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

iLab @ HKURBANlab 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

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

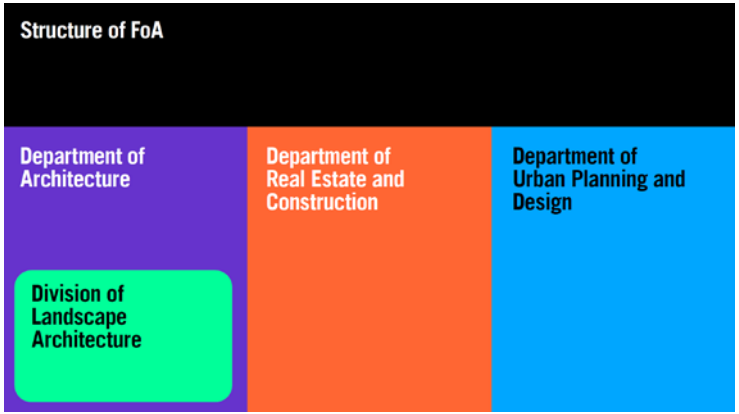
- HKU
- CUHK
- HKUST
- HKPolyU
- HKCityU

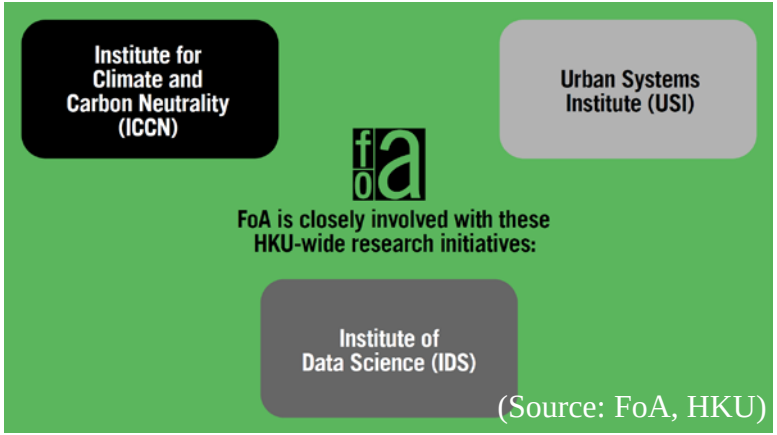
1 University of Hong Kong

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

(Source: CPAO Multimedia, HKU)

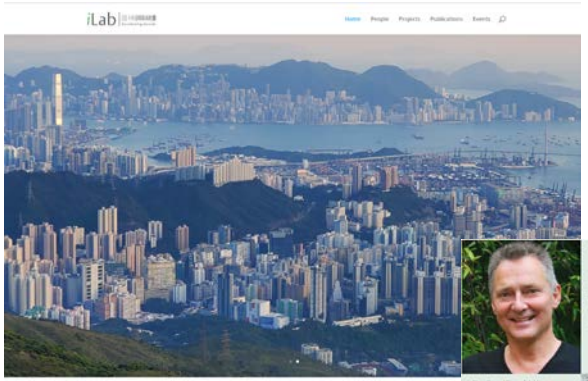
1 Faculty of Architecture

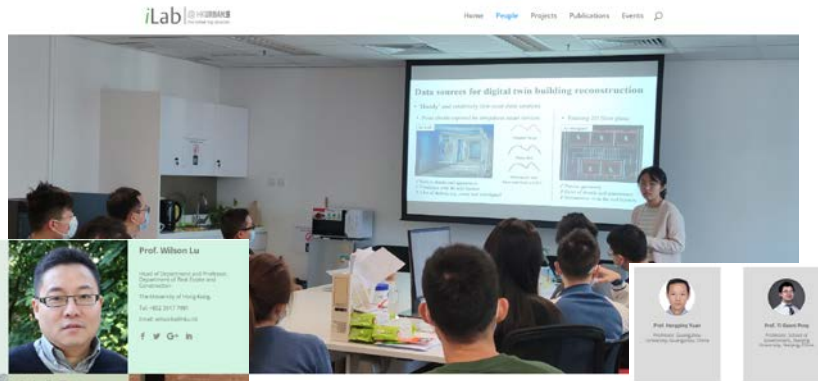


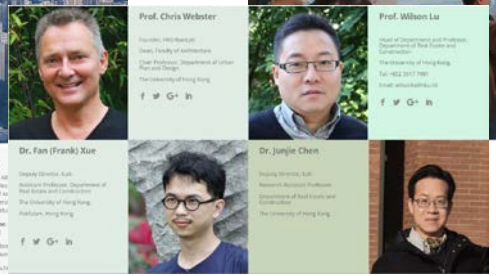


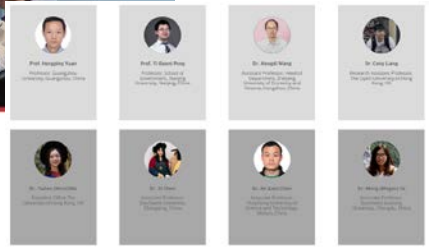
(Source: FoA, HKU)

1 iLab – the urban big data lab

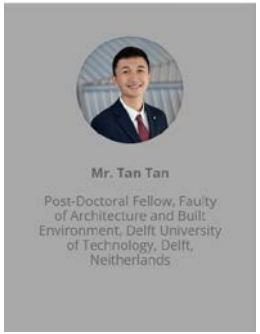








- https://ilab.hku.hk/
- 30 + 11 members
  - Two interest groups
- 23 alumni



1 My background and research interest

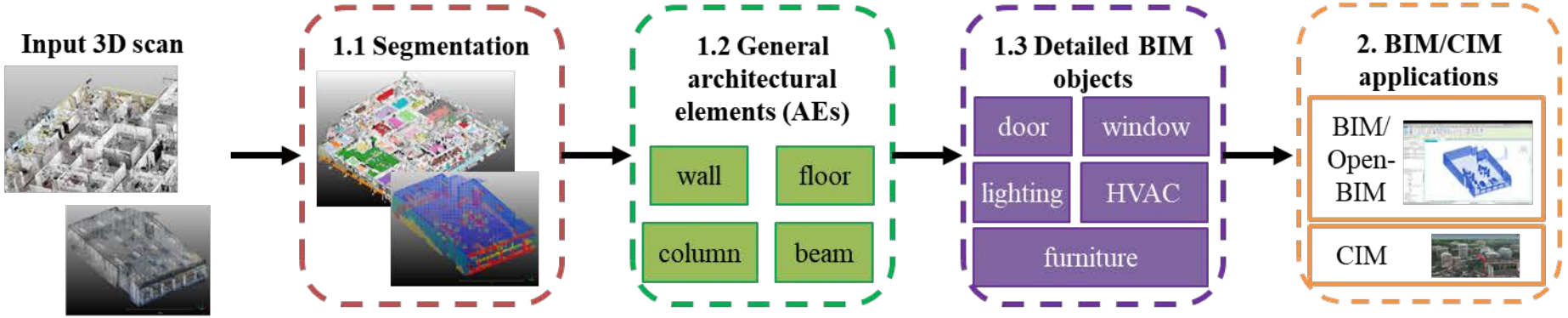
- Xue, Fan (Frank)
- Edu. background
  - BEng in Automation — 2004
  - MSc in Computer Science — 2007
  - PhD in System Engineering — 2013
  - PDF/RAP/AP in Construction IT
- Research interests
  - Urban sensing and computing
  - As-built BIM and Digital Twin
  - Automation/IT in construction
  - Operations research, ML
  - Blockchain applications in construction

- Professional
  - MACM, MHKGISA, MIEEE,
  - SMCGS, MASC, MHKABAEIMA
  - Vice-Chair ACM-HK, Com. CGS-BIM, Com. ASC-Smart Construction

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

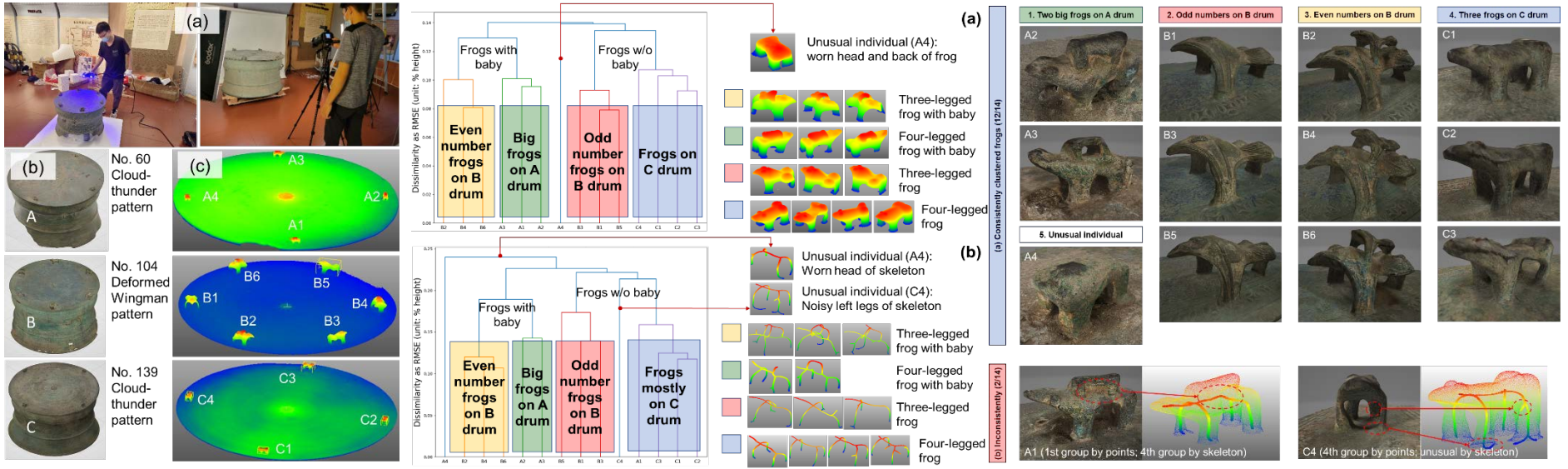
- 1. Normal segment + mesher + ifcopenshell (10+ years)
- 2. 3D deep learning segmentation + clustering (3+ years)
- 3. Our fully auto "dream": Automate >60% workload (1 year)

- Winner of Scan-to-BIM Challenge, CVPR2023



1 My recent work #2: Clustering for heritage DT

- Traditional deviation: 3D surface
  - Q1: Clustering (like building a Covid family tree)?
  - Q2: Can shape skeleton ?
- Cases: Bronze frog drums
  - Result: $F_1 = 0.87$.
  - Not bad, 0.13 rooms to improve



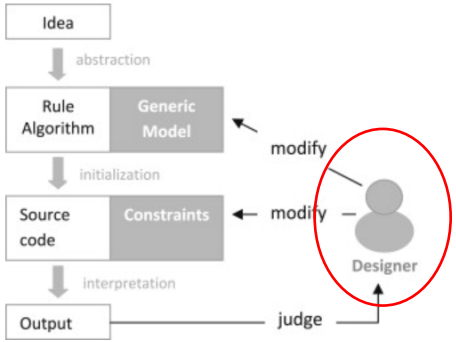
(Xue et al. 2023)

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

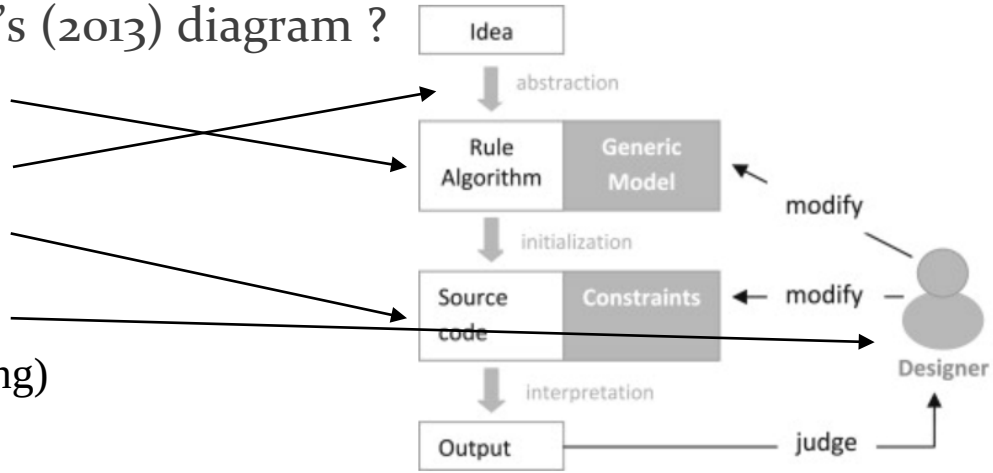


Generative design process (Krish 2011)

2 DfX with DT

- 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"

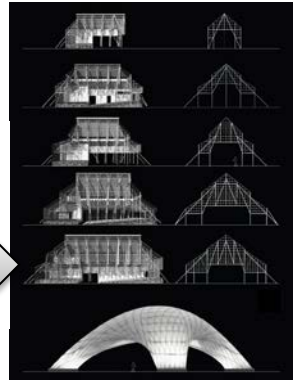
  (DT of low-level decision-making)



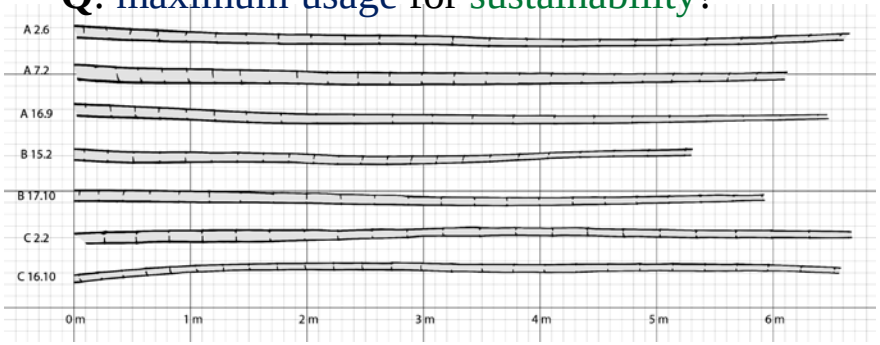
2.1 Case 1: DfX with DTs of materials

- ZCB Bamboo Pavilion

CLIENT BRIEF
- Host public events
- Showcase bamboo potential
- Promote sustainability



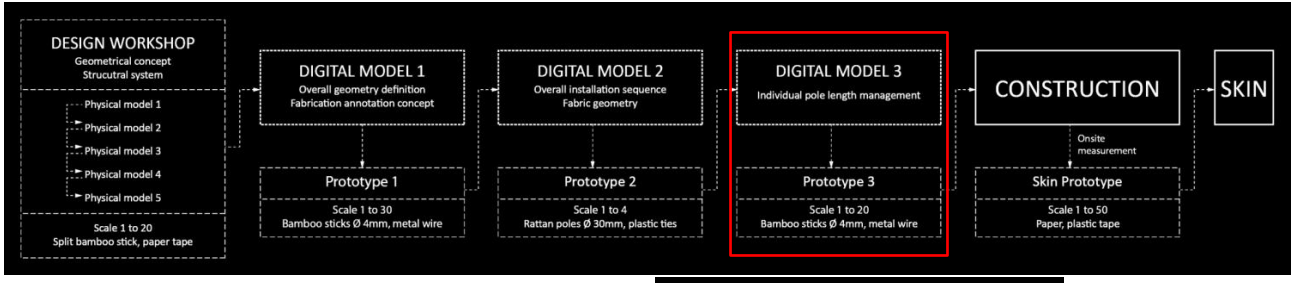
Q: maximum usage for sustainability?

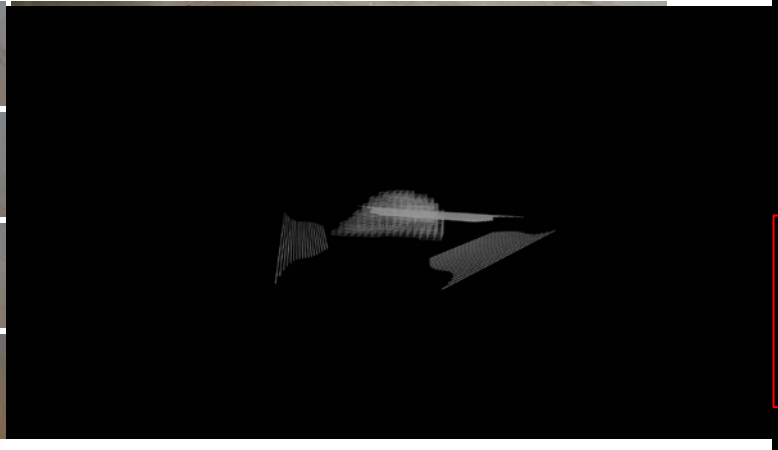


- Dr. Kristof Crolla
kcrolla@hku.hk

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

2.1 Method: Optimizing poles to bamboo “DTs”





2.1 Completion and awards

Web: bsl.hku.hk
Email: kcrolla@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

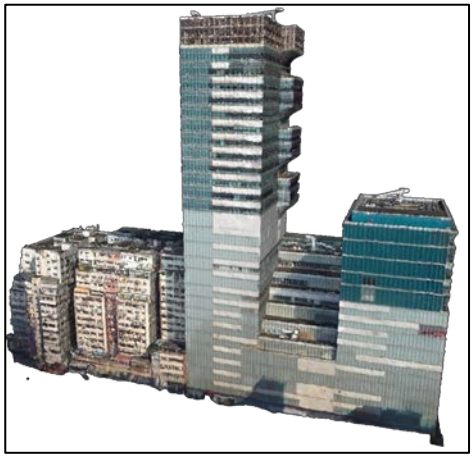
HKDA GLOBAL DESIGN AWARDS
Hospitality & Entertainment Space
GOLD AWARD

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?



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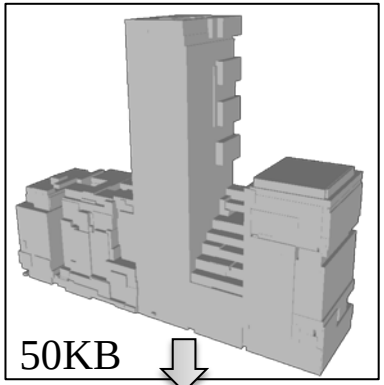


50KB

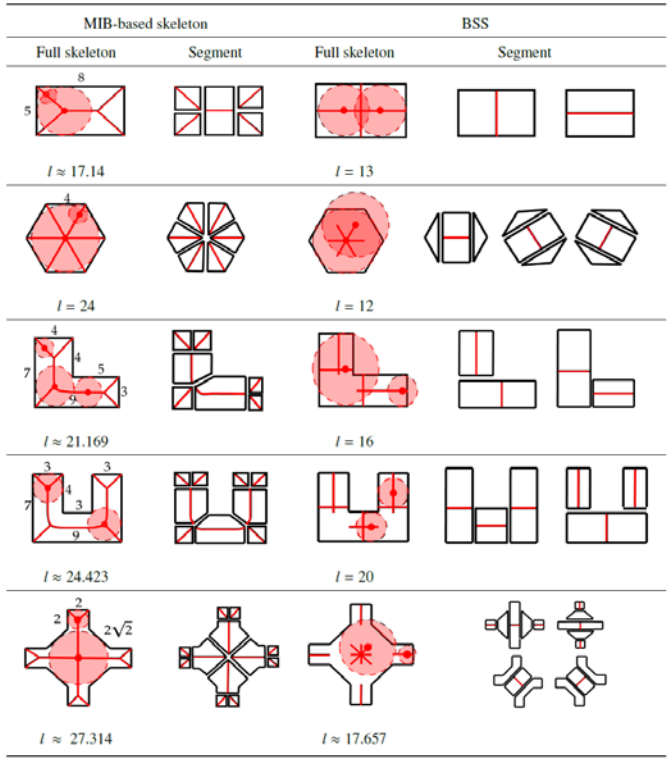
New Hong Kong-ish blocks?

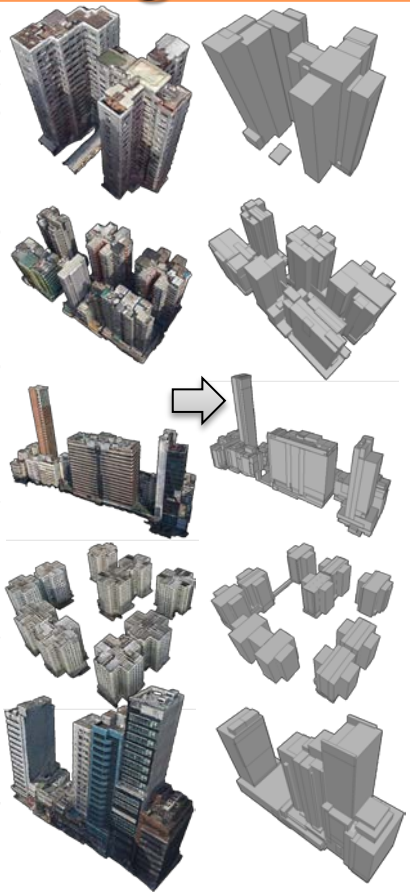
- Miss Yijie Wu
  yijiewu@connect.hku.hk

- Yr-2 PhD candidate
- Team members

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

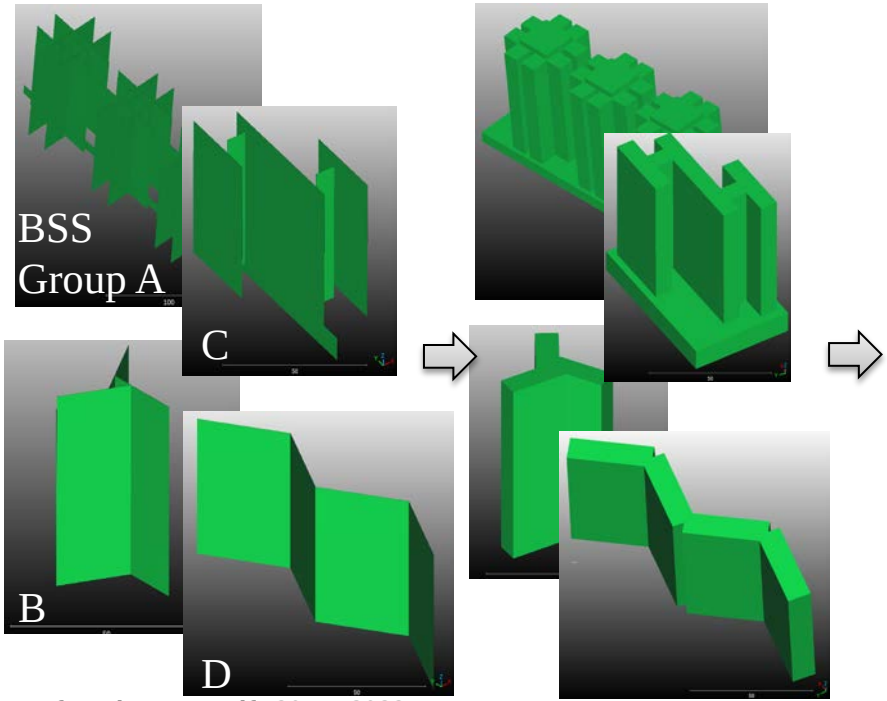
- MIB skeleton in geometry
  - Max Inscribed Ball centers
  - Counter-intuitive for plans
- Building Section Skeleton (BSS)
  - Extends MIB for polygon plans
  - Data-driven building style descriptor
  - High-level abstraction
- Q1 answered

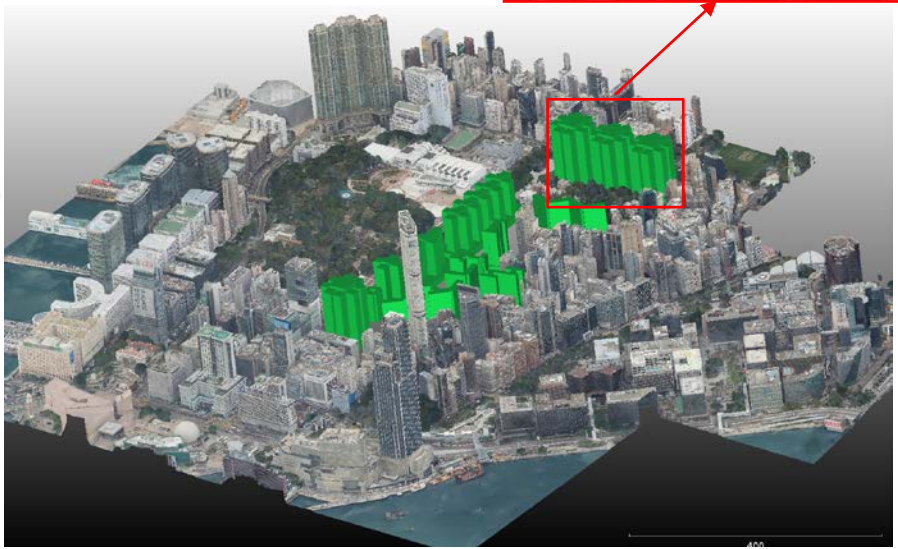




2.2 Generation of buildings and blocks

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



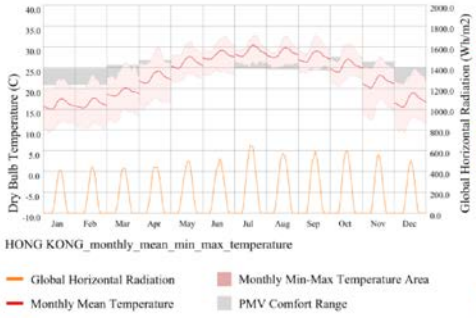


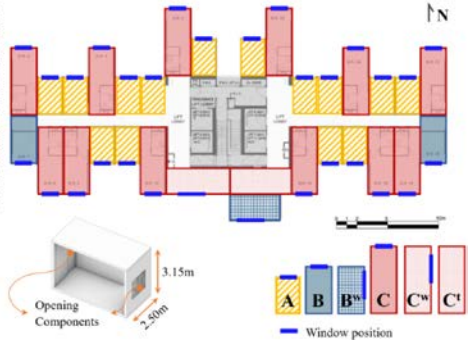
2.3 Case 3: DfX with DTs of climate and 3D env.

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

HKU WCH Student Hostel

HKU High West Hostel

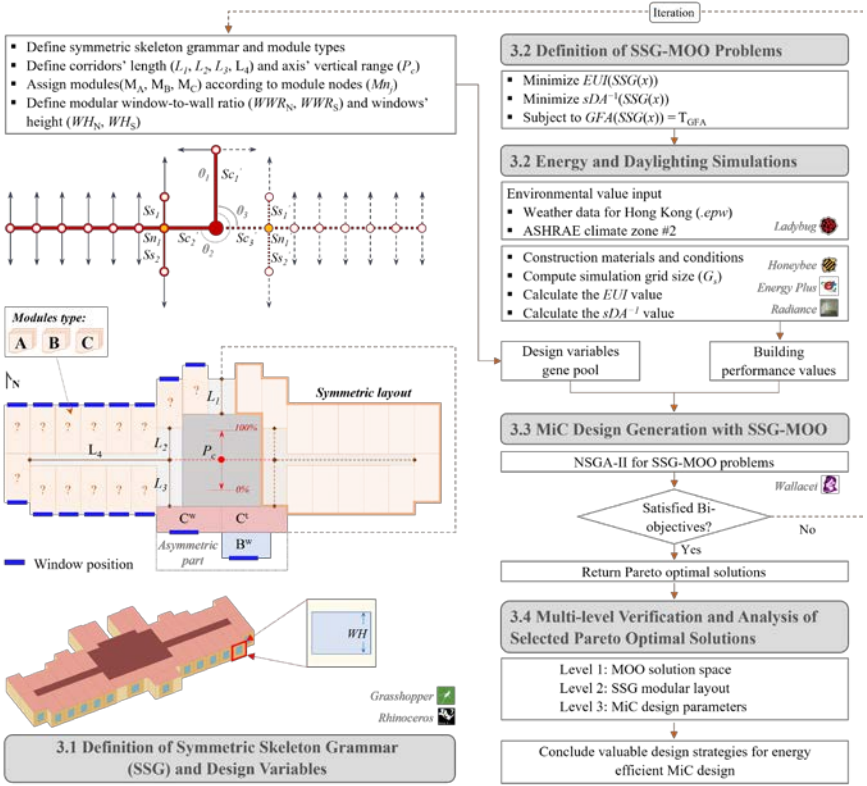


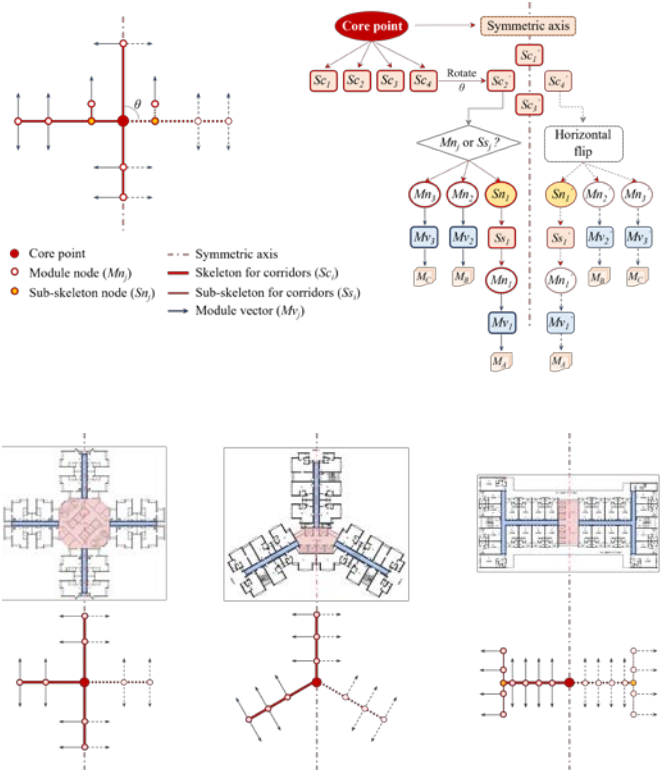


- Miss Qianyun Zhou
  qianyunz@hku.hk

- Yr-1 PhD in Sept.

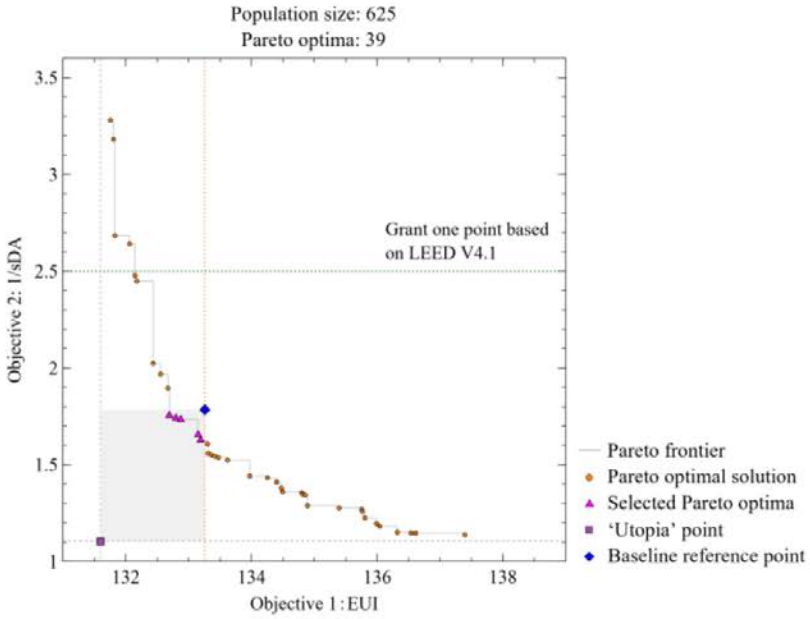
2.3 Method: GA + GH env. simulation (Zhou & Xue 2023)

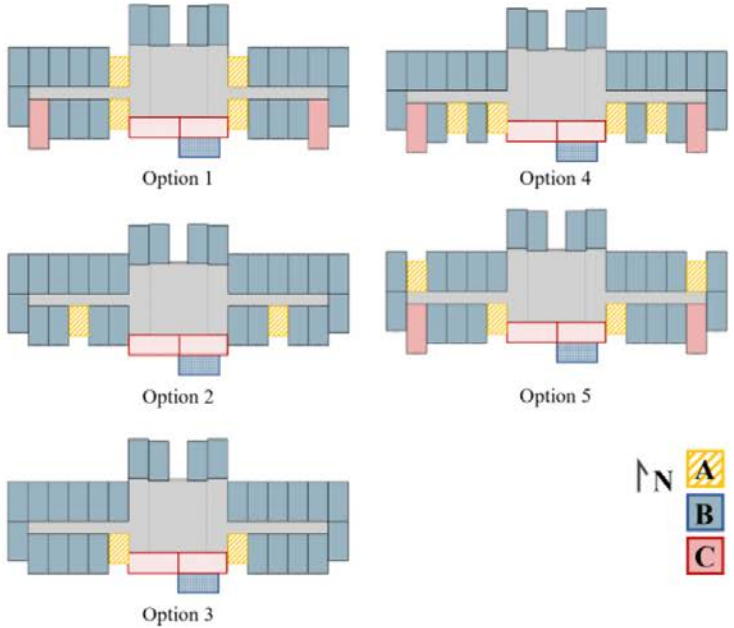




2.3 Results

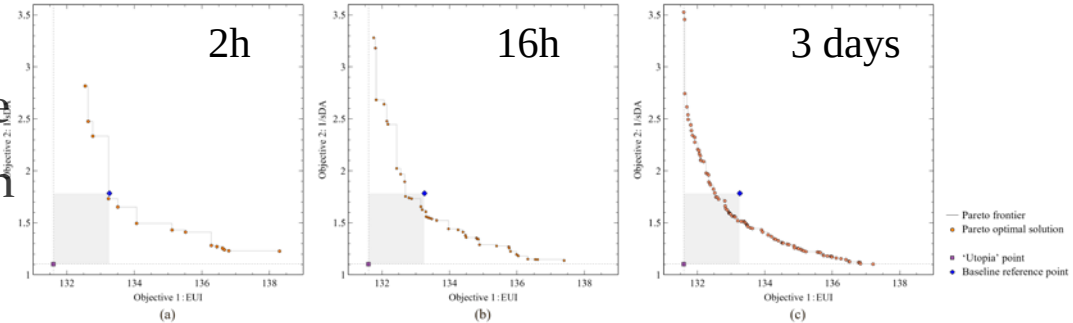
- After 15 hrs (GA+simu), 5 improved plans
  - in a preferred area, improving both Xs
  - EUI improved up to 0.42%, spatial daylight autonomy (sDA) improved up to 9.7%

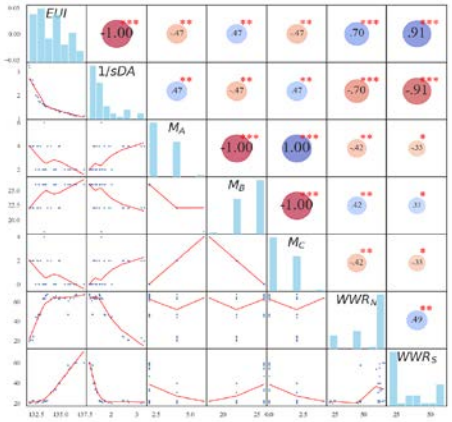


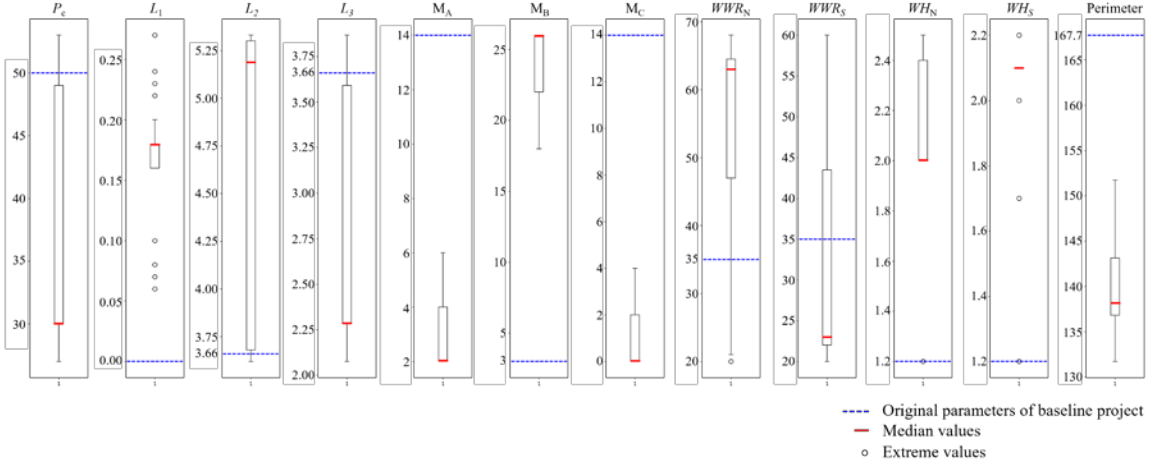


2.3 Analysis of generated Pareto optima

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

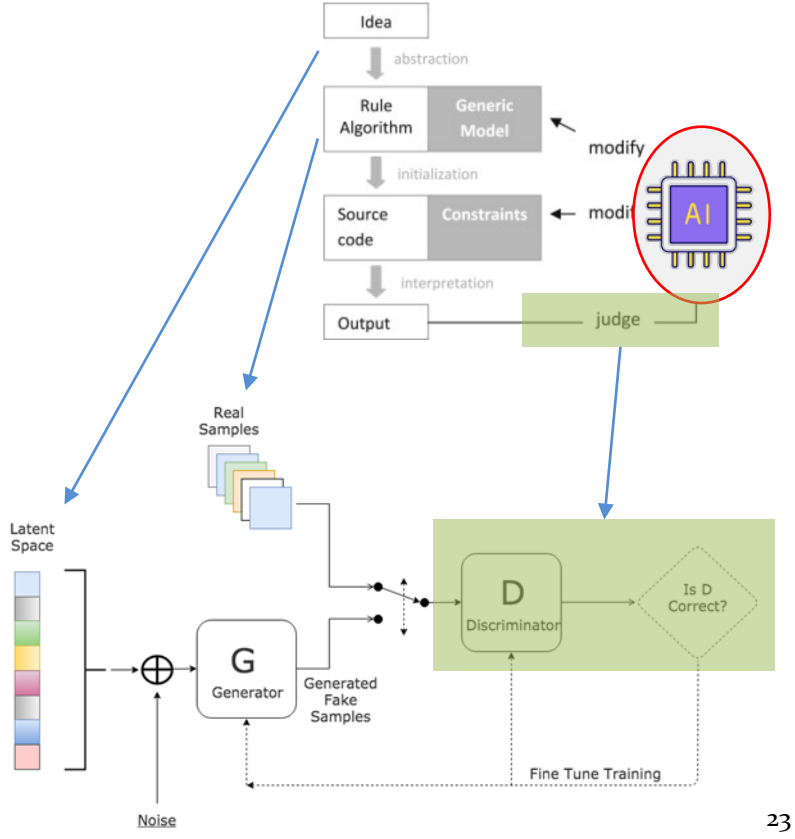






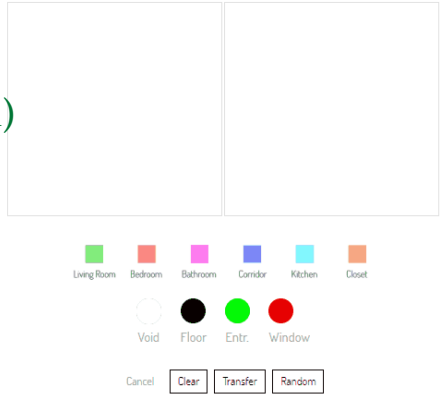
2.4 Case 4: AI-DfX??

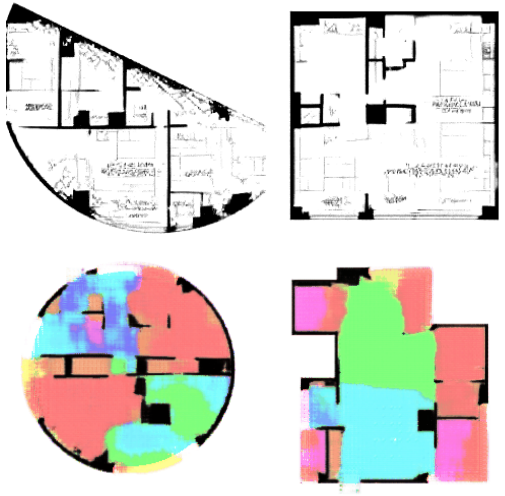
- Deep learning AI, especially GAN (Generative Adversarial Network)
  - Trained on many input samples
    - Against classes, e.g., cat, dog, or latent
  - Can "judge" outputs – to a certain extent
  - Taking the "supervisor" role from human
- The outputs are
  - Generated by an algorithm *G* and
  - Judged by the other *D*
  - So-called "adversarial"

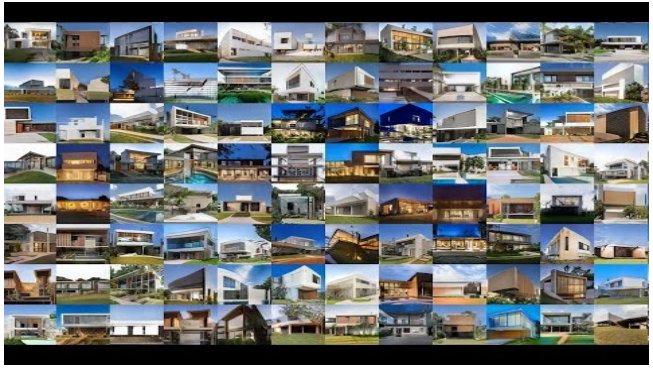


2.4 Intuitive examples

- 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).

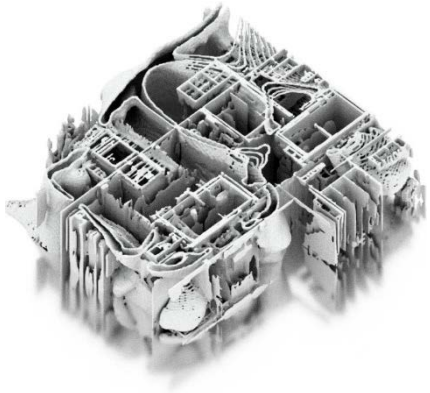






2.4 Research question

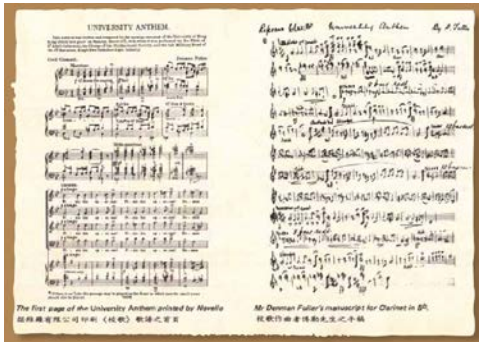
- Q: “Can GAN generate floorplans for the music?”
  - Even better if readers can enjoy similar feelings for the verses
  - In essence: Music-to-plans
- The GAN way
  - Step 1: Music => latent class
  - Step 2: Latent class + real plans => new plans
  - Step 3: Judge and select
- Any successful story?
  - 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*

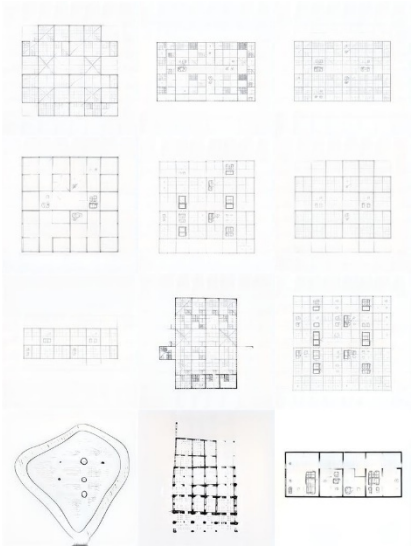
Finis hic operum! Domus Stat potens Academia, Unde ab occiduis recens Ampliore flust plagis Mox doctrina meatu.	Here end our labours! Strong stand the buildings of the University, whence modern learning soon will flow from western land in more ample course.
Fons ubi est sapientia? Et, Scientia, qua lates? 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 iuventam!	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*

(*: Source: https://lib.hku.hk/muslib/HKUanthem.html)

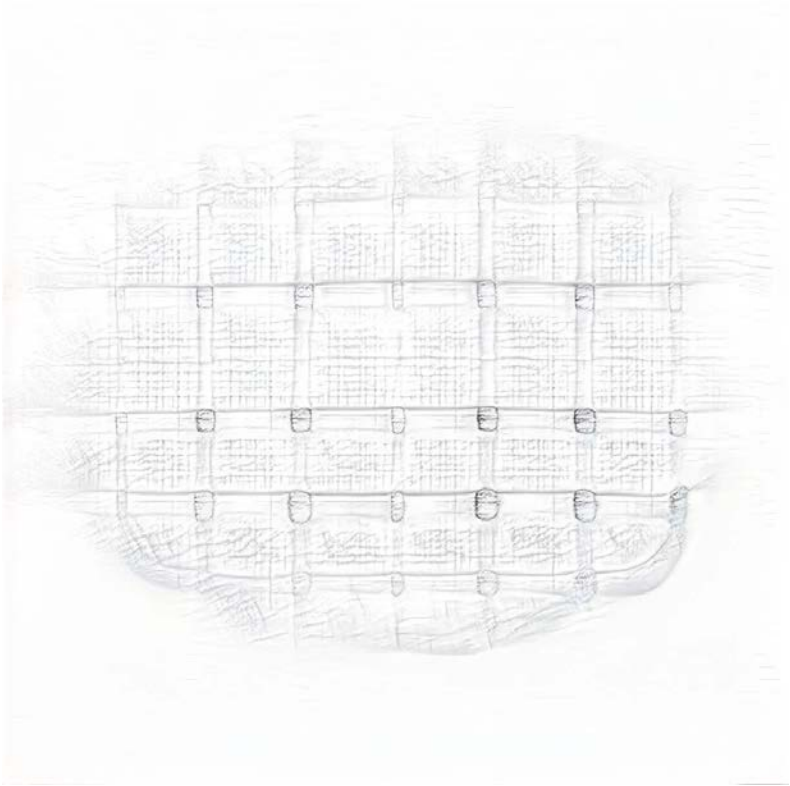
2.4 The ready-to-use music-to-video pipeline

- 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

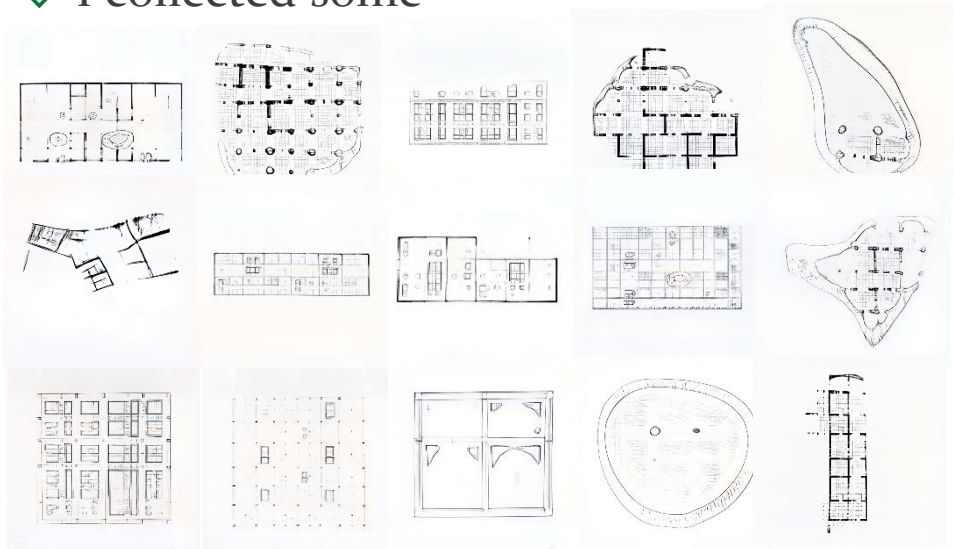


- Python codes (30 lines)
  - 1. Upload the Anthem to Colab virtual machine
  - 2. Load Lucid Sonic Dream with the song
  - 3. Load pre-trained StyleGAN2 model (300MB) for floor plans
  - 4. Run
  - 5. Download video

2.4 Results of generated plans (video)

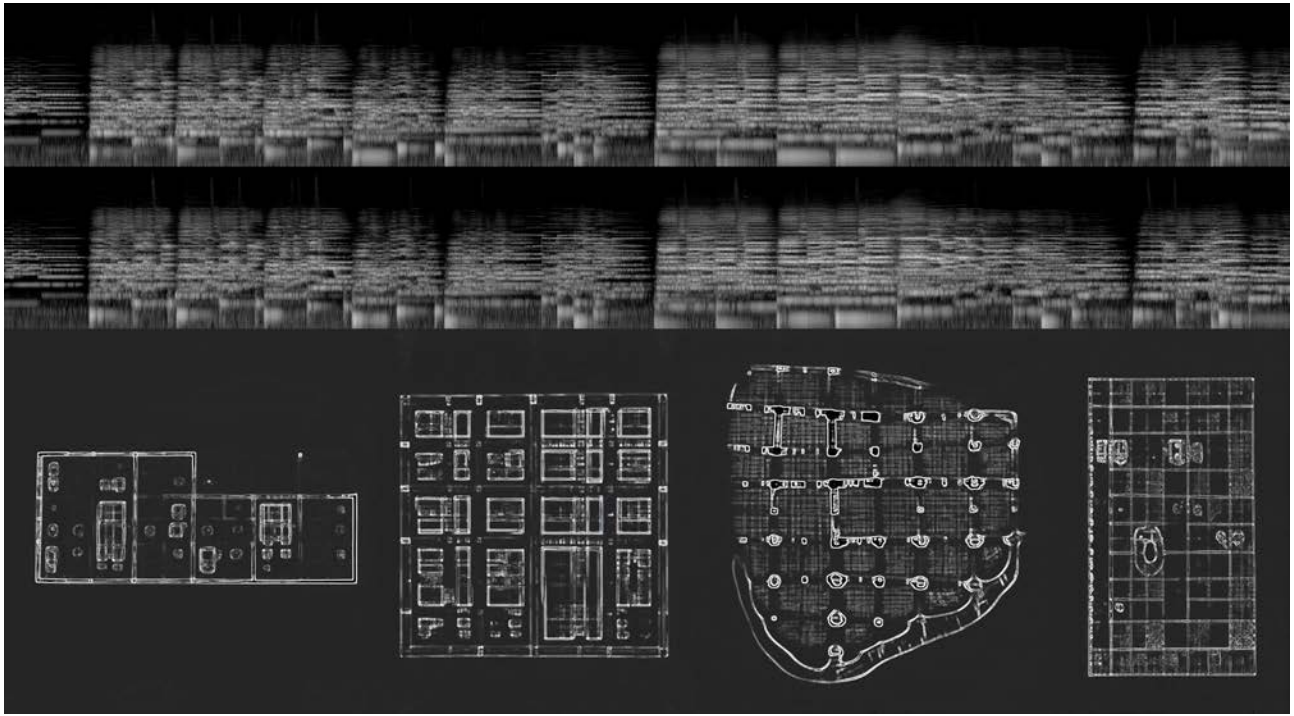


- A 5:54 video
  - With morphing plans
    - Similar to the morphing arts on Page 7
  - “Interpolations” of the training plans
- I collected some



(Full video link on the last page)

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

```python
from lucidsonicdreams import LucidSonicDream
from google.colab import files

import os
import requests

def download(url: str, dest_folder: str):
    if not os.path.exists(dest_folder):
        os.makedirs(dest_folder)  # create folder if it does not exist
    filename = url.split('/')[-1].replace(" ", "_")  # be careful with file names
    file_path = os.path.join(dest_folder, filename)
    r = requests.get(url, stream=True)
    if r.ok:
        print("saving to", os.path.abspath(file_path))
        with open(file_path, 'wb') as f:
            for chunk in r.iter_content(chunk_size=1024 * 8):
                if chunk:
                    f.write(chunk)
                    f.flush()
                    os.fsync(f.fileno())
    else:  # HTTP status code 4XX/5XX
        print("Download failed: status code {}\n{}".format(r.status_code, r.text))

download("https://online.fliphtml5.com/pxkj/ghhi/files/extfile/BackgroundSoundURL.mp3", dest_folder=".")

L = LucidSonicDream(song = 'BackgroundSoundURL.mp3',
                    style = 'floor plans')  # lsun bedrooms, maps, abstract art, modern art

L.hallucinate(file_name = 'floor1.mp4',
              resolution = 1080,
              #start = 81,
              #duration = 5,
              fps=24
              )

files.download("floor1.mp4")
```

- A tutorial of LucidSonicDreams: https://colab.research.google.com/drive/1Y5i5oxSFIuN3V4Md8TB30_GOAtts7RQD#scrollTo=Z7DkKcO9cfM_
- For assigning class mapping, use the parameter below

```python
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

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?)

3.2 A recap

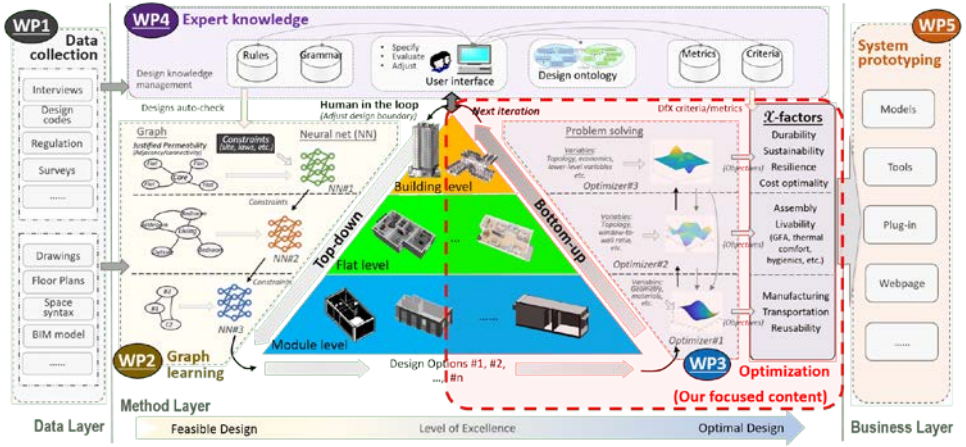
- DfX indicates optimization – finding the best(s)
  - DT can help DfX and generative design in different aspects
    - Abstraction, generic model, constraints, and decision-making
  - Generative design is a human-centric approach for DfX
- A DT contains nothing more than you need
  - Value-driven, Level-of-Detail, 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 mis-understanding or far-fetched arguments

Acknowledgement & job vacancies

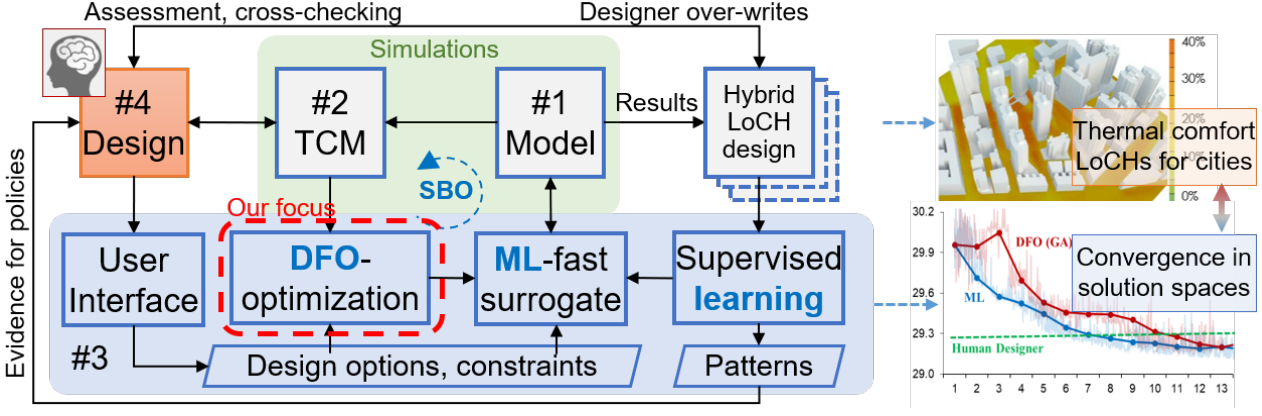
- Supported by our on-going DfX-related projects
  - Hong Kong RGC (C7080-22GF, 5.3M) – Generative DfX in high-rise modular building: An expert-augmented cascade graph learning and optimisation approach
  - Hong Kong RGC (T22-504/21-R, 34.6M) – Healthy and resilient city with pervasive LoCHs (localised 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

Acknowledgement (cont.)



Generative DfX in high-rise modular building

Localised outdoor thermal-comfort hubs



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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

Enjoy your incoming weekend!

Q&A