



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**

Fan Xue

Dept. of Real Estate and Construction, University of Hong Kong  
at Faculty of Architecture and the Built Environment, TU Delft

30 June 2023, Delft, Netherlands



The background of the slide is a photograph of a large, ornate building with a clock tower, likely a university or government building. The building is light-colored with many windows and columns. In the foreground, there are green palm trees and other tropical plants. The sky is blue with some light clouds.

Section 1

# **INTRODUCTION TO OUR LAB**

# 1 Hong Kong



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

- HKU
- CUHK
- HKUST
- HKPolyU
- HKCityU





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# 1 University of Hong Kong



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

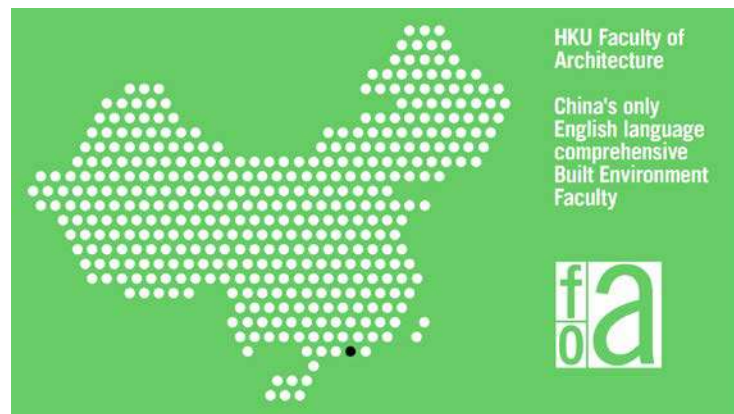


(Source: CPAO Multimedia, HKU)



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# 1 Faculty of Architecture



Architecture, Urbanism, and the Humanities Initiative	iLab	HKU URBAN 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	

Institute for Climate and Carbon Neutrality (ICCN)

Urban Systems Institute (USI)

foa

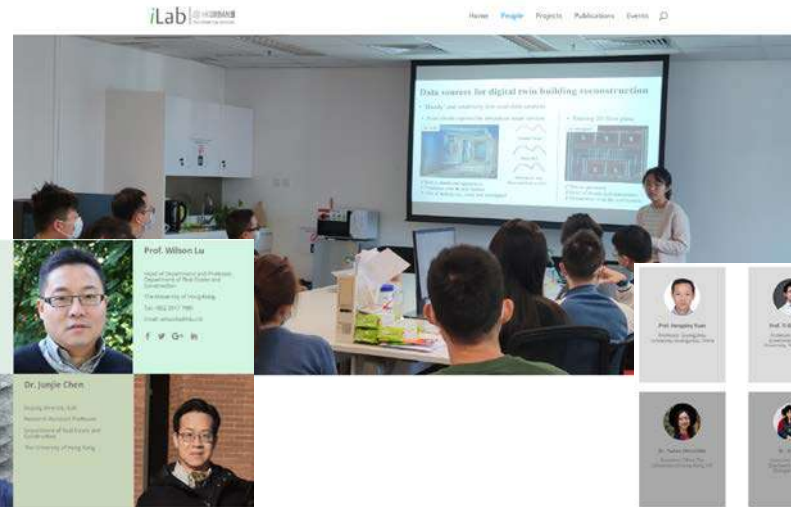
FoA is closely involved with these HKU-wide research initiatives:

Institute of Data Science (IDS)

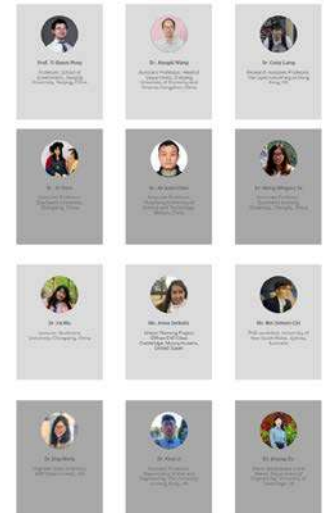
(Source: FoA, HKU)



# 1 iLab – the urban big data lab



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







iLab

# 1 My background and research interest

## ◆ 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

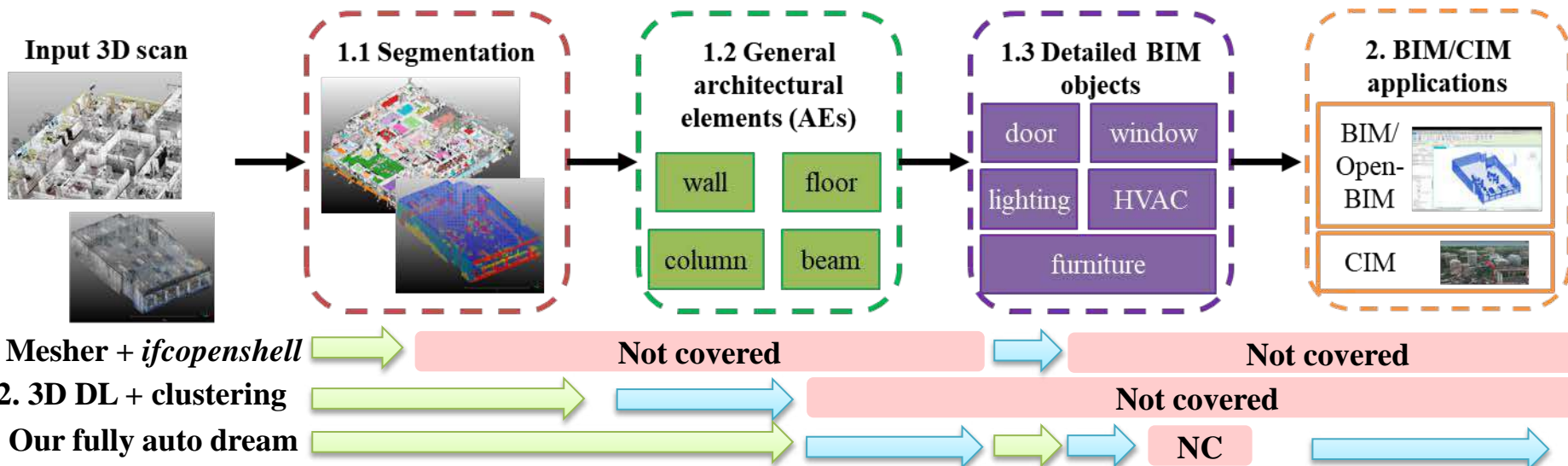




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# 1 My recent work #1: Scan-to-BIM automation

- ◆ 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 My recent work #2: Clustering for heritage DT

◆ Traditional deviation: 3D surface

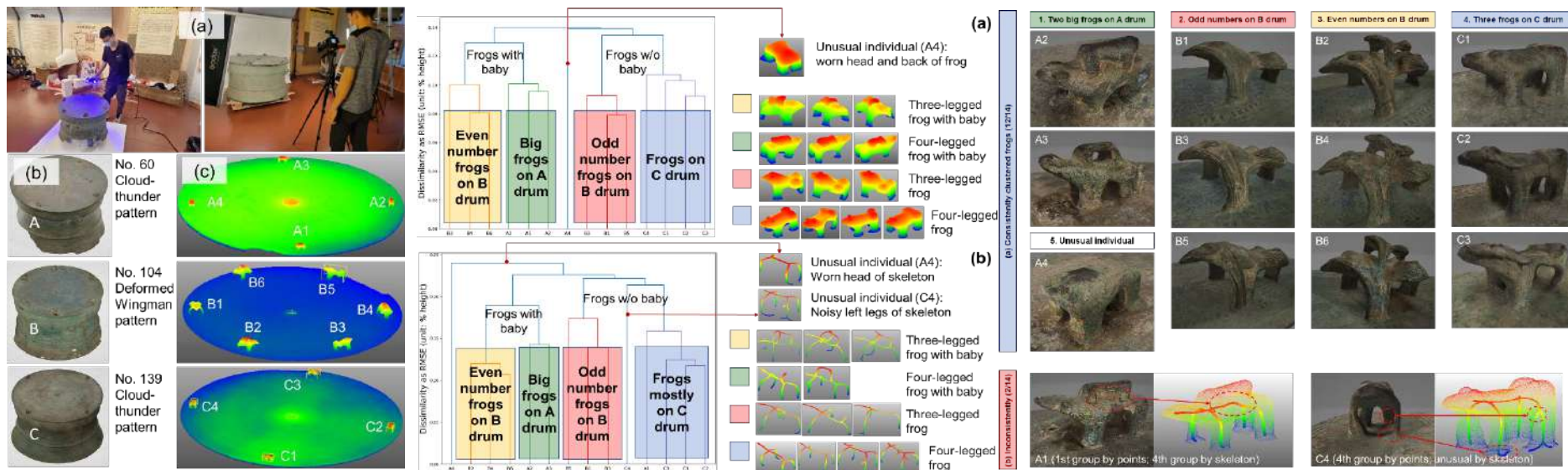
◆ Cases: Bronze frog drums

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

□ Result:  $F_1 = 0.87$ .

□ Q2: Can shape skeleton ?

□ Not bad, 0.13 rooms to improve



The background of the slide is a photograph of a large, multi-story building with a classical architectural style. It features a long facade with numerous columns and a prominent clock tower on the right side. The building is surrounded by lush greenery, including palm trees and other tropical plants. The sky is clear and blue.

## Section 2

# DFX WITH DT

## 2 DfX, generative design

### ◆ Design for MA

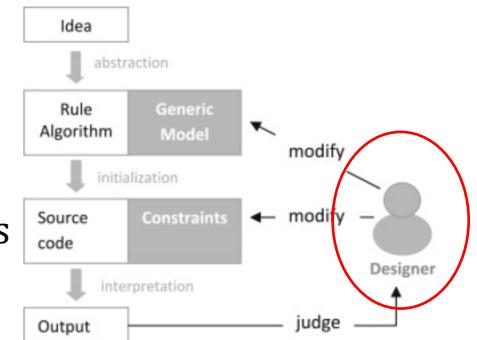
- ▣ Manufacturing and Assembly

### ◆ 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)





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## 2 DfX with DT

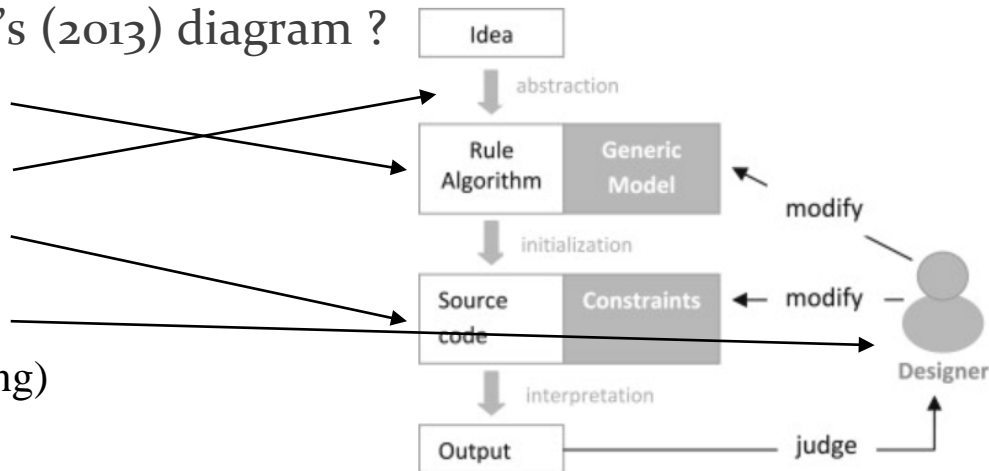
### ◆ A digital twin (UKNIC 2017)

- ▣ “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)





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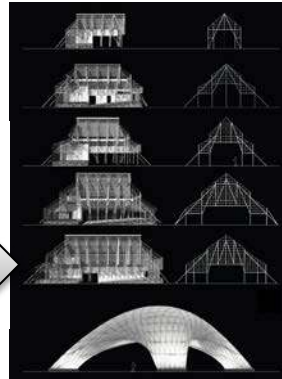
## 2.1 Case 1: DfX with DTs of materials

### ◆ ZCB Bamboo Pavilion

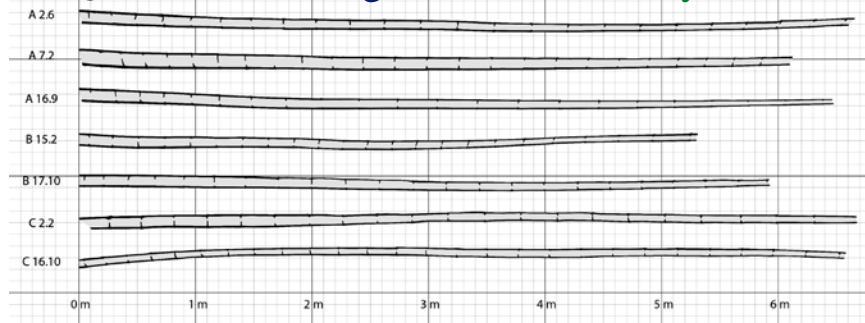


#### CLIENT BRIEF

- Host public events
- Showcase bamboo potential
- Promote sustainability



Q: maximum usage for sustainability?



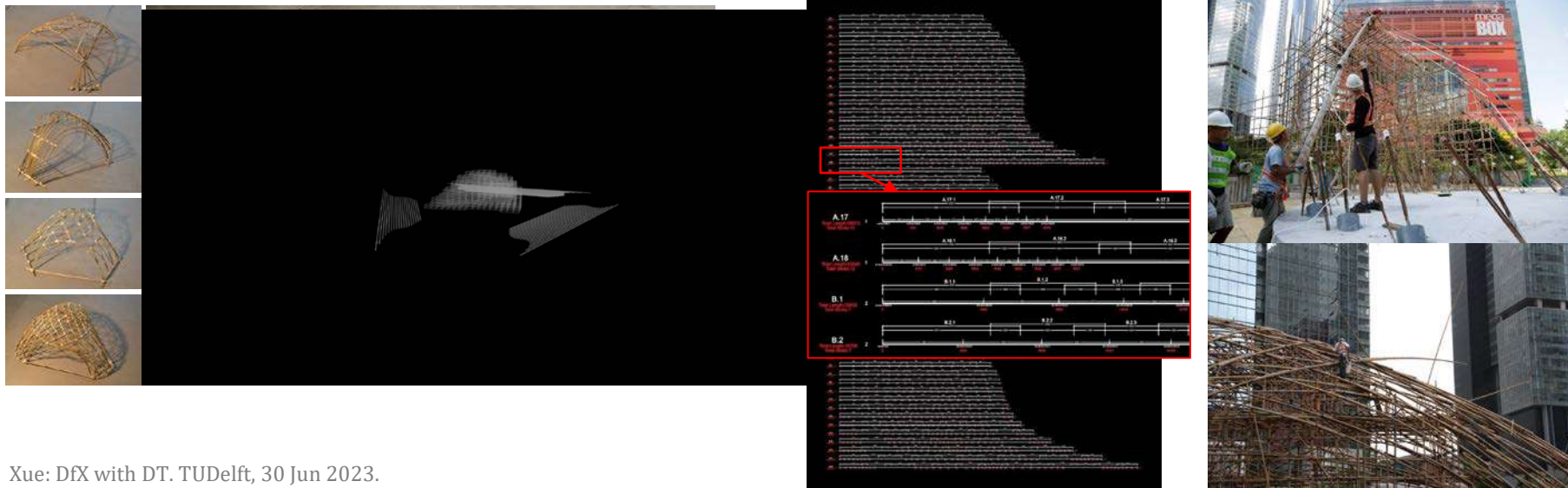
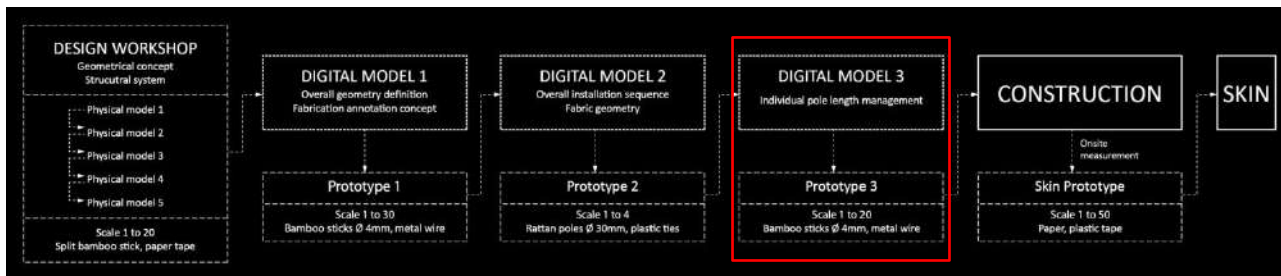
◆ Dr. Kristof Crolla  
[kcrolla@hku.hk](mailto:kcrolla@hku.hk)



◆ Associate Prof.

◆ Investigator of our on-going DfX project

# 2.1 Method: Optimizing poles to bamboo “DTs”







## 2.1 Completion and awards

Web: [bsl.hku.hk](http://bsl.hku.hk)  
Email: [krolla@hku.hk](mailto:krolla@hku.hk)



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

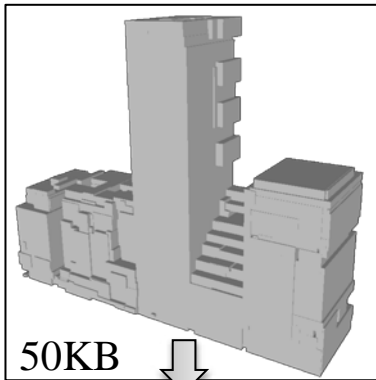


## 2.2 Case 2: DfX with DTs of common styles

- ◆ 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](mailto:yijiewu@connect.hku.hk)



- ◆ Yr-2 PhD candidate
- ◆ Team members



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

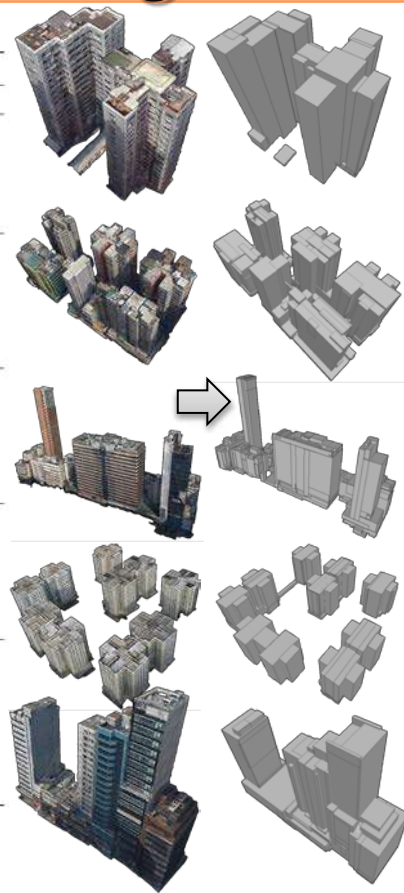
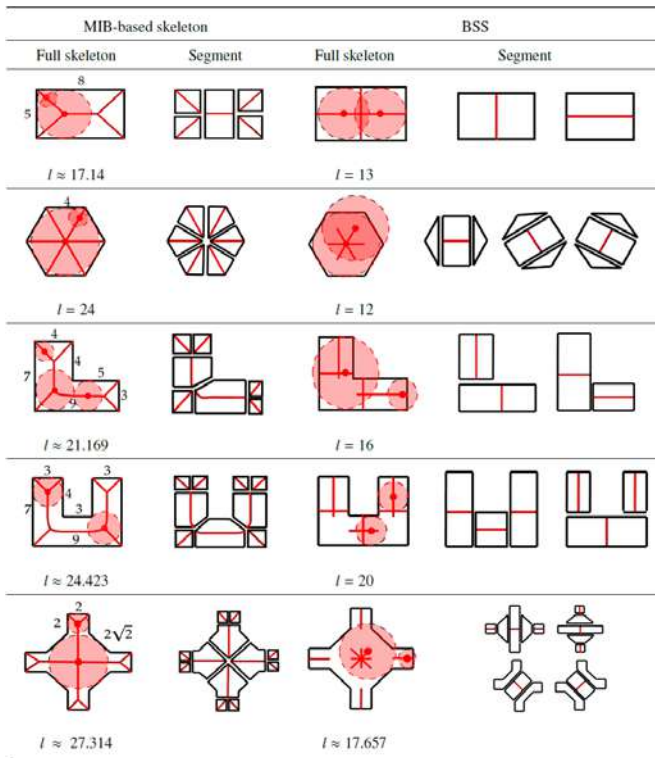
### ◆ MIB skeleton in geometry

- ▣ 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

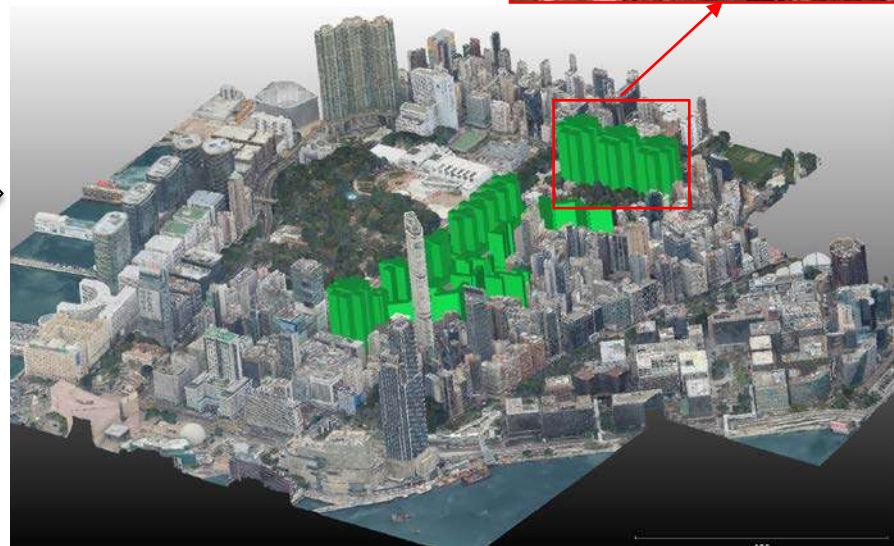
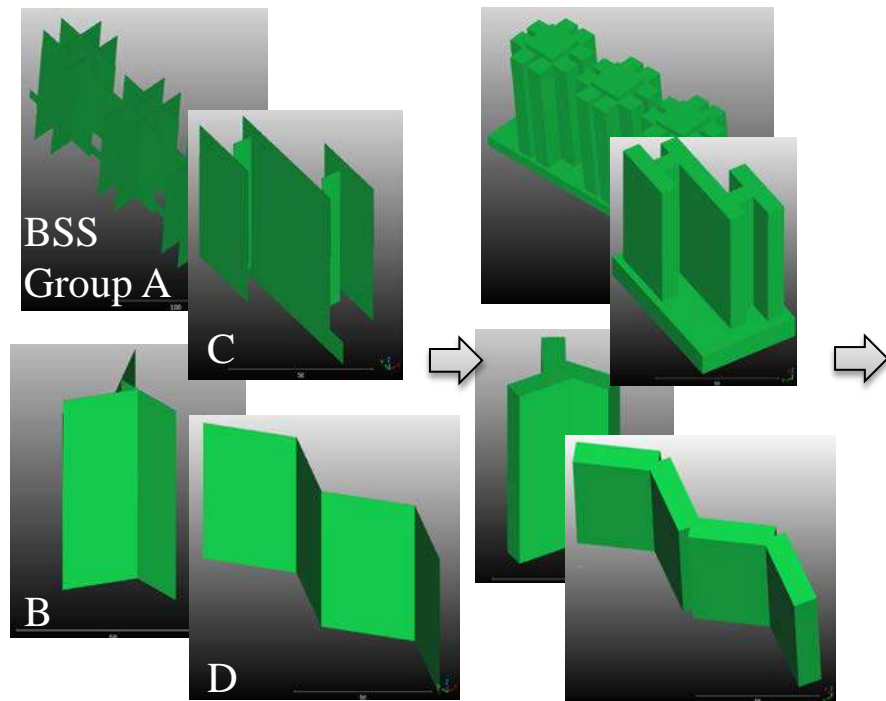
### ◆ Q1 answered





## 2.2 Generation of buildings and blocks

◇ 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](mailto:qianyunz@hku.hk)

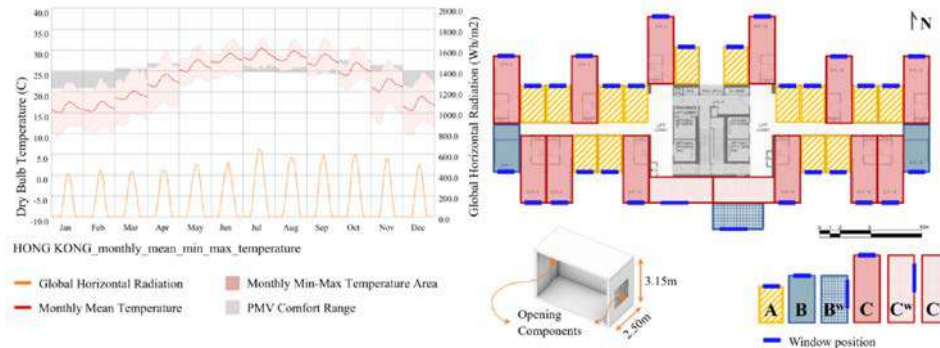
▣ Q-Add: Modular-integrated Construction (MIC) brings **discrete design variables**

▣ 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.

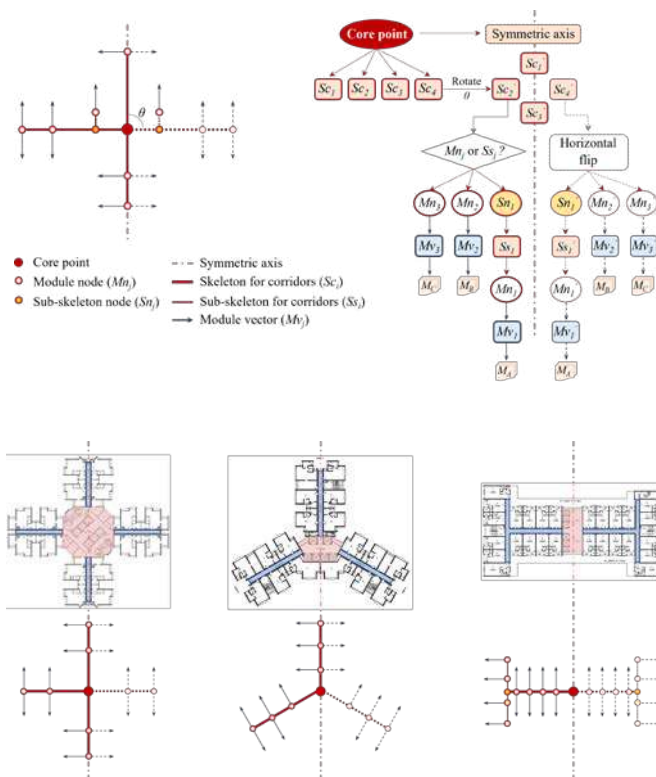
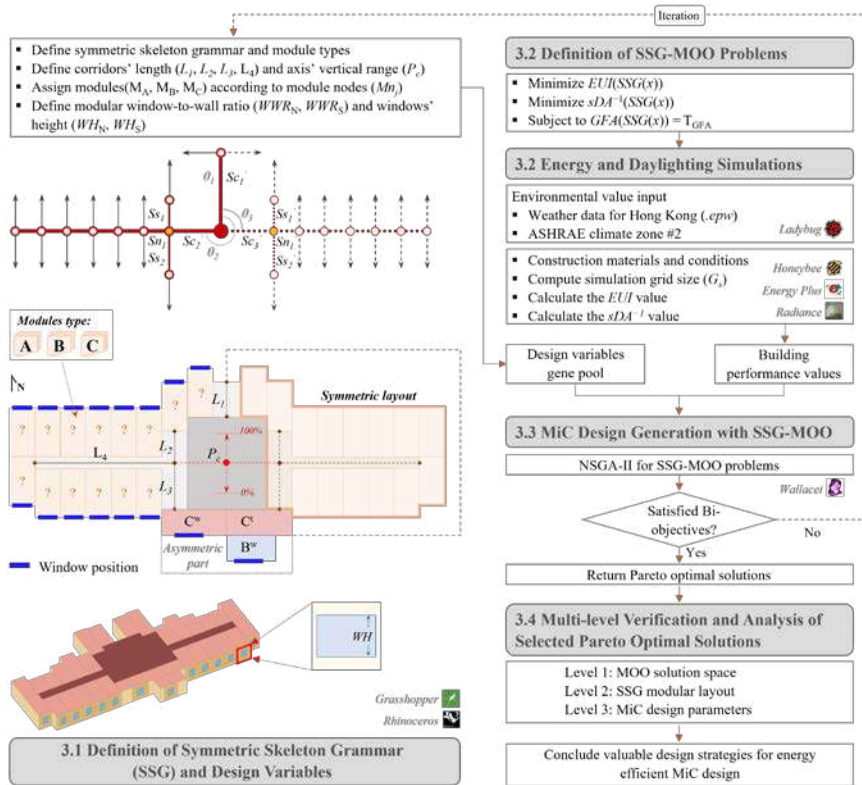


HKU WCH  
Student Hostel

HKU High  
West Hostel

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

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







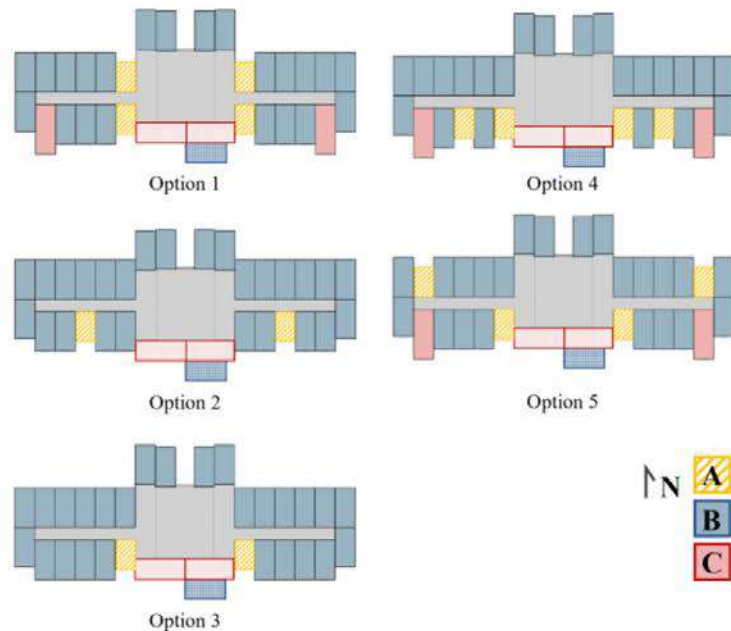
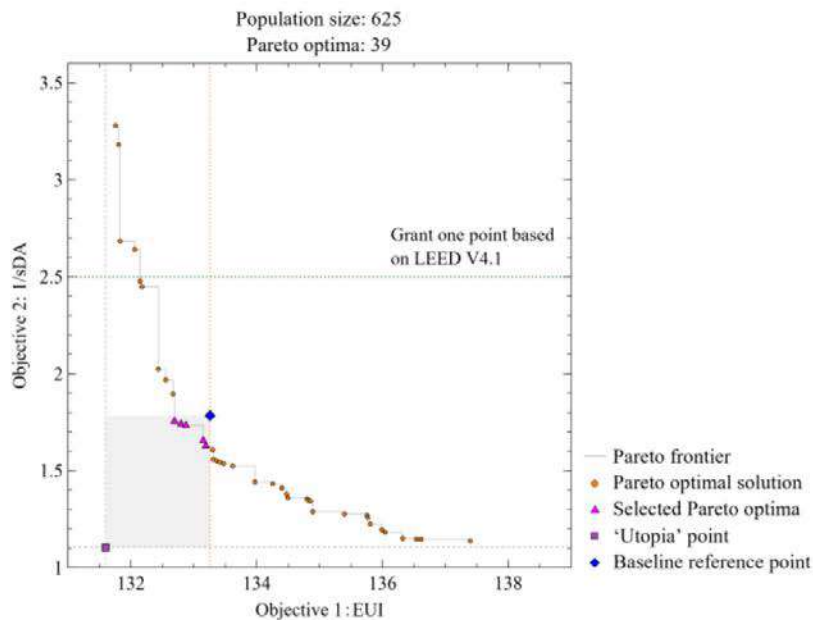
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## 2.3 Results

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

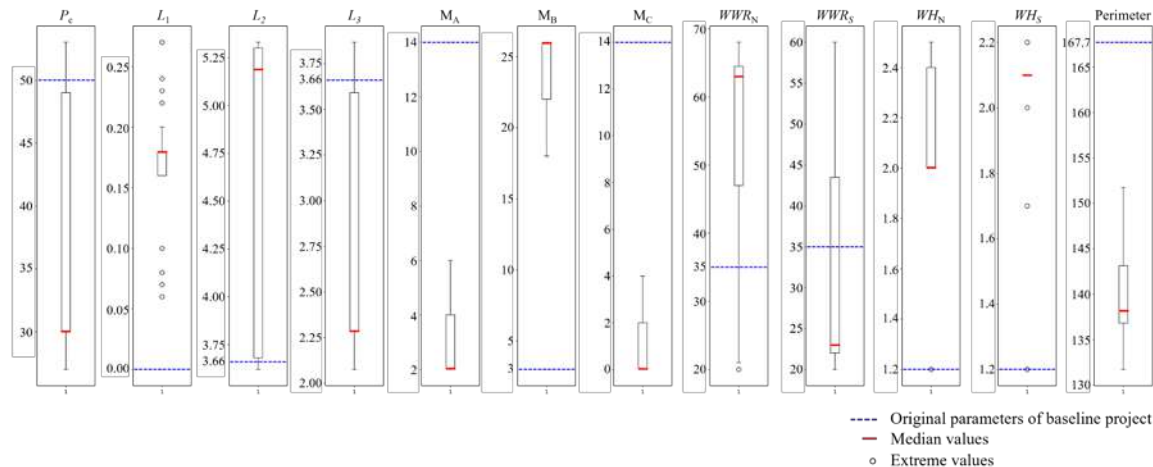
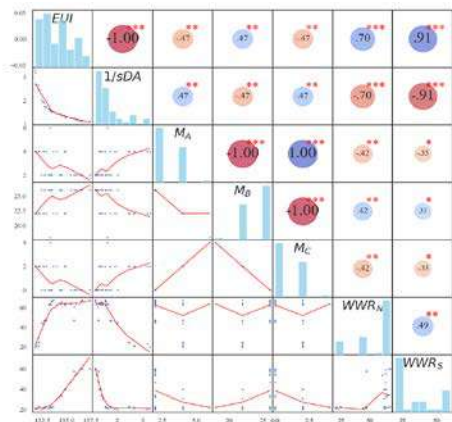
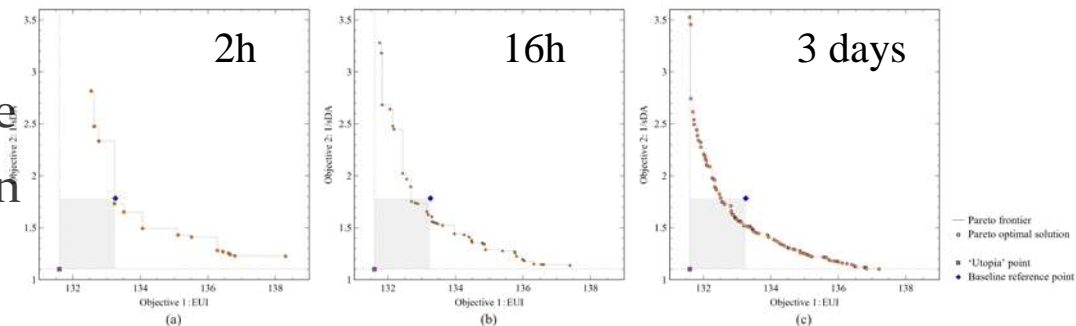
▣ in a preferred area, improving both **Xs**

▣ 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





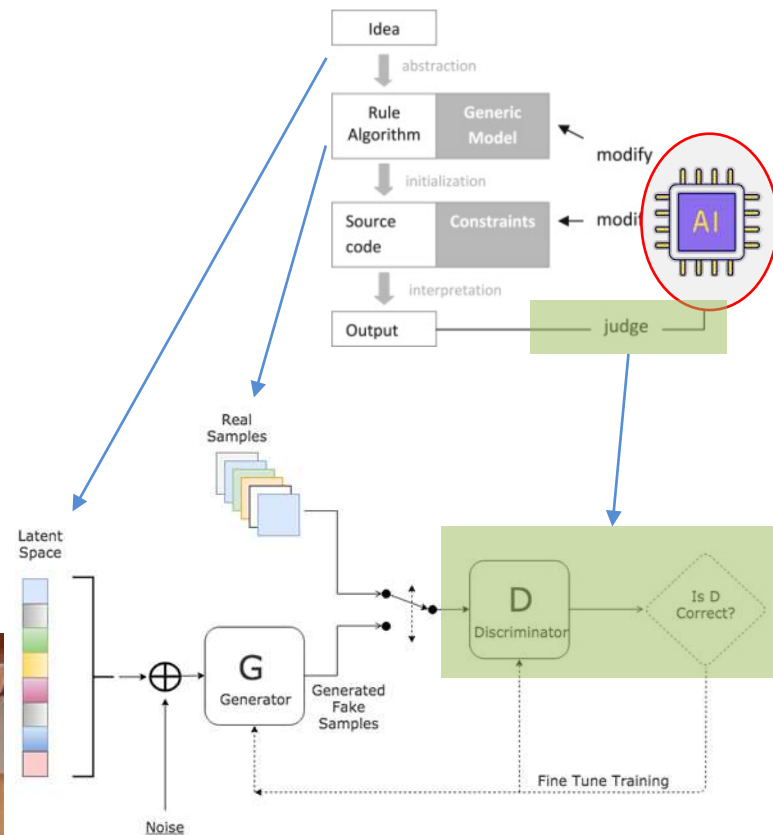
## 2.4 Case 4: AI-DfX??

◆ 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

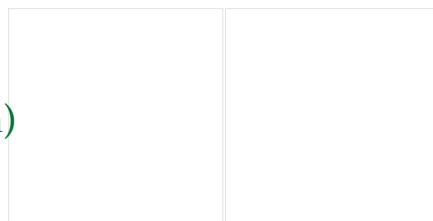
▣ By

- ArchiGAN
- Chaillou (2019), MArch (Harvard)

- ◆ Also for exteriors

▣ By

- StyleGAN-ada
- Rodrigues (2021).

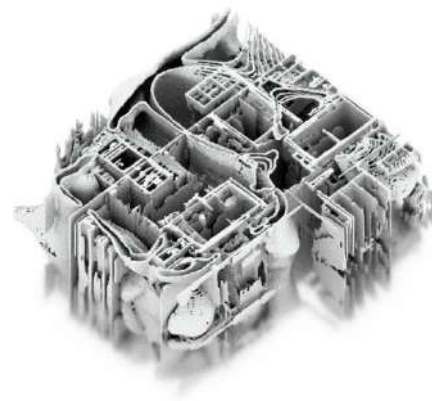




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## 2.4 Research question

- ◆ 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 (20<sup>th</sup> 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 fluit plagis.  
Mox doctrina meatu.

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

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

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.

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

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!

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

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

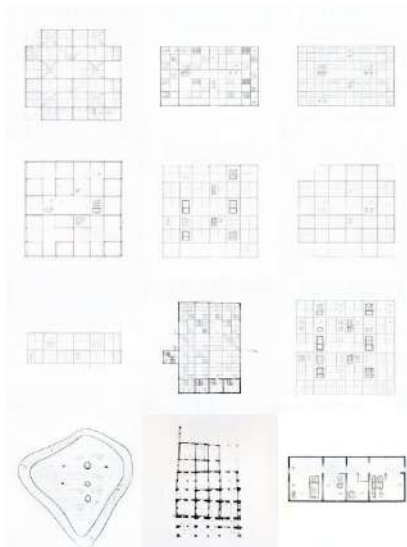
◆ Real plan sketches

▣ Collected by Mayur Mistry ←

○ Antique-like styles

◆ Final pipeline

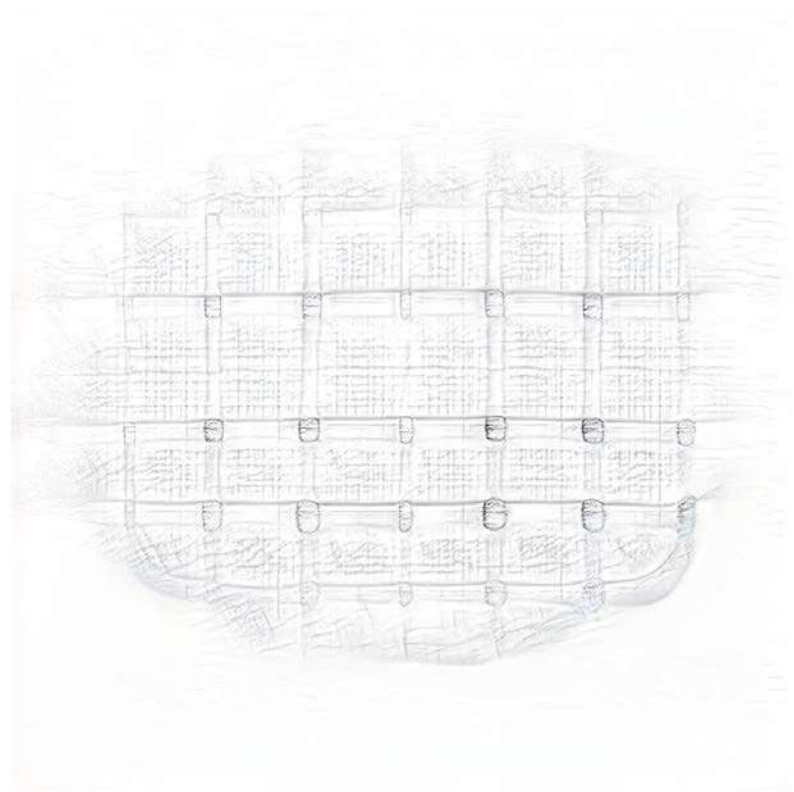
▣ Anthem → Lucid Sonic Dream → StyleGAN2 →  
video of plans → selected plans



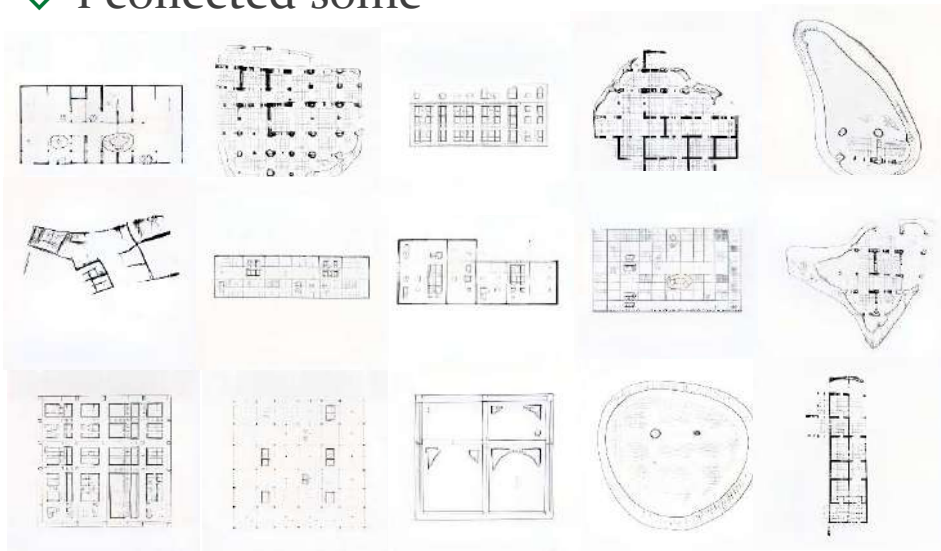
◆ Python codes (30 lines)

- ▣ 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

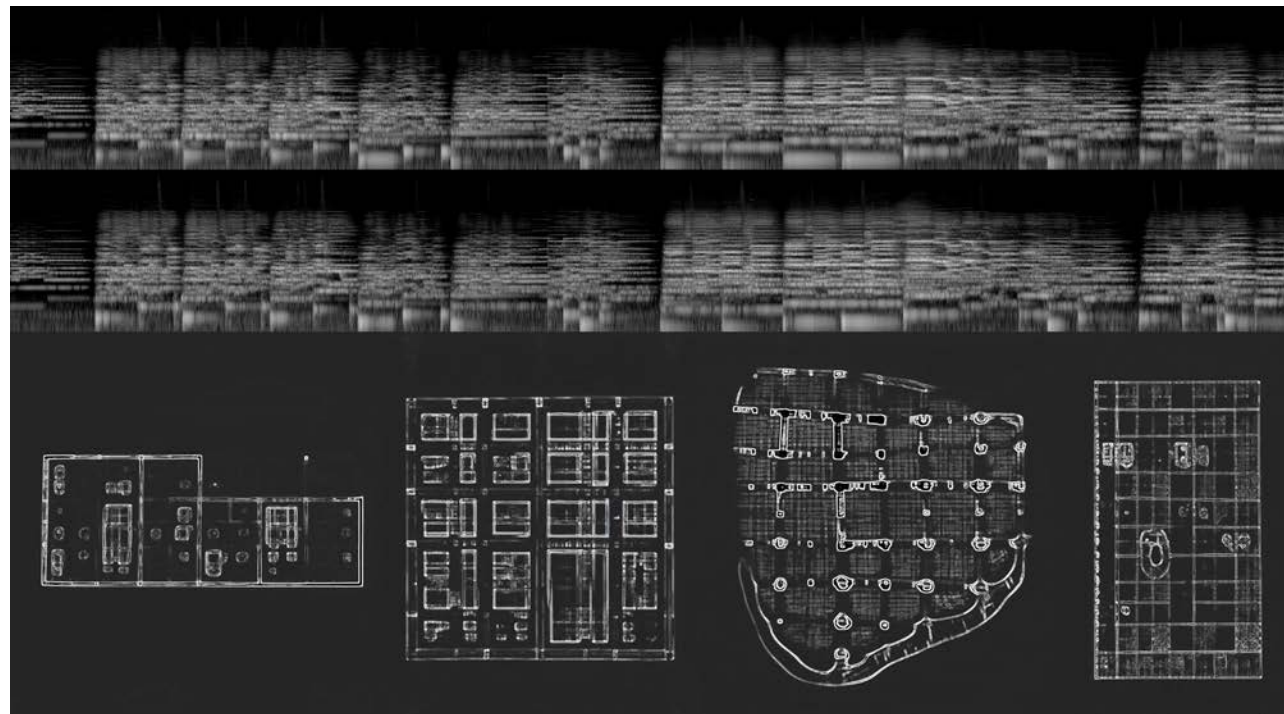
## 2.4 Results of generated plans (video)



- ◆ 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: {}".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/1Y5i5oxSFluN3V4Md8TB3o\\_GOAtts7RQD#scrollTo=Z7DkKcO9cfM](https://colab.research.google.com/drive/1Y5i5oxSFluN3V4Md8TB3o_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)

```

The background of the slide is a photograph of a large, ornate building, likely a university or government structure, featuring a prominent clock tower on the right side. The building has a classical architectural style with many windows and a long facade. In the foreground, there are lush green palm trees and other tropical vegetation, partially obscuring the lower part of the building. The sky is a clear, bright blue.

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

# 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	Abstract
 <b>Dr. Fan Xue</b> Project Coordinator(PC)	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/raising 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.
 <b>Prof. Anthony G.O. Yeh</b> Co-PI	
 <b>Prof. Weisheng Lu</b> Co-PI	




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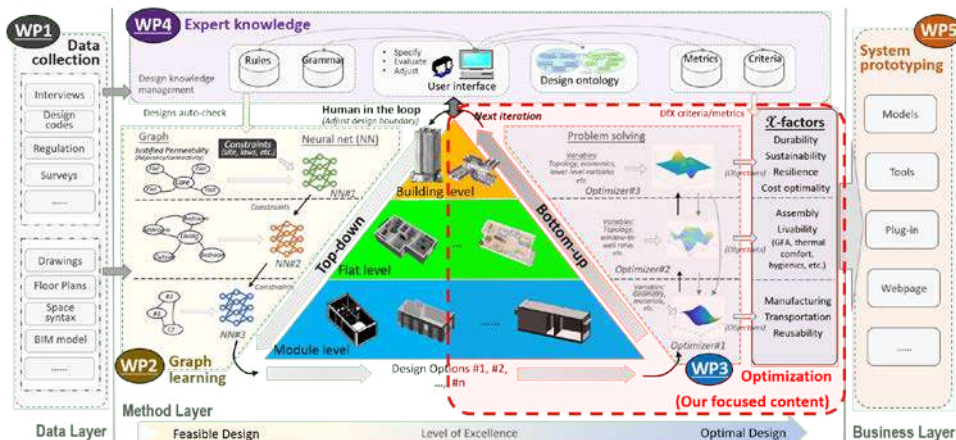






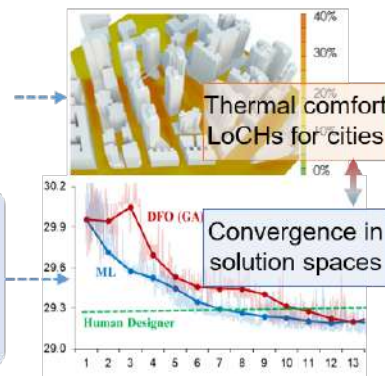
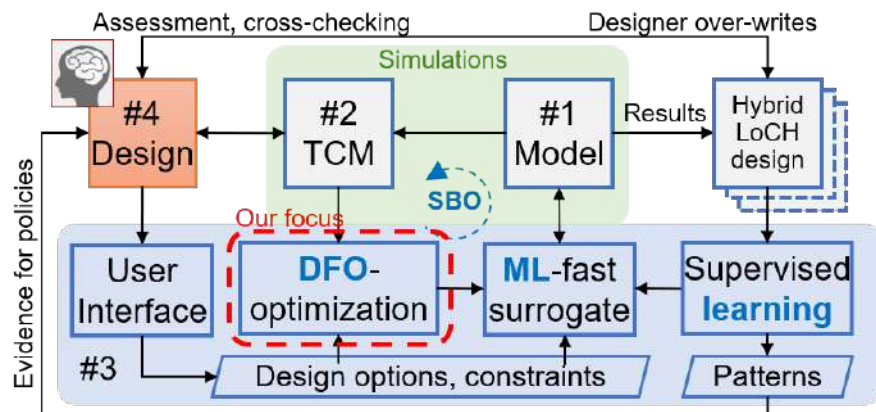


# Acknowledgement (cont.)



## Generative DfX in high-rise modular building

## Localised outdoor thermal-comfort hubs





# References

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- ◇ Xue, F., Zhang, W., Xu, G., Zhou, Q., & Wu, Y. (2023). Surface or skeleton? Automatic hierarchical clustering of 3D point clouds of bronze frog drums for heritage digital twins. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. X-M-1-2023, 293-299. <https://doi.org/10.5194/isprs-annals-X-M-1-2023-293-2023>
- ◇ Zhou, Q., & Xue, F. (2023). Pushing the Boundaries of Modular-Integrated Construction: A Symmetric Skeleton Grammar-Based Multi-objective Optimization of Passive Design for Energy Savings and Daylight Autonomy. *Energy and Buildings*, under review.
- ◇ 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

