: Clustering for heritage DT



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◆ Traditional deviation: 3D surface

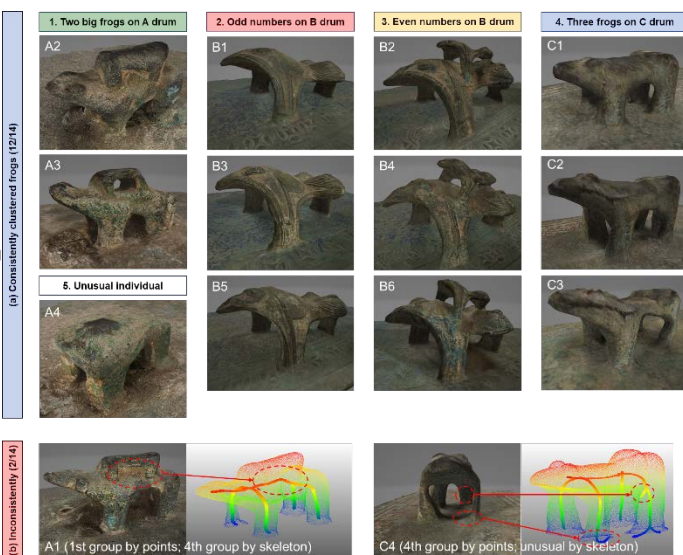
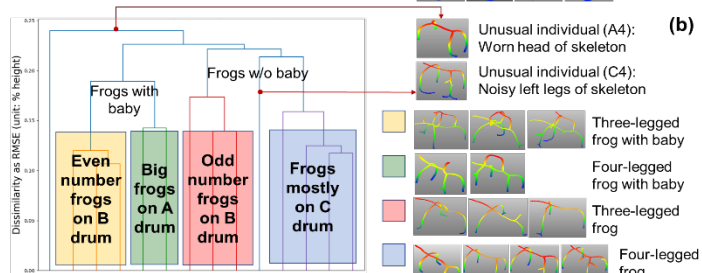
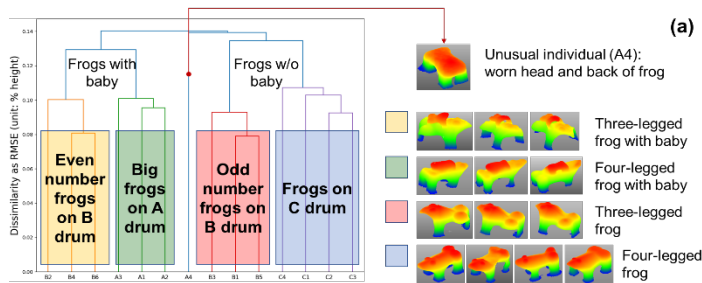
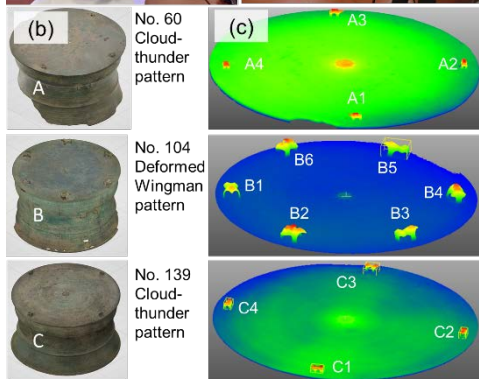
◆ Cases: Bronze frog drums

▣ Q1: Clustering (like building a Covid family tree)?

▣ Result: $F_1 = 0.87$.

▣ Q2: Can shape skeleton ?

▣ Not bad, 0.13 rooms to improve



Section 2

DFX WITH DT

2 DfX, generative design

◆ Design for MA

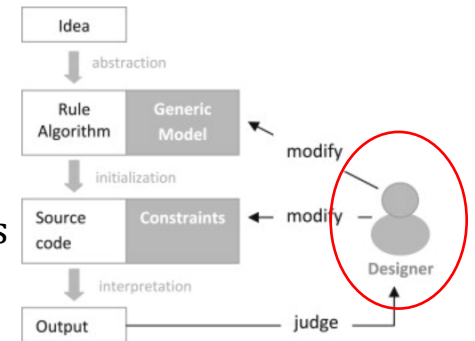
- ▣ Manufacturing and Assembly

◆ Design for X / eXcellence also in

- ▣ structure, quality, cost, logistics, sustainability, resilience, ...
- ▣ Objectives to **optimize**, better with **reality** data

◆ Generative design (Krish 2011)

- ▣ A design exploration process
 - Given an idea
 - Populated by an algorithm (iterative sometimes)
 - Judged (**optimized**) by human designers based on the outputs
- ▣ Designer (decision-maker) as a human
- ▣ → A human-centric approach for DfX



Generative design process (Krish 2011)



2 DfX with DT

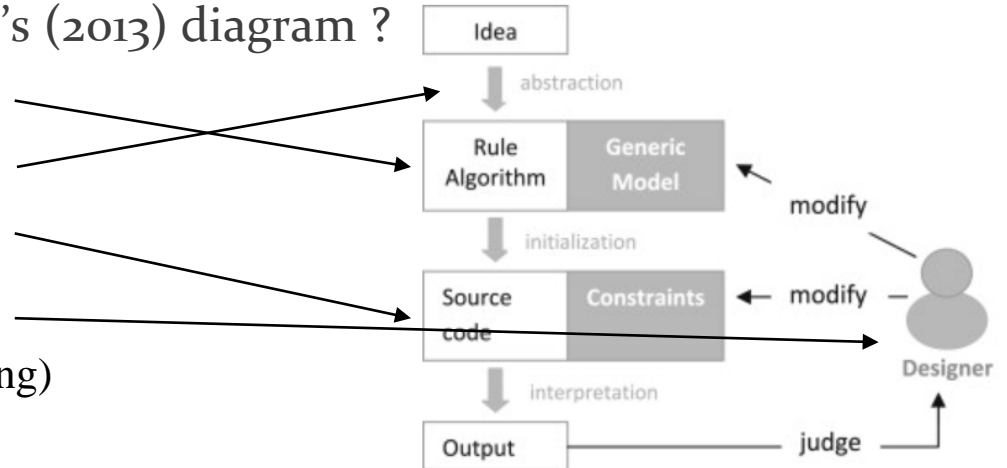


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- ◆ A digital twin (UKNIC 2017)
 - ▣ “A virtual representation of a physical object or system
 - ▣ across its lifecycle, using **real-time** data
 - ▣ to enable understanding, **learning**, and **reasoning**.”

◆ How can DT enable in Krish’s (2013) diagram ?

- ▣ DTs of building materials
- ▣ DTs of common styles
- ▣ DTs of environment
- ▣ “AI designer”
(DT of low-level decision-making)





2.1 Case 1: DfX with DTs of materials



◆ ZCB Bamboo Pavilion

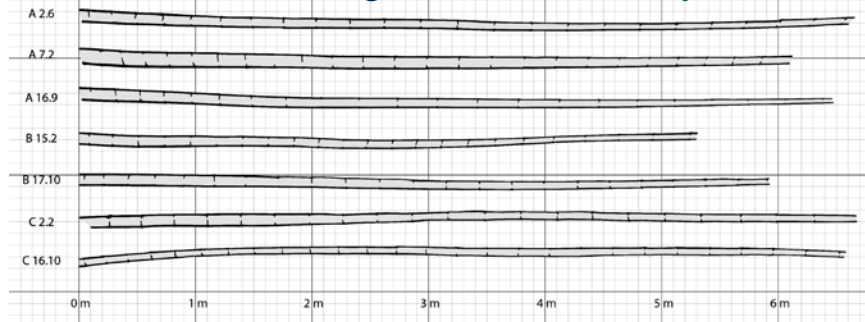


CLIENT BRIEF

- Host public events
- Showcase bamboo potential
- Promote sustainability



Q: maximum usage for sustainability?

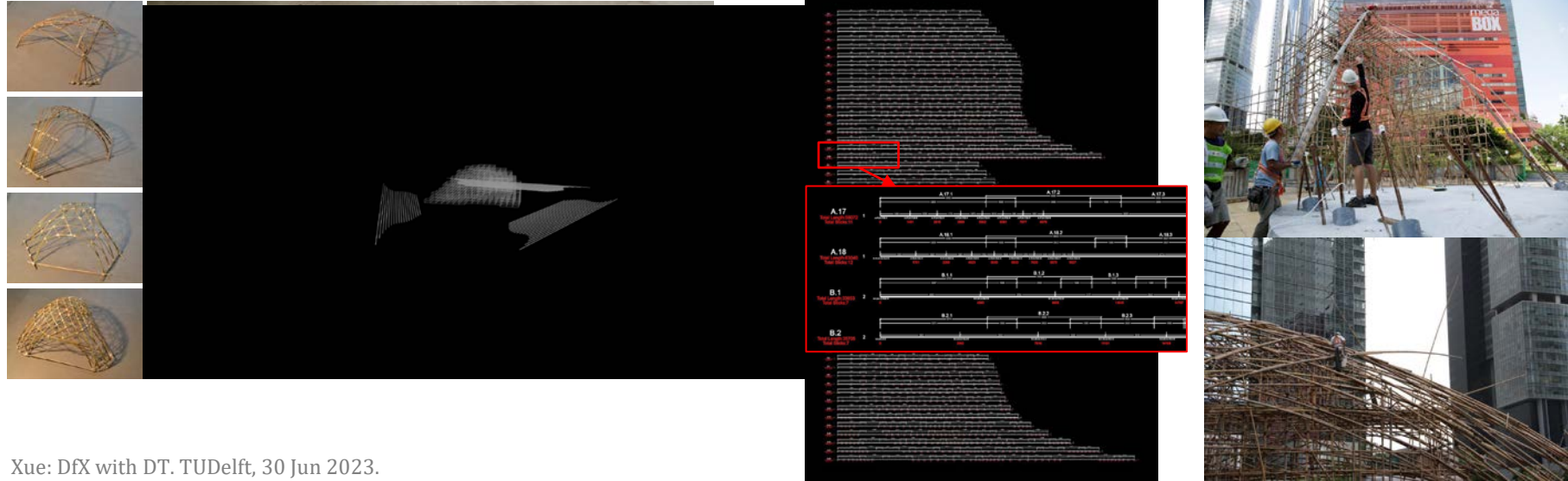
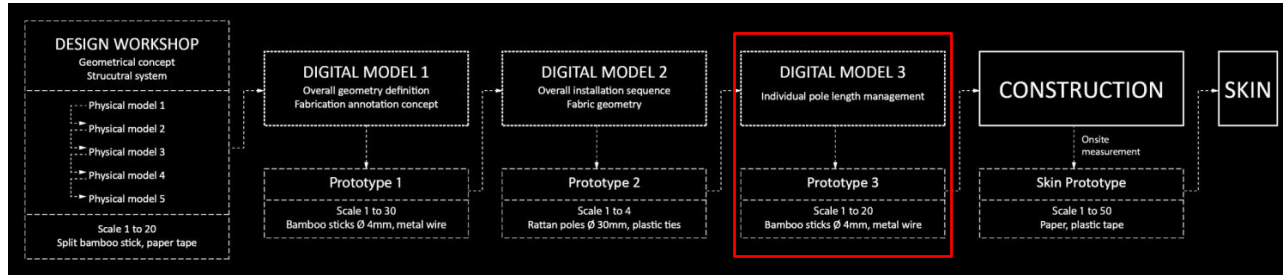


◆ Dr. Kristof Crolla
kcrolla@hku.hk



- ◆ Associate Prof.
- ◆ Investigator of our on-going DfX project

2.1 Method: Optimizing poles to bamboo “DTs”





2.1 Completion and awards

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WORLD ARCHITECTURE FESTIVAL
Small Project of the Year

G-MARK Tokyo, Japan
GOOD DESIGN BEST 100

2016 GOLDEN PIN DESIGN AWARD
Taiwan Design Centre
Spatial Design

HONG KONG DESIGN AWARDS
Pop up, Display, Exhibit & Set Design
GOLD AWARD

ARCHITIZER Architecture + Wood
JURY WINNER

ARCHITIZER Architecture + Engineering
POPULAR CHOICE

ARCHITIZER Architecture + Sustainability
FINALIST

ARCHITIZER Cultural: Pavilions
SPECIAL MENTION



A&D TROPHY AWARD
Architecture & Design Green or Sustainable
BEST OF

INTERNATIONAL PROPERTY AWARDS
☆☆☆☆
BEST LEASURE

GREEN BUILDING AWARDS AWARD
Research and Planning
MERIT AWARD

SUCCESSFUL DESIGN AWARDS
SPACE category
MOST SUCCESSFUL DESIGN AWARD

DESIGN FOR ASIA AWARDS
Hong Kong Design Centre
SILVER AWARD

HKDA GLOBAL DESIGN AWARDS
Hospitality & Entertainment Space
GOLD AWARD

HKDA GLOBAL DESIGN AWARDS
Hospitality & Entertainment Space
JUDGES' CHOICE

HKDA GLOBAL DESIGN AWARDS
Hospitality & Entertainment Space
HONG KONG BEST



2.2 Case 2: DfX with DTs of common styles

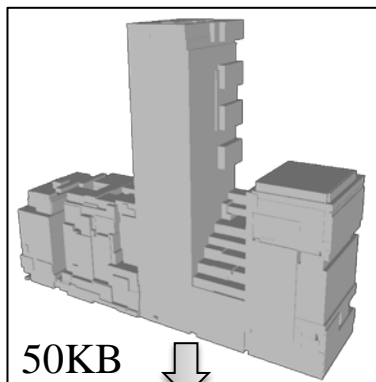


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- ◆ City mesh/point cloud models too huge
 - ▣ Q1: Compact building reconstruction?
 - ▣ Q2: Generating blocks for **mimicking local styles**?



220MB



50KB



New Hong
Kong-ish blocks?

- ◆ Miss Yijie Wu
yijiewu@connect.hku.hk



- ◆ Yr-2 PhD candidate
- ◆ Team members





iLab

2.2 Method: BSS for compact 3D modelling (Wu et al. 2023)

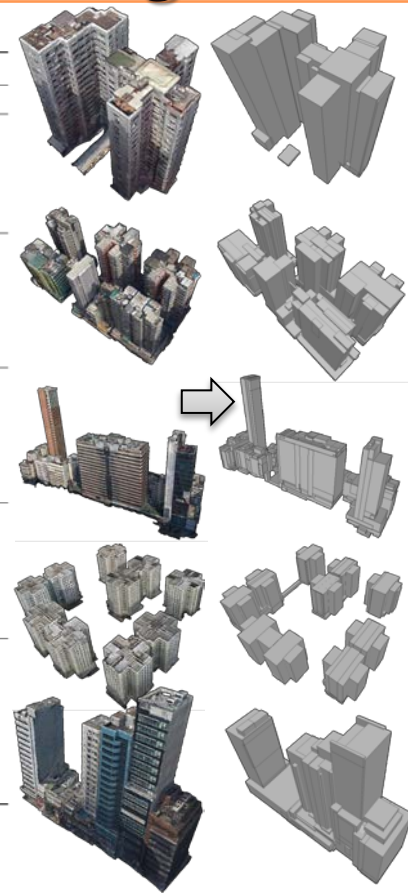
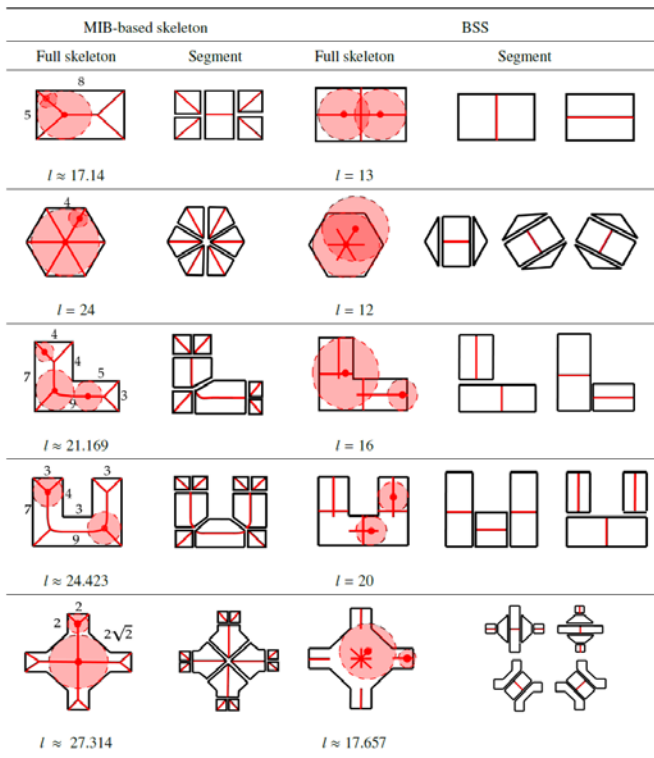
◆ MIB skeleton in geometry

- ▣ Max Inscribed Ball centers
- ▣ Counter-intuitive for plans

◆ Building Section Skeleton (BSS)

- ▣ Extends MIB for polygon plans
- ▣ Data-driven building style descriptor
- ▣ High-level abstraction

◆ Q1 answered



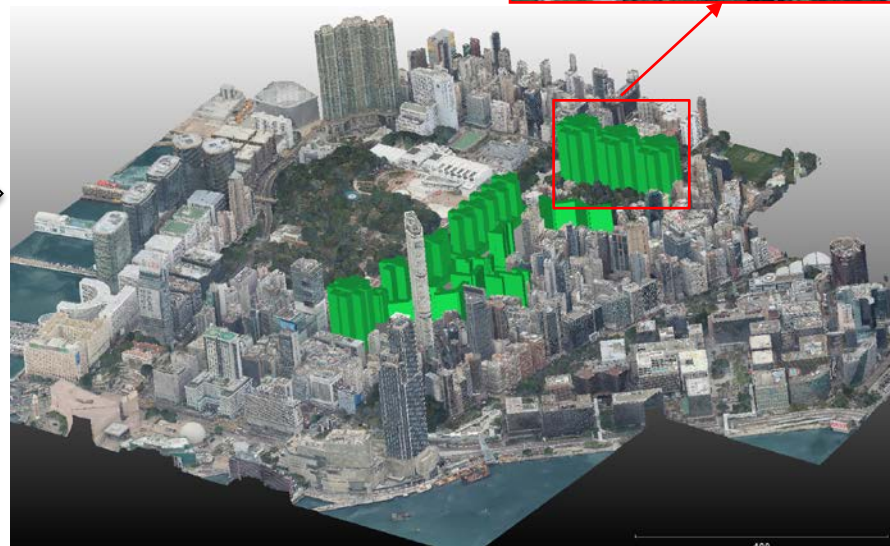
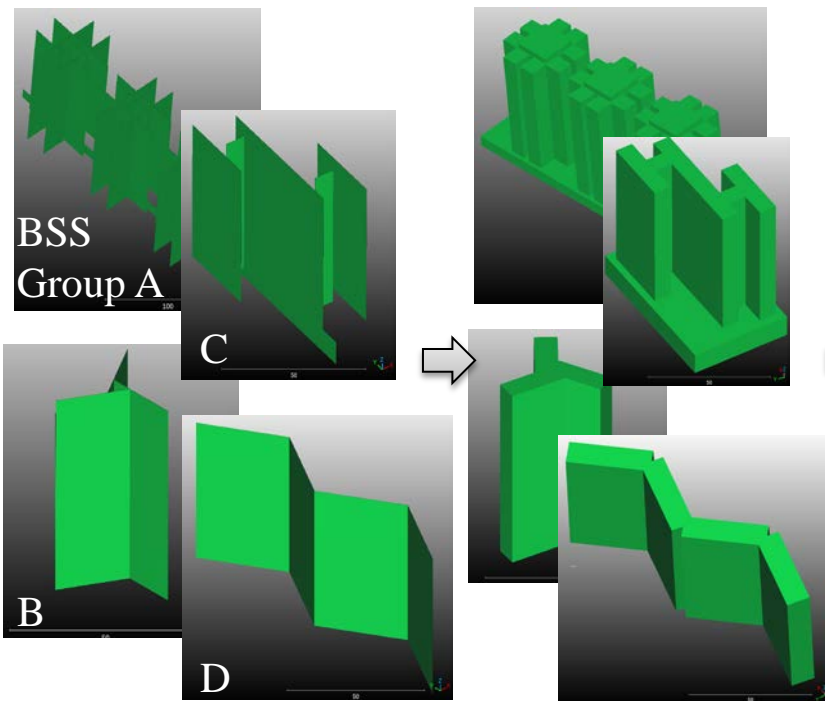


2.2 Generation of buildings and blocks



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◇ Data-driven groups → buildings → virtual blocks at TST





2.3 Case 3: DfX with DTs of climate and 3D env.



◇ Q: MiC floorplan design for **passive energy** and **natural lighting** (conflicting 'Xs' in HK)

◇ Miss Qianyun Zhou
qianyunz@hku.hk

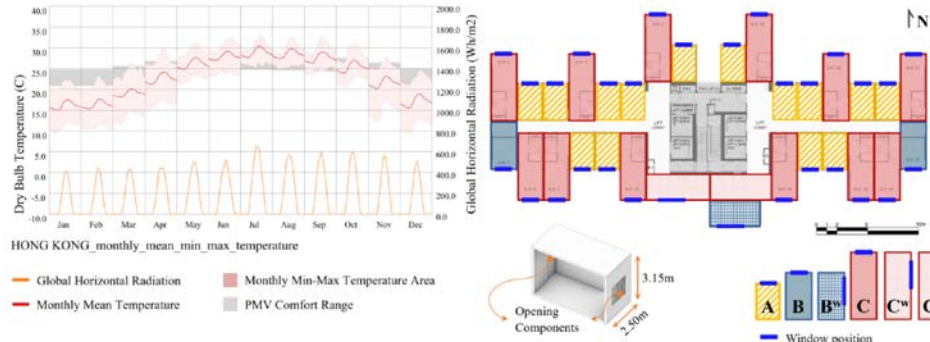
▣ Q-Add: Modular-integrated Construction (MIC) brings **discrete design variables**

▣ Case project: HKU High West student hostel (Block H1)

- 19-story, 31 modules, 3 (6) types, for 470 students
- Constraints: Same GFA, same module sizes, etc.

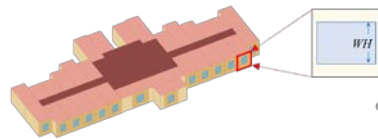
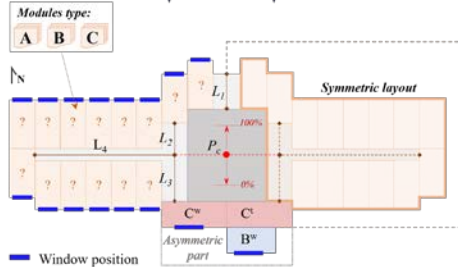
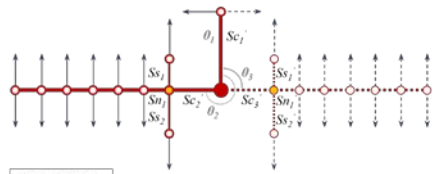


◇ Yr-1 PhD in Sept.



2.3 Method: GA + GH env. simulation (Zhou & Xue 2023)

- Define symmetric skeleton grammar and module types
- Define corridors' length (L_1, L_2, L_3, L_4) and axis' vertical range (P_x)
- Assign modules (M_A, M_B, M_C) according to module nodes (Mn_j)
- Define modular window-to-wall ratio (WWR_{Sc}, WWR_{M}) and windows' height (WH_{Sc}, WH_M)



3.1 Definition of Symmetric Skeleton Grammar (SSG) and Design Variables



Iteration

3.2 Definition of SSG-MOO Problems

- Minimize $EUI(SSG(x))$
- Minimize $sDA^{-1}(SSG(x))$
- Subject to $GFA(SSG(x)) = T_{GFA}$

3.2 Energy and Daylighting Simulations

Environmental value input

- Weather data for Hong Kong (cpw)
- ASHRAE climate zone #2

Construction materials and conditions

- Compute simulation grid size (G_s)
- Calculate the EUI value
- Calculate the sDA^{-1} value

Design variables gene pool

Building performance values

3.3 MiC Design Generation with SSG-MOO

NSGA-II for SSG-MOO problems

Satisfied Bi-objectives?

Yes: Return Pareto optimal solutions

No: WallaceJ

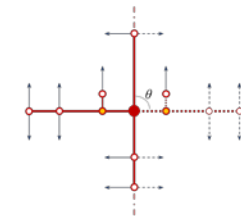
3.4 Multi-level Verification and Analysis of Selected Pareto Optimal Solutions

Level 1: MOO solution space

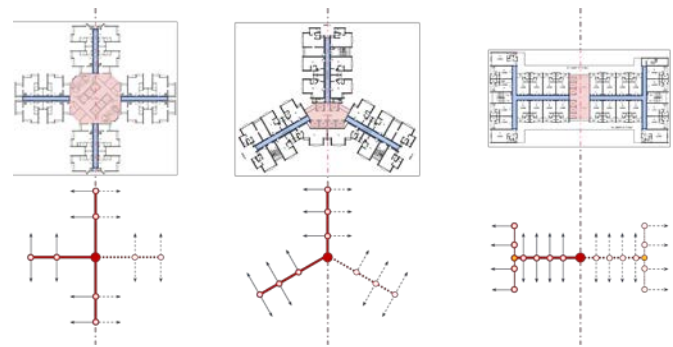
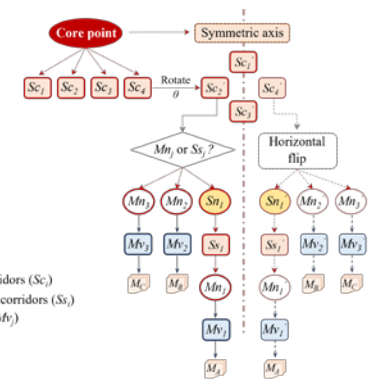
Level 2: SSG modular layout

Level 3: MiC design parameters

Conclude valuable design strategies for energy efficient MiC design



- Core point
- Module node (Mn_j)
- Sub-skeleton node (Sn_j)
- Symmetric axis
- Skeleton for corridors (Sc)
- Sub-skeleton for corridors (Ss)
- Module vector (Mv_j)





2.3 Results

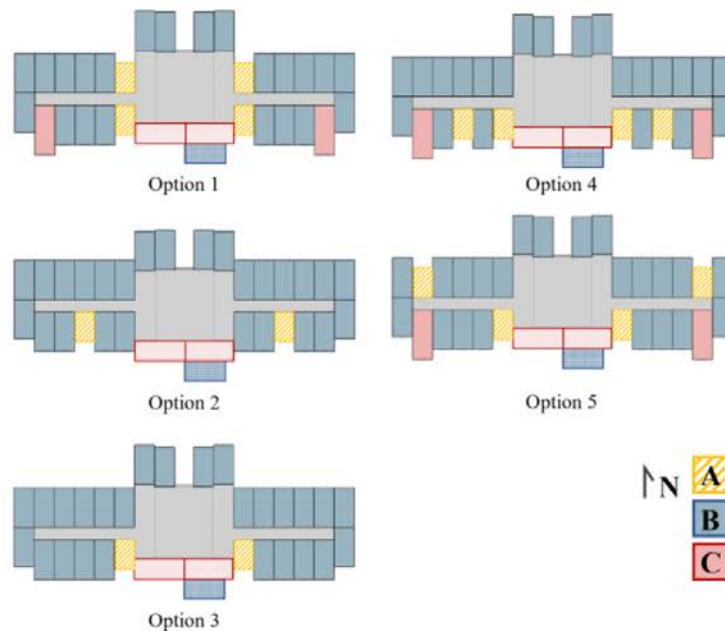
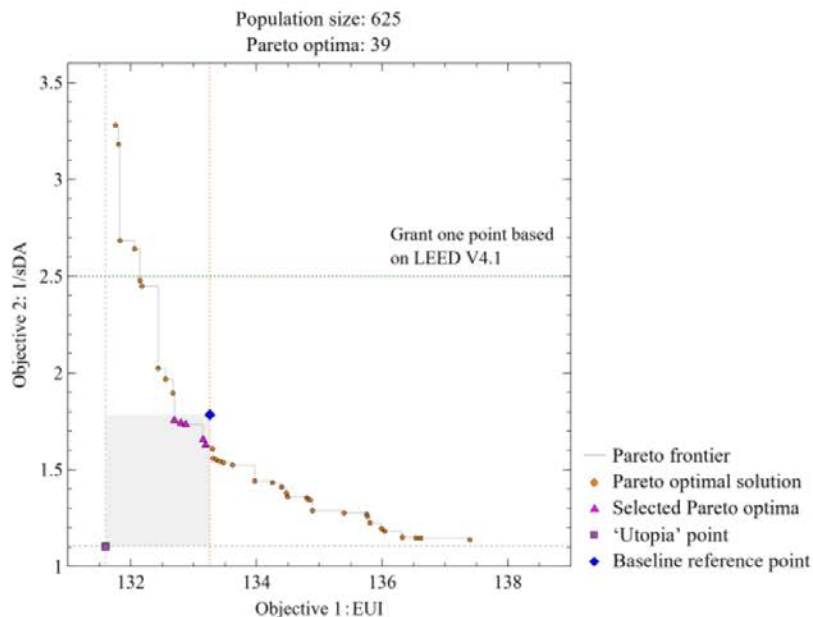


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◇ After 15 hrs (GA+simu), 5 improved plans

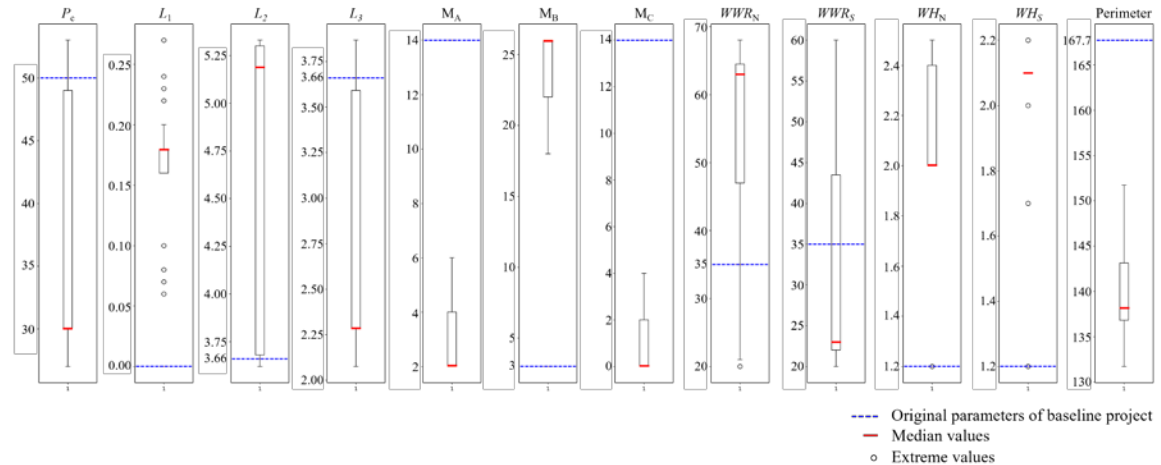
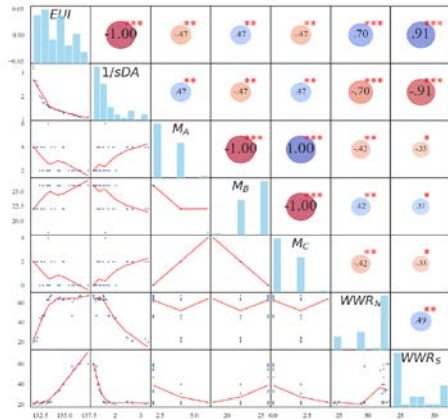
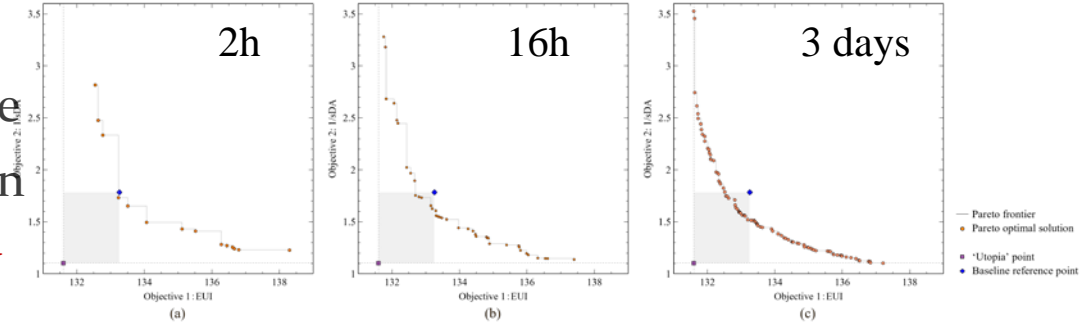
▣ in a preferred area, improving both X s

▣ EUI improved up to 0.42%, spatial daylight autonomy (sDA) improved up to 9.7%



2.3 Analysis of generated Pareto optima

- ◆ More iter. = more results
- ◆ $window_{south}$ is more sensitive
- ◆ 5 out of 11 design variables in the production **discouraged** by the Pareto optima



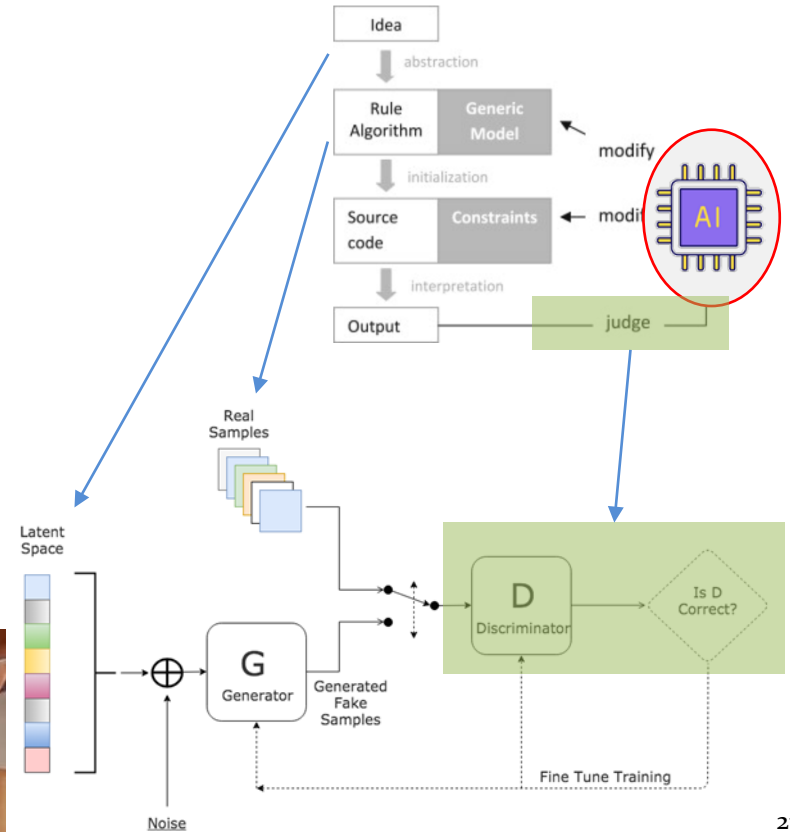
2.4 Case 4: AI-DfX??

◆ Deep learning AI, especially GAN (Generative Adversarial Network)

- ▣ Trained on many input samples
 - Against classes, e.g., cat, dog, or latent
- ▣ Can “judge” outputs – to a certain extent
- ▣ Taking the “supervisor” role from human

◆ The outputs are

- ▣ Generated by an algorithm G and
- ▣ Judged by the other D
- ▣ So-called “adversarial”

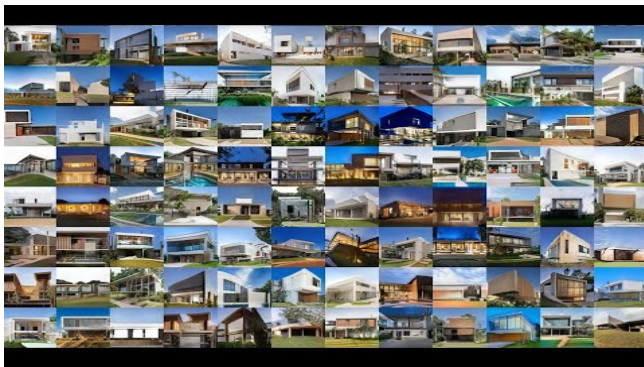
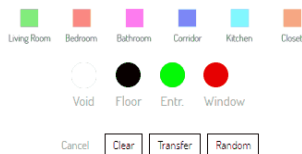
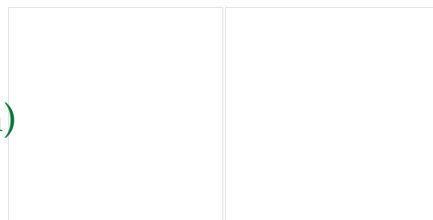




2.4 Intuitive examples

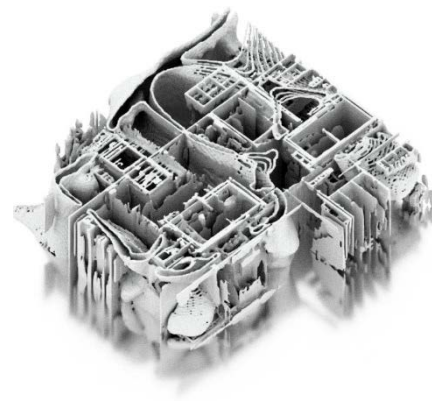


- ◆ Geometric prompts/inputs
- ◆ Apartment interiors (interpolation)
 - ▣ Input 1: Real samples
 - ▣ Input 2: Boundary + windows
 - ▣ By
 - ArchiGAN
 - Chaillou (2019), MArch (Harvard)
- ◆ Also for exteriors
 - ▣ By
 - StyleGAN-ada
 - Rodrigues (2021).



2.4 Research question

- ◆ Q: “Can GAN generate floorplans **for** the music?”
 - Even better if readers can enjoy similar **feelings** for the verses
 - ▣ In essence: Music-to-plans
- ◆ The GAN way
 - ▣ Step 1: Music => latent class
 - ▣ Step 2: Latent class + real plans => new plans
 - ▣ Step 3: Judge and select
- ◆ Any successful story?
 - ▣ Step 1 + 2: LucidSonicDreams <https://youtu.be/iEFqcMrszH0>
 - ▣ Step 2: StyleGAN <https://twitter.com/erikswahn/status/1123951017148788738>
 - <https://mobile.twitter.com/erikswahn/status/1129472697514242048?cxt=HHwWgMC17eTb2KwfAAAA>



2.4 Input: HKU Anthem

◆ A brief history

- **March 11, 1912:** first performed at the Opening Ceremony of HKU, in front of the newly completed Main Building.
- **Until 1930s:** used at formal University occasions
- **After 1940s war:** forgotten
- **May 18, 2011:** Revived to celebrate HKU's centenary
 - Recorded with 150 musicians in the City Hall

◆ Lyrics by Sir Cecil Clementi (20th Governor)

- 4 verses, mentioning
 - “modern from western,” “science [and] art hidden,”
 - “train youth’s vigor” and “light of wisdom”

(Selected subjectively, based on the translation)



The 1912 Anthem*

Finis hic operum! Domus
Stat potens Academia,
Unde ab occiduis recens
Ampliore flust plagis
Mox doctrina meatu.

Fons ubi est sapientia?
Et, Scientia, qua lates?
Pontus has negat in suis
Subditas latebris, negat
Has se Terra tenere.

En! Dei reverentia
Hae scientia! Qui malis
Abstinet, sapit. Hoc diu
Munere assidue valentem
Exercete iuventam!

Pandite ostia! Iam Deo
Gratias agimus. Dei
Semper auxilio novum
Splendet sapientia
Lumen ex Oriente! AMEN

Here end our labours!
Strong stand the buildings of the University,
whence modern learning soon will flow
from western land in more ample course.

Where is the fountain of wisdom?
And how, O science, art thou hidden?
The Sea denies that these are concealed
in his hiding-place
and the Earth denies that she contains them.

Lo! The fear of God—that is science!
Whoso abstains from evil, he is wise.
Long and earnestly may ye train
youth's vigour in this duty!

Fling open the gates!
Now we give thanks to God.
By God's grace may the new light of wisdom
ever shine out from the East! AMEN

The lyrics*



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2.4 The ready-to-use music-to-video pipeline

◇ Software: Lucid Sonic Dream, StyleGAN2

▣ <https://github.com/mikaelalafriz/lucid-sonic-dreams>

▣ <https://github.com/NVlabs/stylegan2>

◇ Platform: Google Colab

▣ Free GPU for 2 hrs every day

◇ Audio source: HKUL

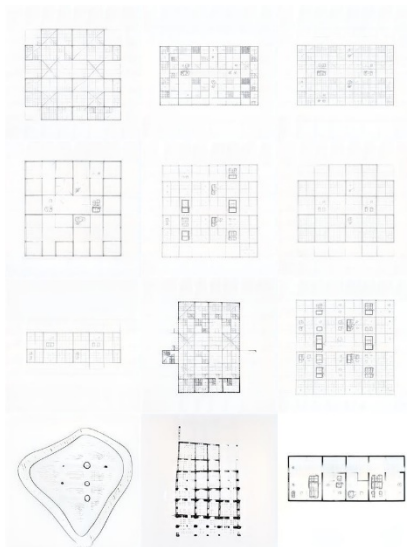
◇ Real plan sketches

▣ Collected by Mayur Mistry ←

○ Antique-like styles

◇ Final pipeline

▣ Anthem → Lucid Sonic Dream → StyleGAN2 →
video of plans → selected plans



◇ Python codes (30 lines)

▣ 1. Upload the Anthem to Colab virtual machine

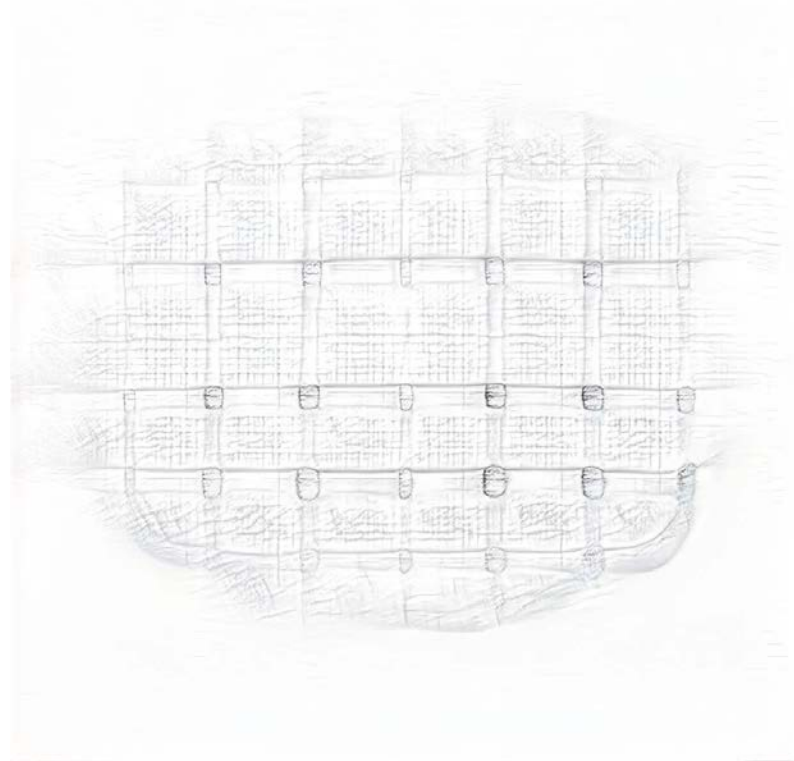
▣ 2. Load Lucid Sonic Dream with the song

▣ 3. Load pre-trained StyleGAN2 model (300MB) for floor plans

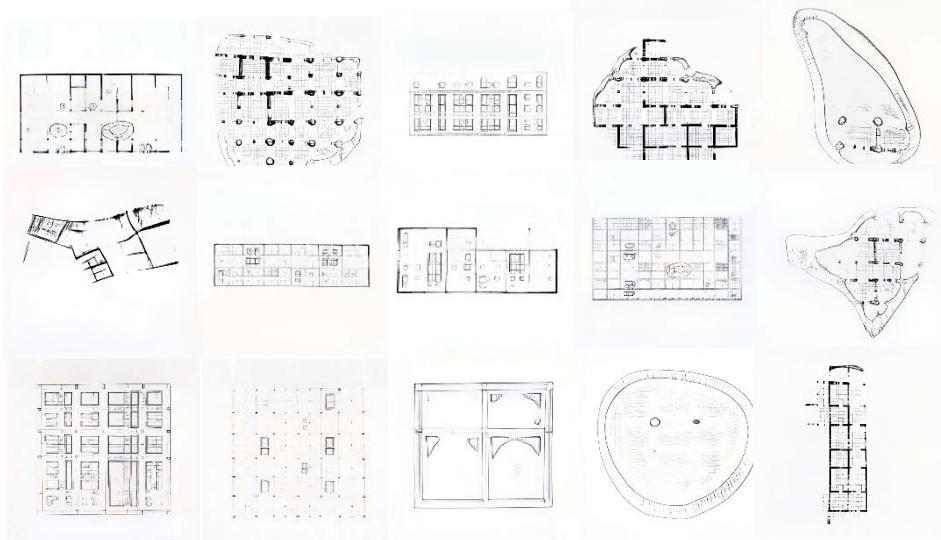
▣ 4. Run

▣ 5. Download video

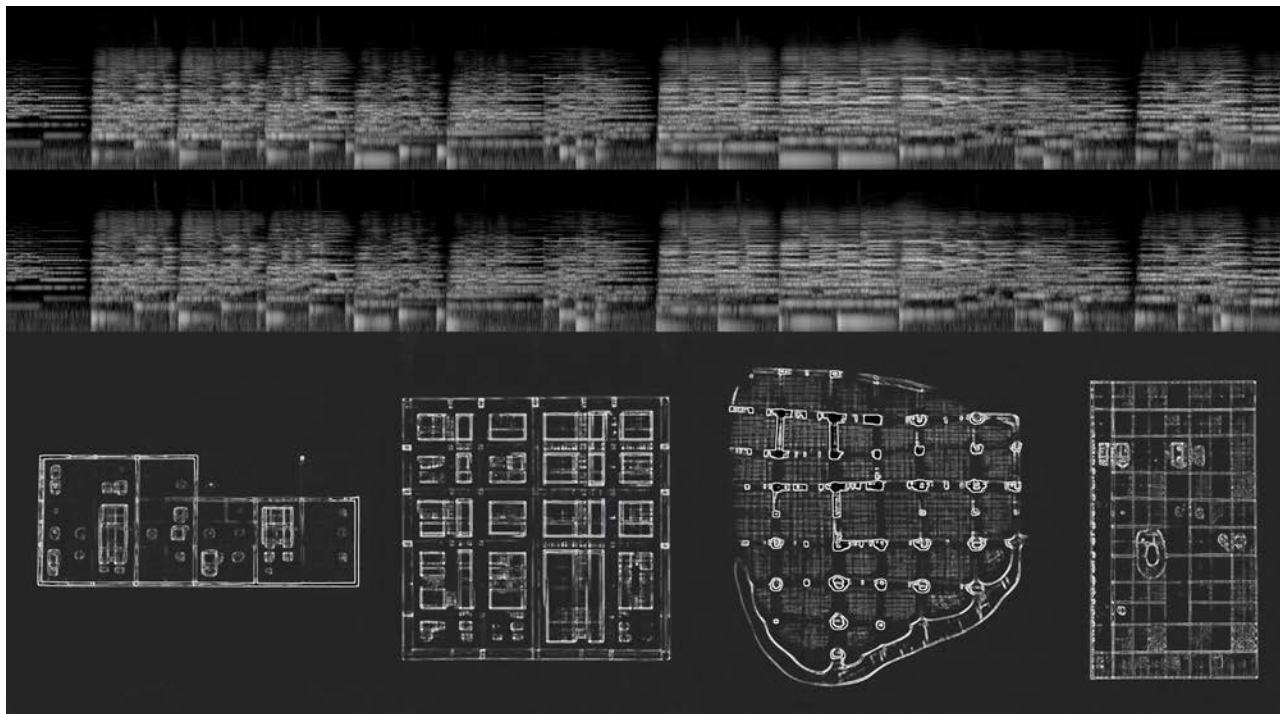
2.4 Results of generated plans (video)



- ◆ A 5:54 video
 - ▣ With morphing plans
 - Similar to the morphing arts on Page 7
 - ▣ “Interpolations” of the training plans
- ◆ I collected some



2.4 Featured on the cover page of Dean's RoundUp



- ◆ Upper:
 - ▣ Spectrogram of the Anthem
 - ▣ By “foobar2k”
- ◆ Lower:
 - ▣ Four selected subjectively
- ◆ Next...
 - ▣ May the plans trigger similar feelings to those from Anthem?



2.4 30-line codes and class adjustment



```

1 from lucidsonicdreams import LucidSonicDream
2 from google.colab import files
3
4 import os
5 import requests
6
7 def download(url: str, dest_folder: str):
8     if not os.path.exists(dest_folder):
9         os.makedirs(dest_folder) # create folder if it does not exist
10    filename = url.split('/')[-1].replace(".", "_") # be careful with file names
11    file_path = os.path.join(dest_folder, filename)
12    r = requests.get(url, stream=True)
13    if r.ok:
14        print("saving to", os.path.abspath(file_path))
15        with open(file_path, 'wb') as f:
16            for chunk in r.iter_content(chunk_size=1024*8):
17                if chunk:
18                    f.write(chunk)
19                    f.flush()
20                os.fsync(f.fileno())
21    else: # HTTP status code 4XX/5XX
22        print("Download failed: status code: {} \n {}".format(r.status_code, r.text))
23
24    download("https://online.fliphtml5.com/pxkj/ghhi/files/extfile/BackgroundSoundURL.mp3", dest_folder=".")
25
26 L = LucidSonicDream(song = 'BackgroundSoundURL.mp3',
27                    style = 'floor plans') # lsun, bedrooms, maps, abstract art, modern art
28
29 L.hallucinate(file_name = 'floor1.mp4',
30              resolution = 1080,
31              #start = 81,
32              #duration = 5,
33              fps=24
34              )
35
36 files.download("floor1.mp4")

```

- ◆ A tutorial of LucidSonicDreams: https://colab.research.google.com/drive/1Y5i5oxSF1uN3V4Md8TB3o_GOAtts7RQD#scrollTo=Z7DkKcO9cfM
- ◆ For assigning class mapping, use the parameter below

```

L.hallucinate('lucidsonicdreams.mp4',
             resolution = 360,
             start = 32,
             duration = 60,
             pulse_react = 0.25,
             motion_react = 0,
             classes = [1,5,9,16,23,27,28,30,50,68,71,89],
             dominant_classes_first = True,
             class_shuffle_seconds = 8,
             class_smooth_seconds = 4,
             class_pitch_react = 0.2,
             contrast_strength = 0.3,
             flash_strength = 0.1)

```

Section 3

DISCUSSION





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3.1 Summary

	Data granularity	Semantics in “DT”	Handy tools	Simulation-based optimization
2.1	Individual bamboo	Bamboo lengths	GH	Yes
2.2	Building / block	Buildings’ section skeleton	CloudCompare to edit 3D points	Data-driven + integer programming
2.3	MiC module	Env. (climate, 3D env.)	GH/ wallacei, energy plus, ladybug, honeybee, radiance	Yes (GA)
2.4	(?Music?)	(?Verse, tone, volume?)	AIGC/ Lucid Sonic Dream, StyleGAN2	(?My manual selection?)



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3.2 A recap

- ◆ DfX indicates optimization – finding the best(s)
 - ▣ DT can help DfX and generative design in different aspects
 - Abstraction, generic model, constraints, and decision-making
 - ▣ Generative design is a **human-centric** approach for DfX
- ◆ A DT contains nothing more than you need
 - ▣ Value-driven, Level-of-Detail, Level Of Information Needed
- ◆ Many handy tools are on GH
 - ▣ Some are open-sourced elsewhere; some need Python coding
- ◆ Designer is still a human for AIGC
 - ▣ “AI designer” as an “employee” for low-level, tedious decisions
- ◆ Disclaimer
 - ▣ I am a software architect, not a real architect.
 - ▣ My apology for potential misunderstanding or far-fetched arguments



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Acknowledgement & job vacancies

- ◆ Supported by our on-going DfX-related projects
 - ▣ Hong Kong RGC (C7080-22GF, 5.3M) – **Generative DfX in high-rise modular building**: An expert-augmented cascade graph learning and optimisation approach
 - ▣ Hong Kong RGC (T22-504/21-R, 34.6M) – Healthy and resilient city with pervasive LoCHs (**localised outdoor thermal-comfort hubs**)
 - ▣ Hong Kong ITF (ITP/004/23LP, 7.5M) – “SBASE” project
- ◆ Job vacancies in my group
 - ▣ Postdoctoral Fellow: 1~5
 - ▣ Research Assistant: 5
 - ▣ PhD posts: 1~2

Xue: DfX with DT. TUDelft, 30 Jun 2023.

Project Reference: ITP/004/23LP
 Funding amount: HK\$5,209,500.00
 Schedule: 31/03/2023 - 31/03/2025

Scan-to-BIM Automation System (SBASE) for Built Assets Digitalization in Hong Kong

面向香港建設資產的三維點云自動建模系統

Project Team



Dr. Fan Xue
Project Coordinator(PC)



Prof. Anthony G.O. Yeh
Co-PI



Prof. Weisheng Lu
Co-PI

Abstract

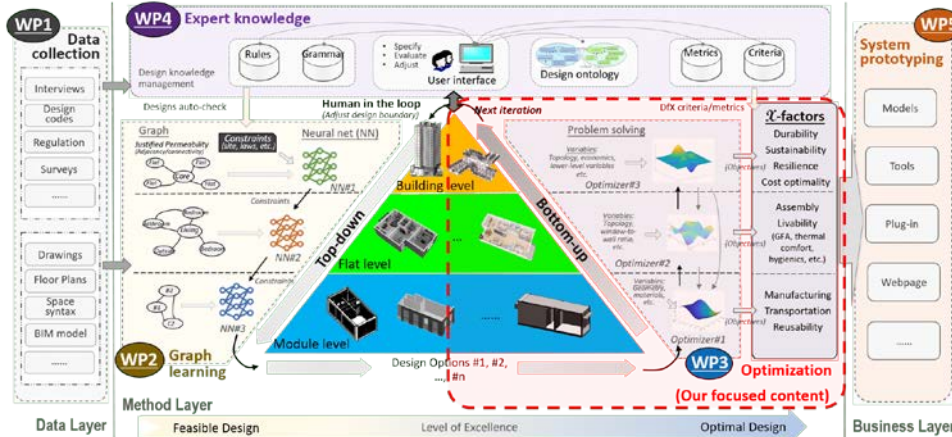
BIM is the key to construction digitalization. Scan to BIM involves the technique of surveying and reconstructing a digital representation of an existing building condition with its functional and physical attributes. The Scan-to-BIM has a huge emerging market of built assets digitalization, but has been hindered by low productivity (slow and costly manual work) and applicability (low-level object semantics, no Hong Kong context, huge file size and without texture). By solving/leasing the pains, this R&D project aims to develop a Scan-to-BIM Automation System (SBASE) for built assets digitalization in Hong Kong.

As a new Scan-to-BIM paradigm, SBASE aims to (1) double the productivity: automated point segmentation and 3D BIM object fitting; solidly based on our award-winning algorithms; and deep learning models trained for Hong Kong's projects datasets, and (2) create new values in applicability: 3 types of new functions for built assets, including verification, objects listing and checking, lightweight textured CIM output.

The critical value and urgency for SBASE can be gauged from committed strategies and recent initiatives. The proposed project is firmly built upon award-winning algorithms and R&D strengths accumulated among the applicant and collaboration departments at the University of Hong Kong. It will help Hong Kong to strengthen its smart construction and digitalization by continuously devising innovations and technologies.



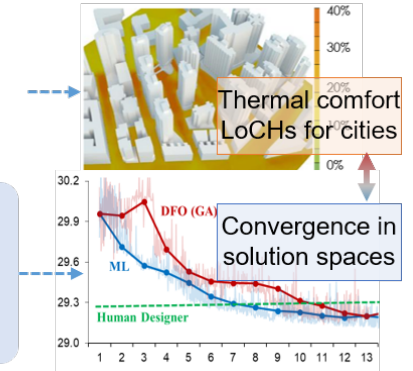
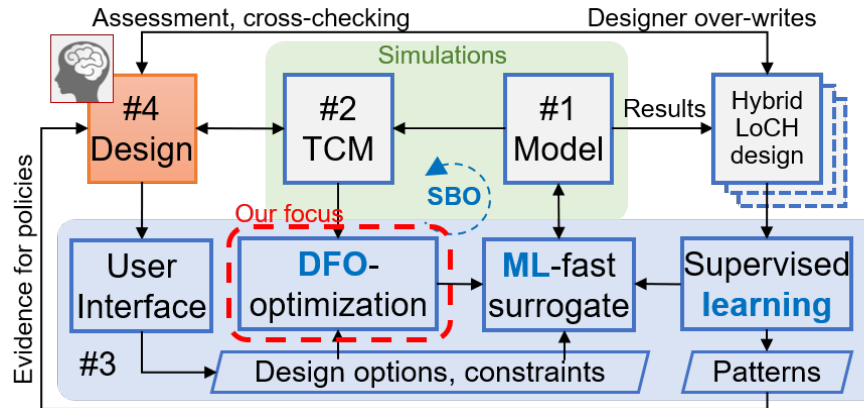
Acknowledgement (cont.)



Generative DfX in high-rise modular building

Localised outdoor thermal-comfort hubs

Xue: DfX with DT. TUDelft, 30 Jun 2023.





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- ◇ **Full video** (78M in 1080p) generated from the Anthem:
 - ▣ <https://www.dropbox.com/s/n02e5z83f17h73w/Floor%20plans%20generated%20using%20HKU%20Anthem%20as%20the%20input.mp4?dl=0>



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Enjoy your incoming weekend!

Q&A

