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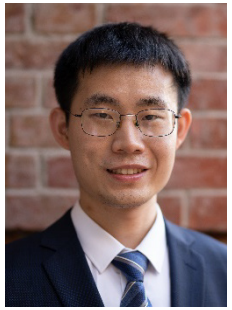
Efficient assessment of window views in high-rise, high-density urban areas using 3D color City Information Models



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Faculty of Architecture, HKU

CUPUM
COMPUTATIONAL URBAN PLANNING & URBAN MANAGEMENT

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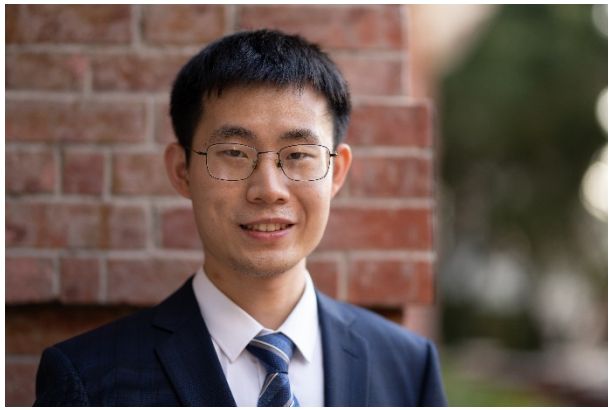

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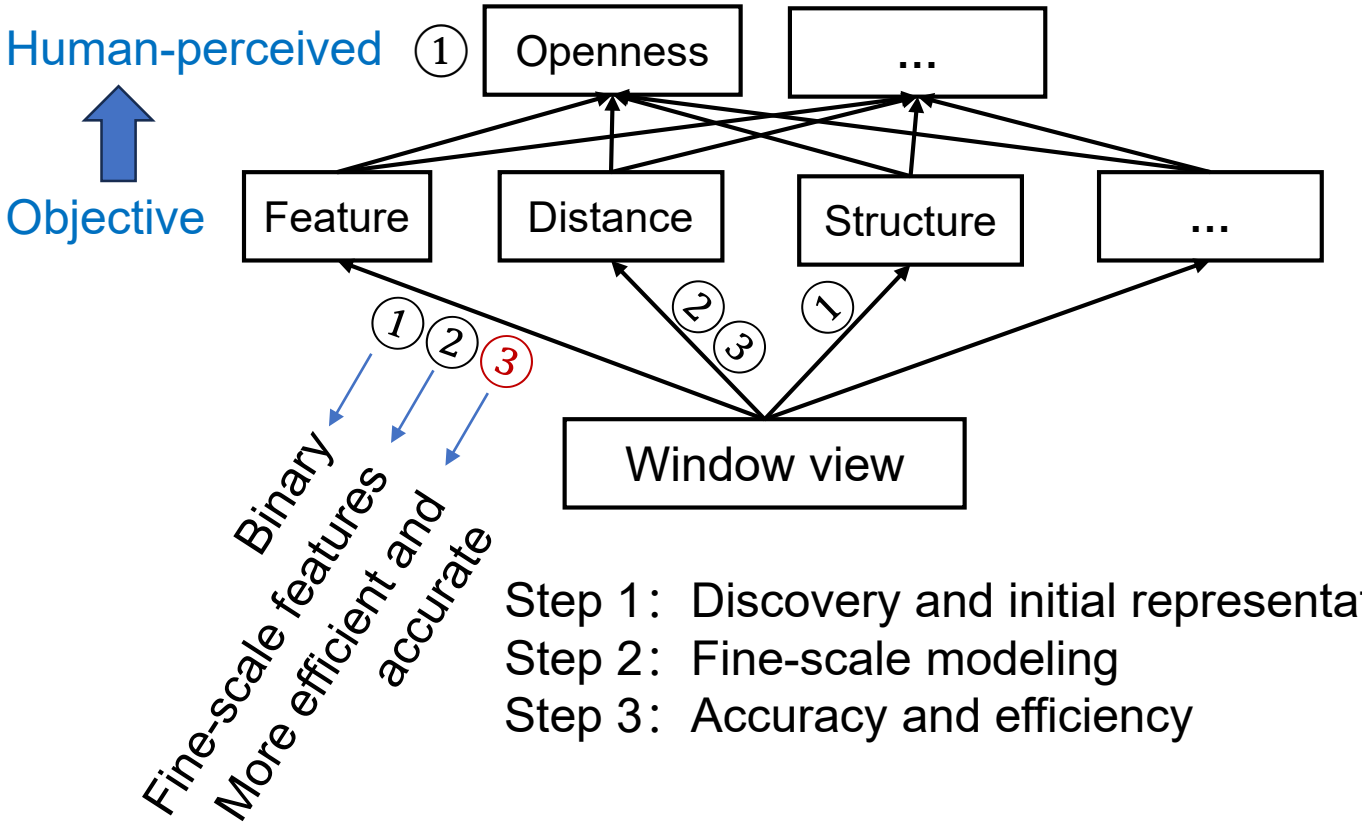
Supervisors:
Prof. Anthony Gar On Yeh, Department of Urban Planning and Design;
Dr. Fan Xue, Department of Real Estate and Construction.

Research interest:
Create automatic decision support methods and tools → quantify **urban semantics** through 3D City Information Modeling, Machine Learning, and Data Analytics → smarter urban planning and urban management.



Step 1: Discovery and initial representation
Step 2: Fine-scale modeling
Step 3: Accuracy and efficiency

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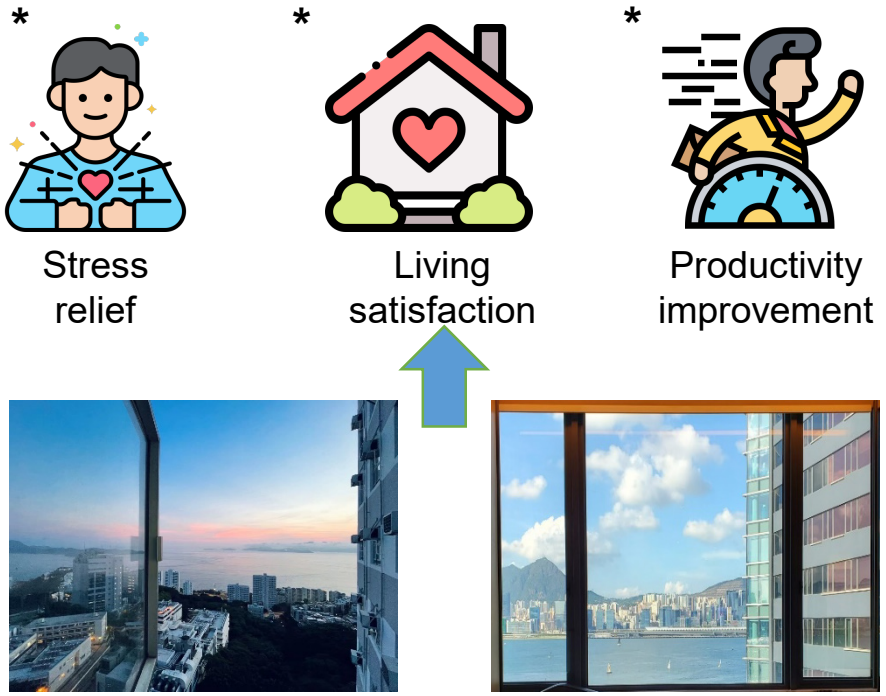
1.1 Background

❑ A **high-quality** window view,

- with **more** greenery, sky, waterbody, and **fewer** construction elements
- treasured by urban dwellers especially in **high-rise, high-density (HRHD) urban areas**



Recognized benefits

Increasingly long-term indoor occupation

Note: * (*Source: flaticon.com*)

1.1 Background

- ❑ Assessment of window views,
  - →**quantified evidence** for multiple **urban applications**
- ❑ However, window views are **numerous** especially in HRHD areas,
  - ❑ change in large numbers with the vertical development of neighborhoods

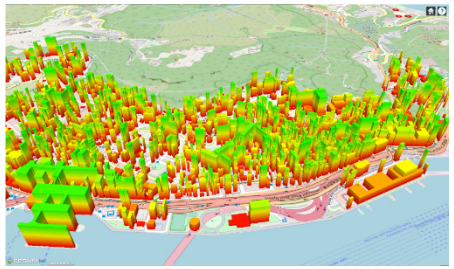
So many views to be assessed

Thus, both **efficient** and **accurate** assessment of window views

- Can aid housing property agencies, architectural designers, and urban planners
- Significant in advancing the window view assessment for urban-scale applications

and valuation planning improvement

Note: * (*Source: flaticon.com*)



Urban-scale window view assessment

Should I still do it?

(*Source: wallpaperflare.com*)

1.2 Literature review

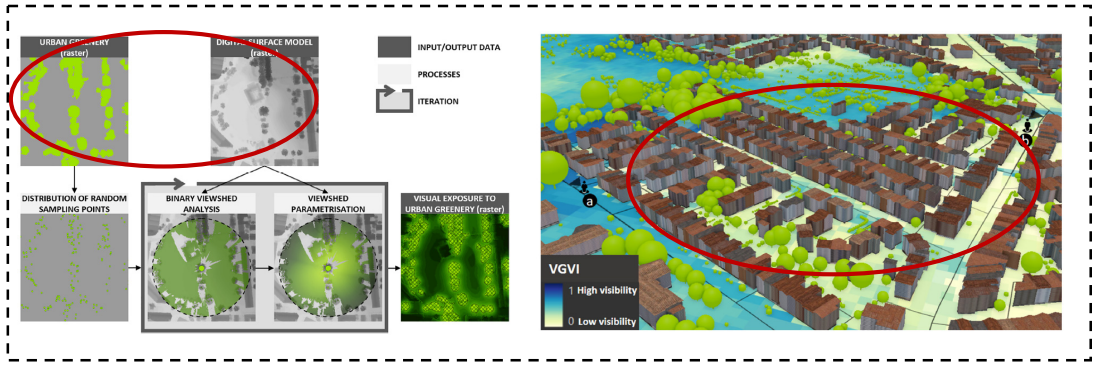
❑ Window view assessment: Manual measurement and Simulation

Method type	Example	Field	Status	Problem
Manual measurement	❑ Onsite photo collection	❑ Psychology ❑ Built environment ❑ Architectural design	High cost and laborious	**Unscalable** to the urban scale
Simulation	❑ Visibility analysis	❑ Urban planning and design	Still shows “preference” for oversimplified models (Fig. 1)	**Inaccurate**

Thus, next generation of assessment methods

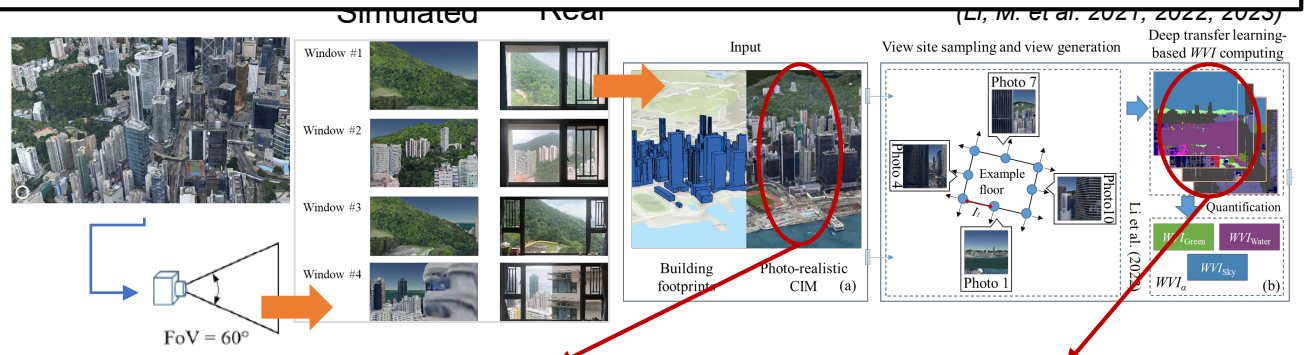
→ **improve** the **processing efficiency** for an **accurate** quantification,

→ Supporting urban-scale assessment and update of window view indices.



(Cimburova and Blumentrath. 2022)

(S.M. Labib et al. 2021)



(Li, M. et al. 2021, 2022, 2023)

a) High burden of texture image loading and rendering

b) Repetitive 2D segmentation

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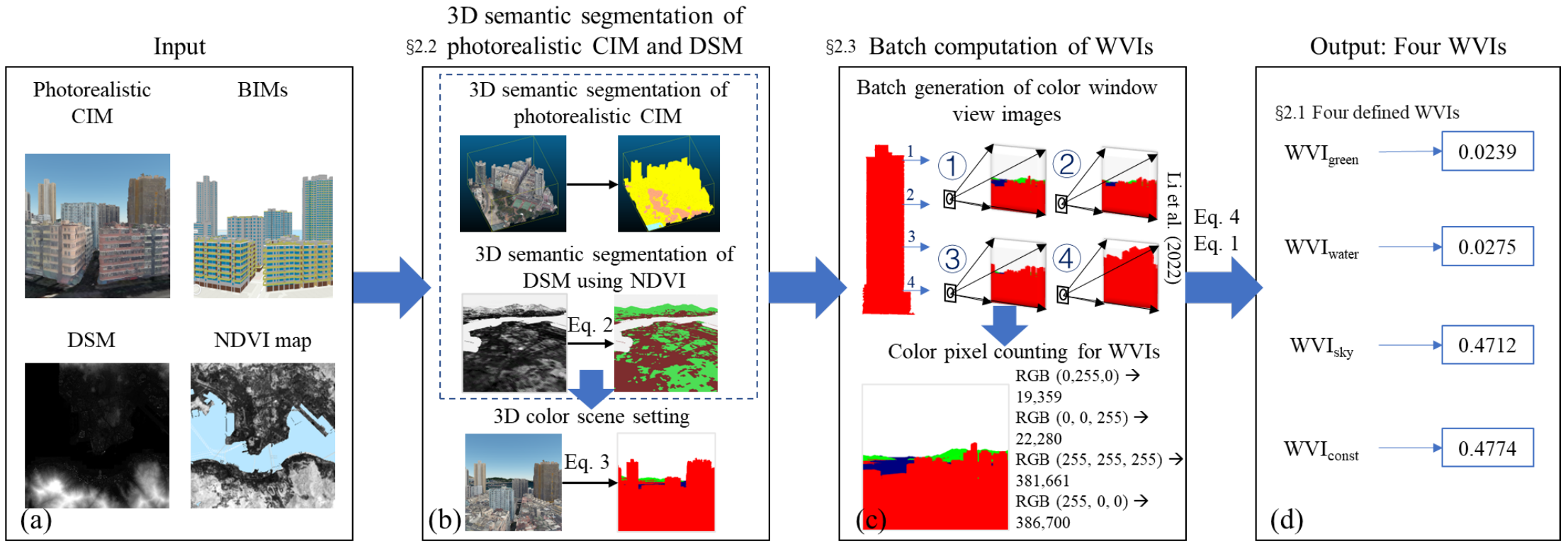
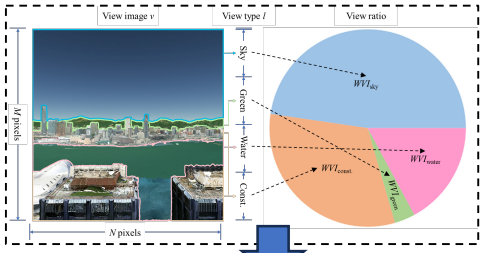
2.1 Workflow of the proposed method

- ❑ Input: Four datasets
- ❑ Methods: 3D semantic segmentation + model view photography + color pixel counting
- ❑ Output: Four Window View Indices (WVIs)
  - greenery, waterbody, sky, and construction.

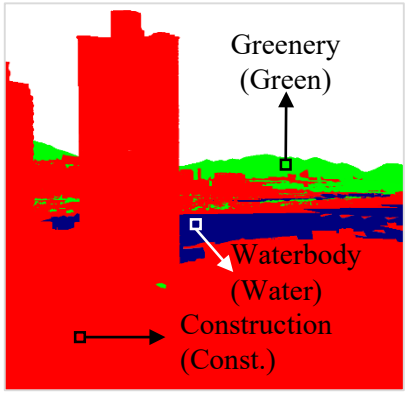


2.2 Definition of WVIs

- WVIs: Defined as a ratio ranging from 0 to 1 on an 8-bit RGB color view image
  - Extension of definition defined on a 3D photorealistic scene (Li et al. 2022).

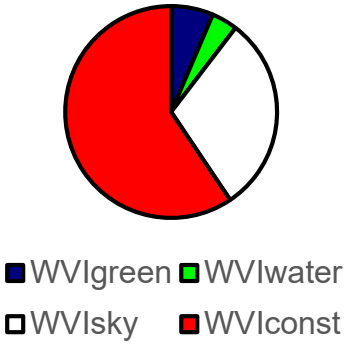


WVI_l (Li et al.'s (2022) method)



8-bit RGB color window view image c

Eq. 1

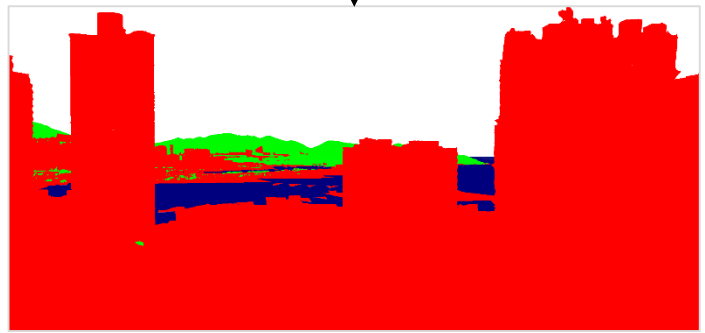


$$WVI_l = |\{p|\ p \in c,\ m(p_{\text{color}}) = l\}| / n,\ l \in L,$$

$$L = \{\text{'greenery'},\ \text{'waterbody'},\ \text{'sky'},\ \text{'const.'}\}, \qquad (1)$$

3D photorealistic scene

3D color scene

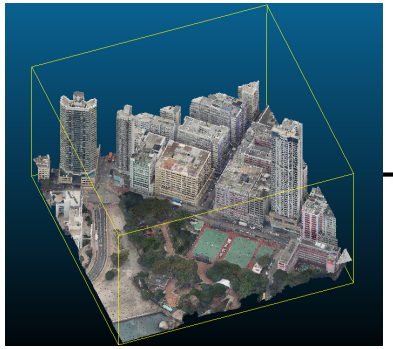


3D scene colored by L

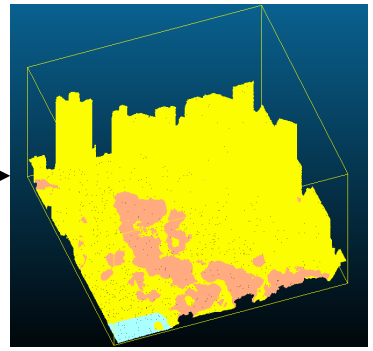
2.3 3D semantic segmentation of CIM for a 3D color scene

- 3D semantic segmentation: KPConv (Thomas et al. 2019) and A priori-based rules
- 3D scene color setting

3D semantic segmentation of photorealistic mesh models

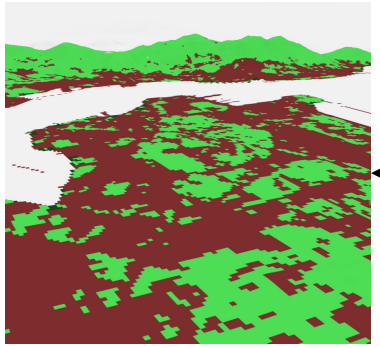


KPConv

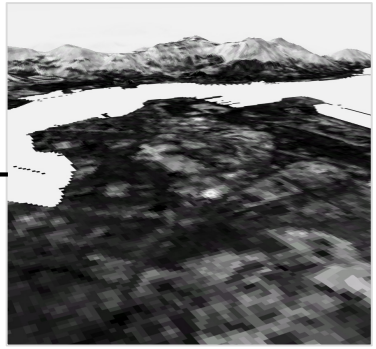


Greenery Waterbody Const.

3D semantic segmentation of DSM using NDVI

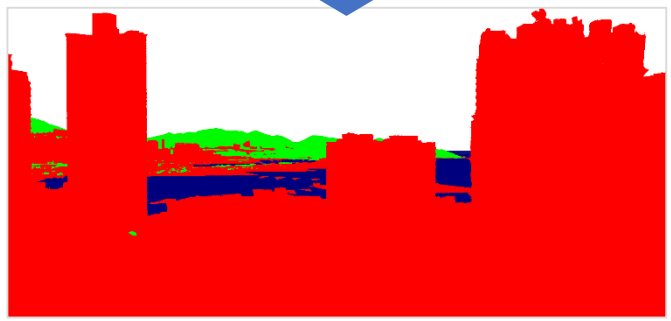


Eq. 2



Greenery Waterbody Const.

Eq. 3



Greenery Waterbody Sky Const.

Eq. 3

$$color(v_l) = \begin{cases} \text{RGB } (0,255,0),\ l = \text{greenery}, \\ \text{RGB } (0,0,255),\ l = \text{waterbody}, \\ \text{RGB } (255,255,255),\ l = \text{sky}, \\ \text{RGB } (255,0,0),\ l = \text{construction}, \end{cases}$$

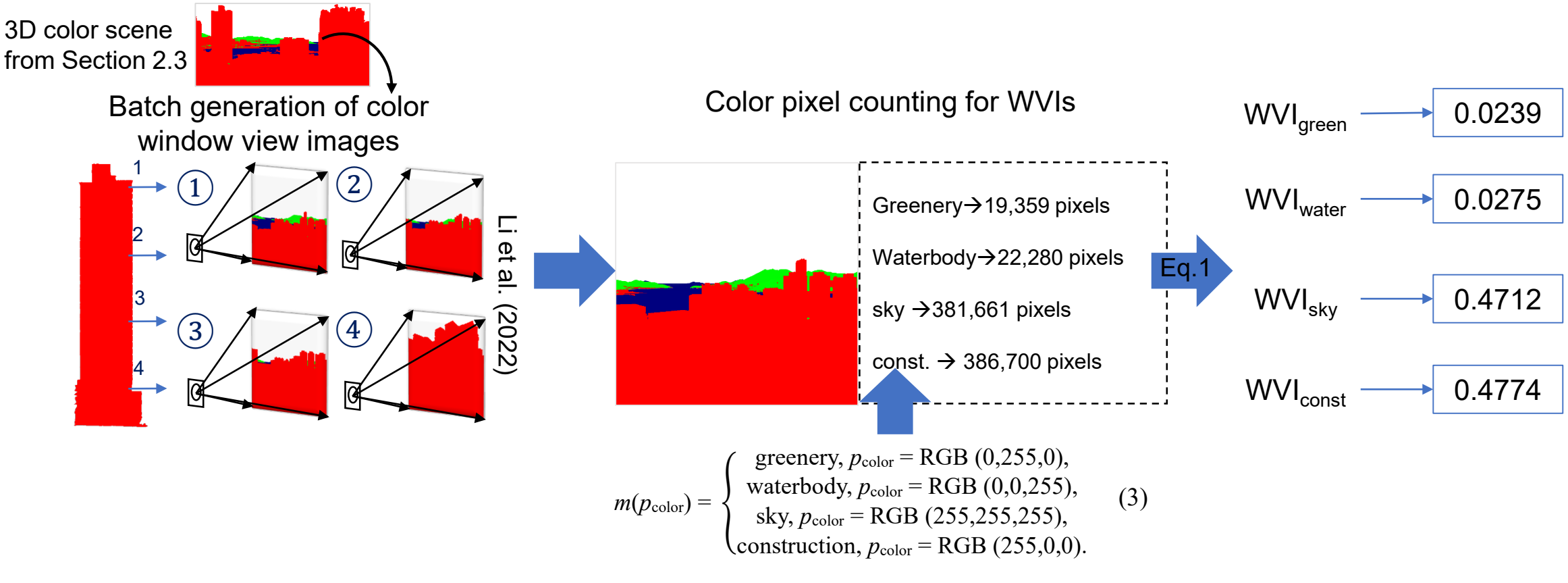
Eq. 2

$$l_{pg} = \begin{cases} \text{greenery}, & NDVI_{pg} \geq 0.1, \\ \text{construction}, & 0 \leq NDVI_{pg} \leq 0.1, \\ \text{waterbody}, & NDVI_{pg} = \text{no data}, \end{cases}$$

2.4 Batch computation of WVIs using color view images

❑ Two-step computation process

- Window view generation in the 3D color scene
- Color pixel counting for WVIs



$$m(p_{\text{color}}) = \begin{cases} \text{greenery}, p_{\text{color}} = \text{RGB } (0,255,0), \\ \text{waterbody}, p_{\text{color}} = \text{RGB } (0,0,255), \\ \text{sky}, p_{\text{color}} = \text{RGB } (255,255,255), \\ \text{construction}, p_{\text{color}} = \text{RGB } (255,0,0). \end{cases} \quad (3)$$

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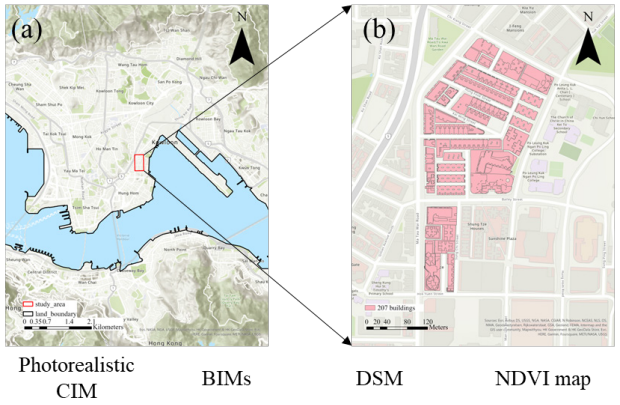
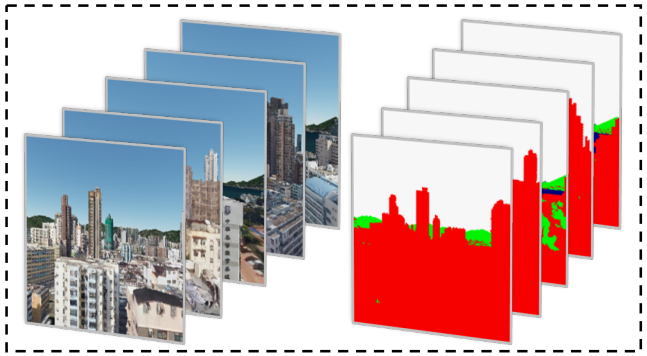
3.1 Experimental settings

- Using 100 random window views from 207 buildings in To Kwa Wan, Kowloon Peninsula of Hong Kong
  - To test the feasibility of the proposed method.





100 photorealistic views and color views

Dataset

3D photorealistic mesh models and annotations (Lands Department, 2017; Li et al. 2023)	Building information models (Urban Renewal Authority, 2022)
Digital surface model (Lands Department, 2020)	NDVI map (B. Morgan and B. Guénard, 2019)

Software

3D segmentation of CIM KPConv (Thomas et al. 2019) for photorealistic mesh ArcGIS Pro (2.9.0) for DSM	Batch computation of WVIs Cesium (1.99), Python (ver. 3.7.11)
Baseline method (Li et al. 2022) Deeplab V3+ (Chen et al. 2018), Orange 3 (ver. 3.26)	Deep learning environment Docker - Ubuntu (ver. 18.04.5), Python (ver. 3.7.11), Pytorch (ver. 1.10.0)

Workstation

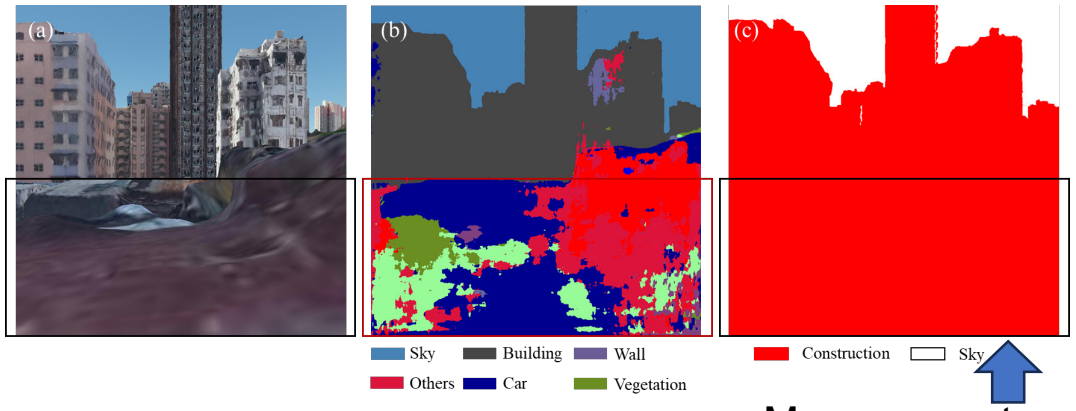
Intel i9-11900K CPU (3.50 GHz, 16 cores)	64 GB memory
24G Nvidia GeForce RTX 3090 graphic card	Windows 10 operating system

3.2 Accuracy and efficiency

- Comparison with Li et al.'s (2022) 2D segmentation method, the proposed 3D segmentation method:
  - Accuracy → RMSE < 0.01; Improvement: 76.26%;
  - Efficiency → Total < 0.6 s; Improvement: 73%.

Table 1. Comparison of assessment accuracy of two methods on 100 test windows

	RMSE		
	Li et al.'s 2D method	Our 3D method	Improvement
WVI_{green}	0.0283	0.0059	79.15%
WVI_{water}	0.0243	0.0048	80.25%
WVI_{sky}	0.0098	0.0044	55.10%
$WVI_{const.}$	0.0405	0.0092	77.28%
Average	0.0257	0.0061	76.26%



More accurate segmentation results

Table 2. Comparison of computational time of the two methods (average of 100 windows)

Step	Processing	Li et al.'s 2D method	Our 3D method	Improvement
1	Window view generation	1.94 s	0.54 s	72%
2	Quantification of WVIs	0.16 s	0.03 s	81%
	Total	2.10 s	0.57 s	73%

Li et al.'s (2022) 2D method

① Models with textures

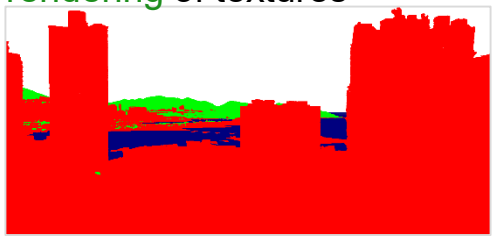
② 

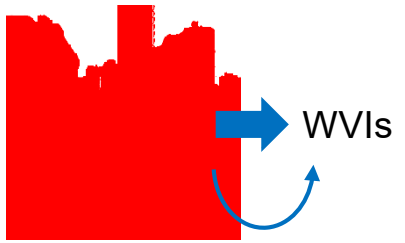
2D Segmentation

Pixel counting

Our 3D segmentation method

Models without preparation and rendering of textures





Only pixel counting

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- This study proposes a both **efficient** and **accurate** window view assessment method
  - Using **3D semantic segmentation** and **3D color CIM**

- Significance
  - Improvement of the accuracy and efficiency
    - For urban-scale quantification and update of four WVIs
    - RMSE < 0.01 and 3.68 times faster
  - Advancing urban-scale planning, design, and real estate applications to use quantified WVIs
    - Urban planners and architectural designers in urban planning and design
    - Housing purchasers, renters, property agencies in real estate market

- Limitation
  - A full 3D color scene needed for assessing four WVIs
    - Small-scale quantification may not afford the large-scale but one-off preprocessing cost
  - Batch quantification of window views regardless of the similarity
    - Window view pattern mining for a more efficient assessment

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