Facade Segmentation for Solar Photovoltaic Suitability

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Introduction

Buildings account for almost 40% of global energy use and CO_2 emissions [1].

More than 85% of Europe's buildings were constructed before 2000, and around 75% exhibit poor energy performance.

[1] United Nations, "THE STRATEGIC PLAN 2020-2023," 2020, www.unhabitat.org.

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Introduction

Facade retrofits for on-site energy generation with **building-integrated photovoltaic (PV) facades**

Especially in contexts where..

– roof areas are insufficient

– ground-mounted arrays are infeasible.

[1] Philip Heckhausen. jessenvollenweider – Amt für Umwelt und Energie, Basel. https://www.philipheckhausen.com/photos/amt-fuer-umwelt-und-energie/.

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Gradient Spaces

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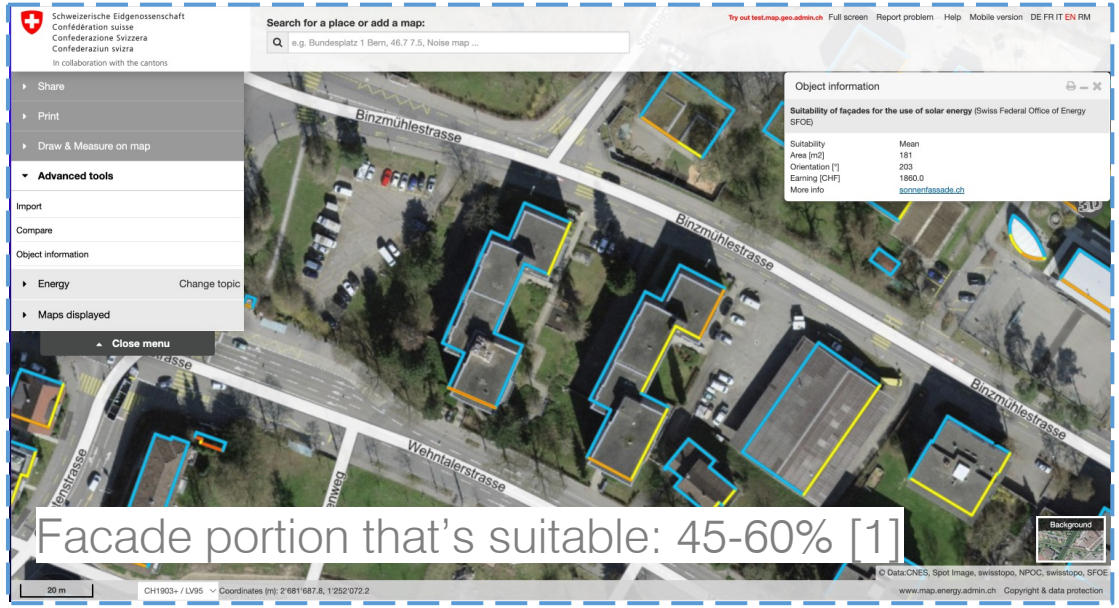
Research problem

sonnenfassade.ch

25% / 50% /100%

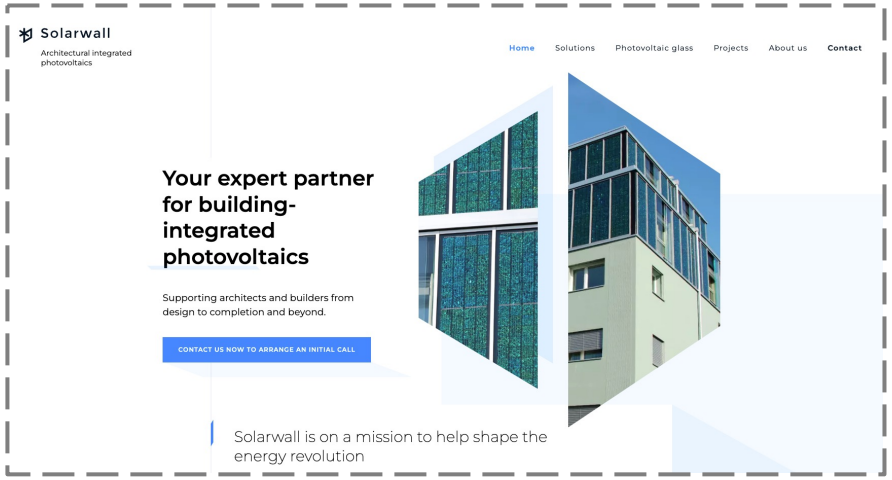


Facade portion that's suitable: 45-60% [1]

International Energy Agency (IEA)

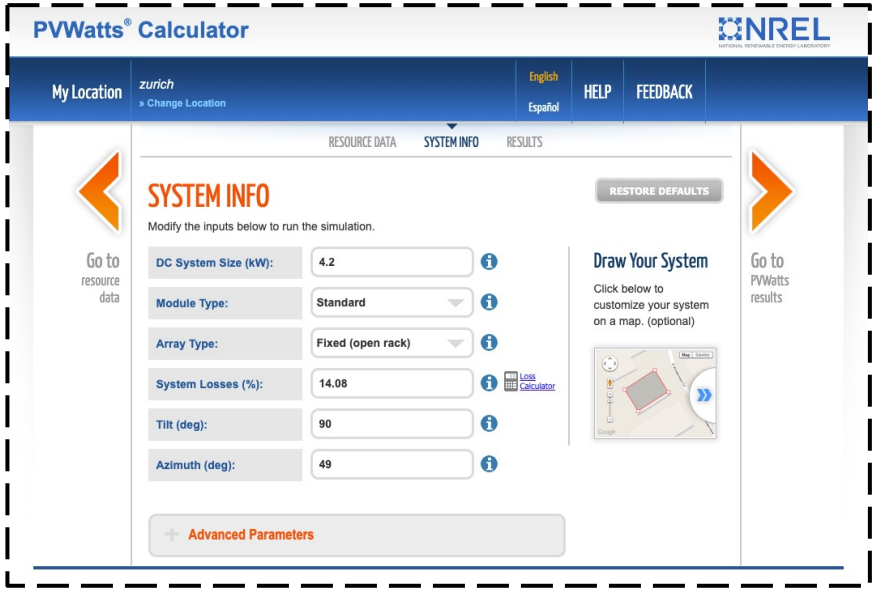
Suitable building envelope parts: 20% [2]

Commercial services



PVWatts

manual user input



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Aims and contributions

An automated methodology to..

– Estimate **PV potential** for facades **more accurately** by considering **architectural details.**

– Bridge the gap between **theoretically eligible surfaces** and a practical building-integrated PV **layout design**.

Method

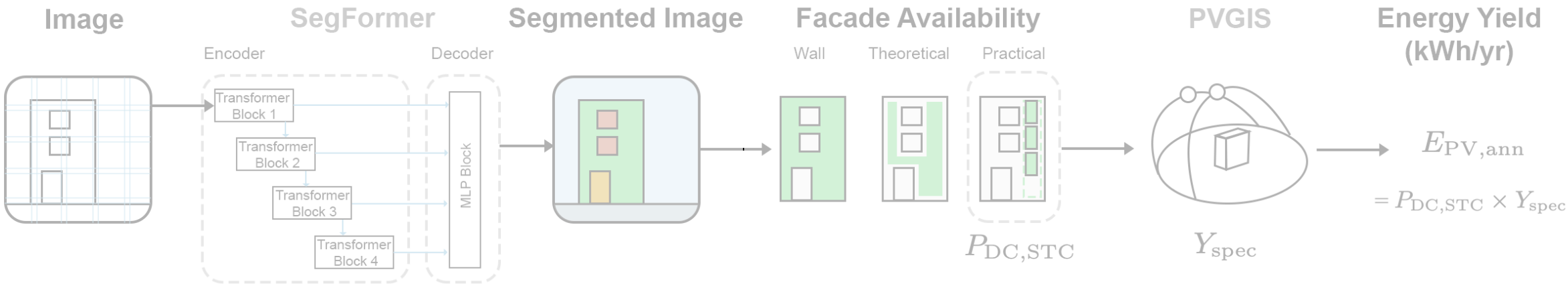
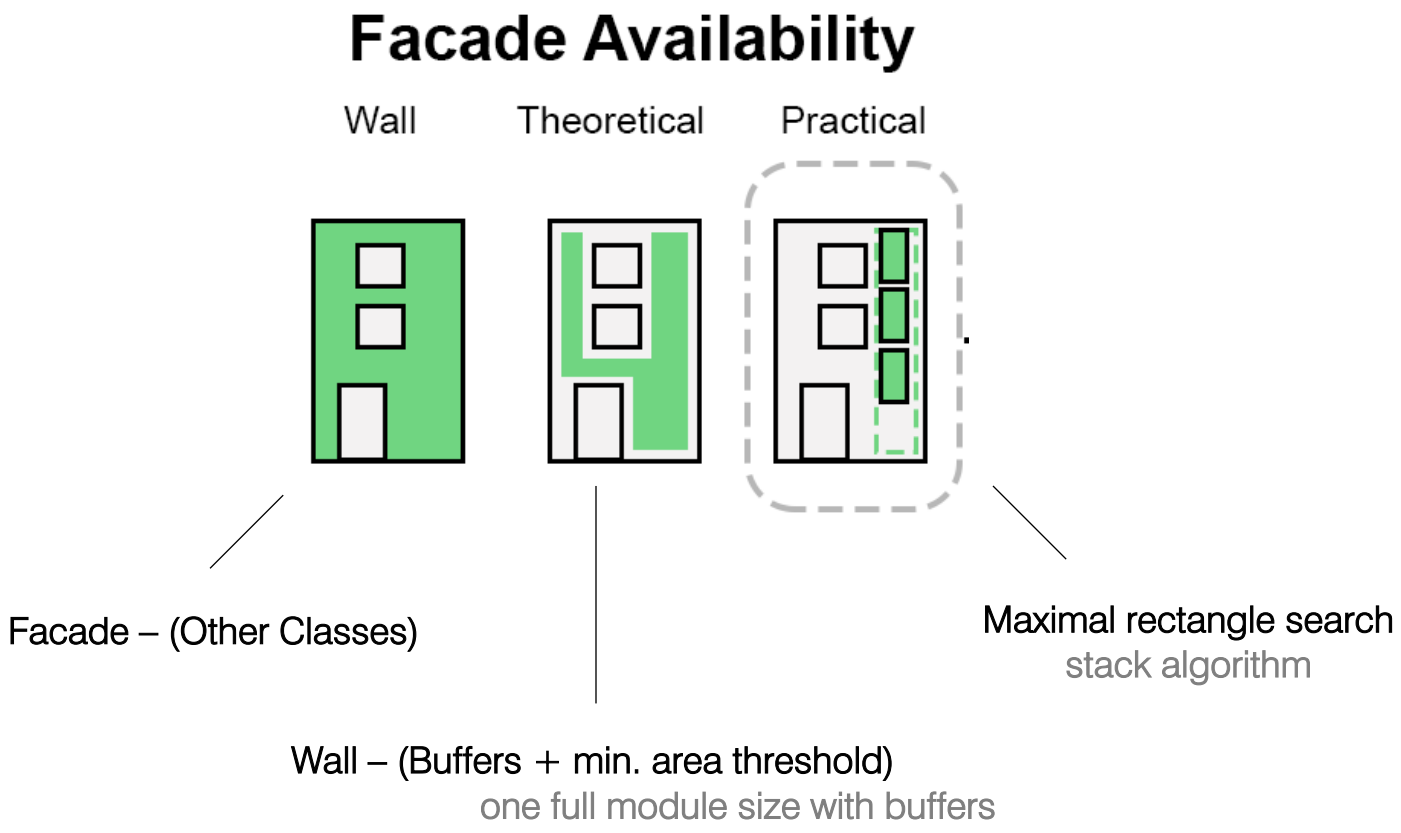


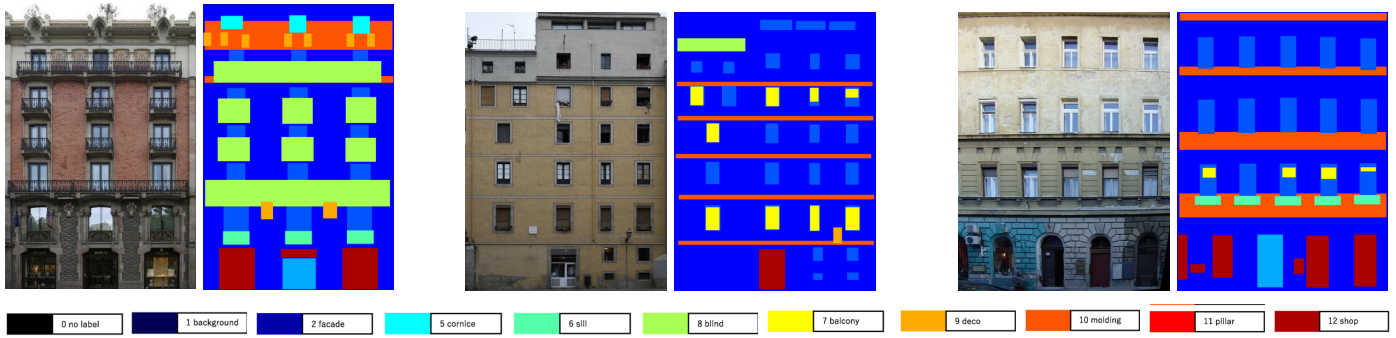
Image
SegFormer
Encoder
Decoder
Transformer Block 1
Transformer Block 2
Transformer Block 3
Transformer Block 4
MLP Block
Segmented Image
Facade Availability
Wall
Theoretical
Practical
$P_{\mathrm{DC,STC}}$
PVGIS
Y_{spec}
Energy Yield (kWh/yr)
$E_{\mathrm{PV,ann}}$
$= P_{\mathrm{DC,STC}} \times Y_{\mathrm{spec}}$
CMP Facades (N= 606)
Images + Semantic Labels
LSAA (N=373)
Images + Dimension + Orientation

Method


Facade Availability
Wall
Theoretical
Practical
Facade – (Other Classes)
Wall – (Buffers + min. area threshold)
one full module size with buffers
Maximal rectangle search
stack algorithm

Datasets

CMP Facades [1]: 606 annotated images with 13 classes of architectural elements (training, validation, test).



LSAA [2]: 373 rectified images of facades with known facade area and orientation from 10 cities (application).

24.1 × 20
41.5°

11.1 × 12
106.5°

26.8 × 19
304°

14.9.8 × 13
88°

[1] 1 Tyleček R and Šára R (2013) “Spatial Pattern Templates for Recognition of Objects with Regular Structure Pattern Recognition Lecture Notes” In: Weickert, J., Hein, M., Schiele, B. (eds) Pattern Recognition. GCPR 2013. Lecture Notes in Computer Science, vol 8142.

[2] Zhu P, Para W R, Fruhstuck A, Femiani J and Wonka P (2022) “Large-Scale Architectural Asset Extraction from Panoramic Imagery” In: IEEE Trans. Vis. Comput. Graph. 28.2, pp. 1301–16

Facade Segmentation

SegFormer B5

Method	mIoU	Pixel Acc.	Precision	Recall	F1
Ours (SegFormer-B5)	**0.52**	**0.76**	**0.68**	**0.68**	**0.68**
Auto–Context (ST3) [1]	0.36	0.66	—	0.49	—
Auto–Context (PW3) [1]	0.38	0.68	—	0.49	—
Baseline – Uniform Rand.	0.03	0.08	0.08	0.06	0.05
Baseline – Majority Class	0.03	0.24	0.02	0.08	0.03

[1] Raghudeep Gadde, Varun Jampani, Renaud Marlet, and Peter V. Gehler. Efficient 2D and 3D Facade Segmentation using Auto-Context, 2016. URL https://arxiv.org/abs/1606.06437. Version Number:1.

Facade Segmentation

SegFormer B5

MAE_{wall} = 7.29 pp

$RMSE_{wall}$ = 12.17 pp

$MAE_{win+shop}$ = 3.13 pp

$RMSE_{win+shop}$ = 9.43 pp

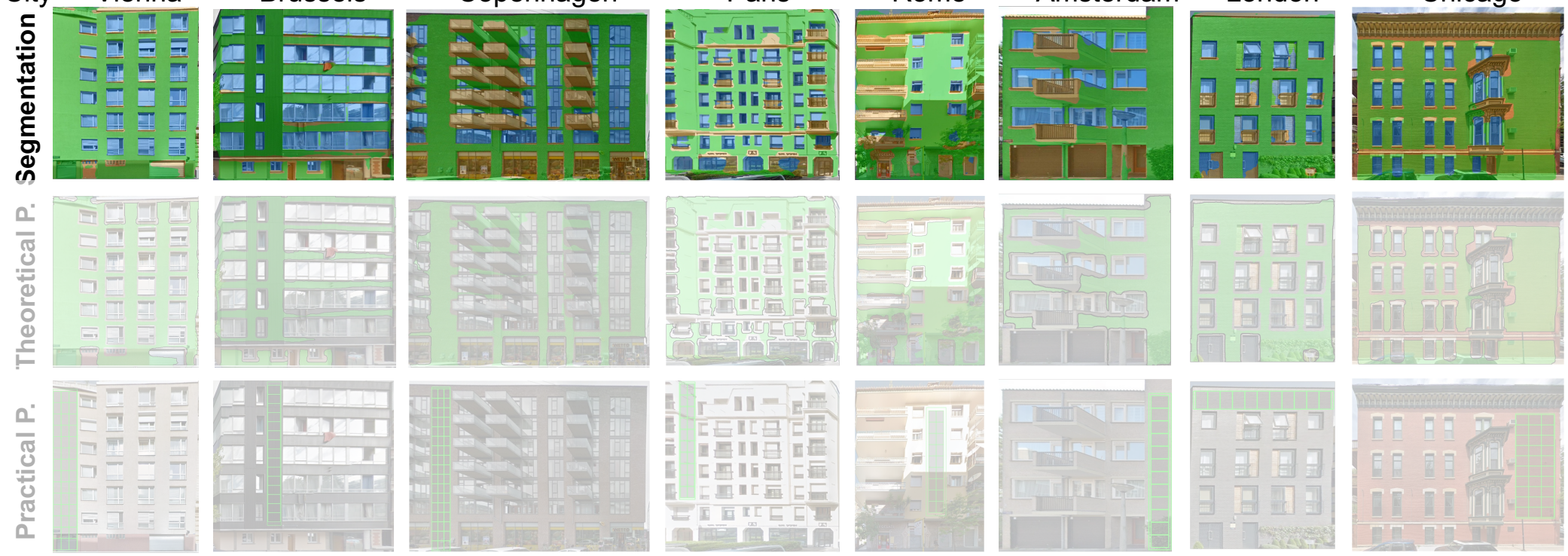
	Wall (%)	Window+Shop(%)	Rest (%)
GT (Ground Truth)	49.39	16.08	34.53
Pred (Prediction)	47.42	16.48	36.10

Facade Segmentation

SegFormer B5

Method	Bg	Fac	Win	Door	Corn	Sill	Balc	Blind	Mold	Deco	Pill	Shop
Ours	0.74	0.62	0.69	0.46	0.51	0.48	0.50	0.56	0.37	0.52	0.33	0.43

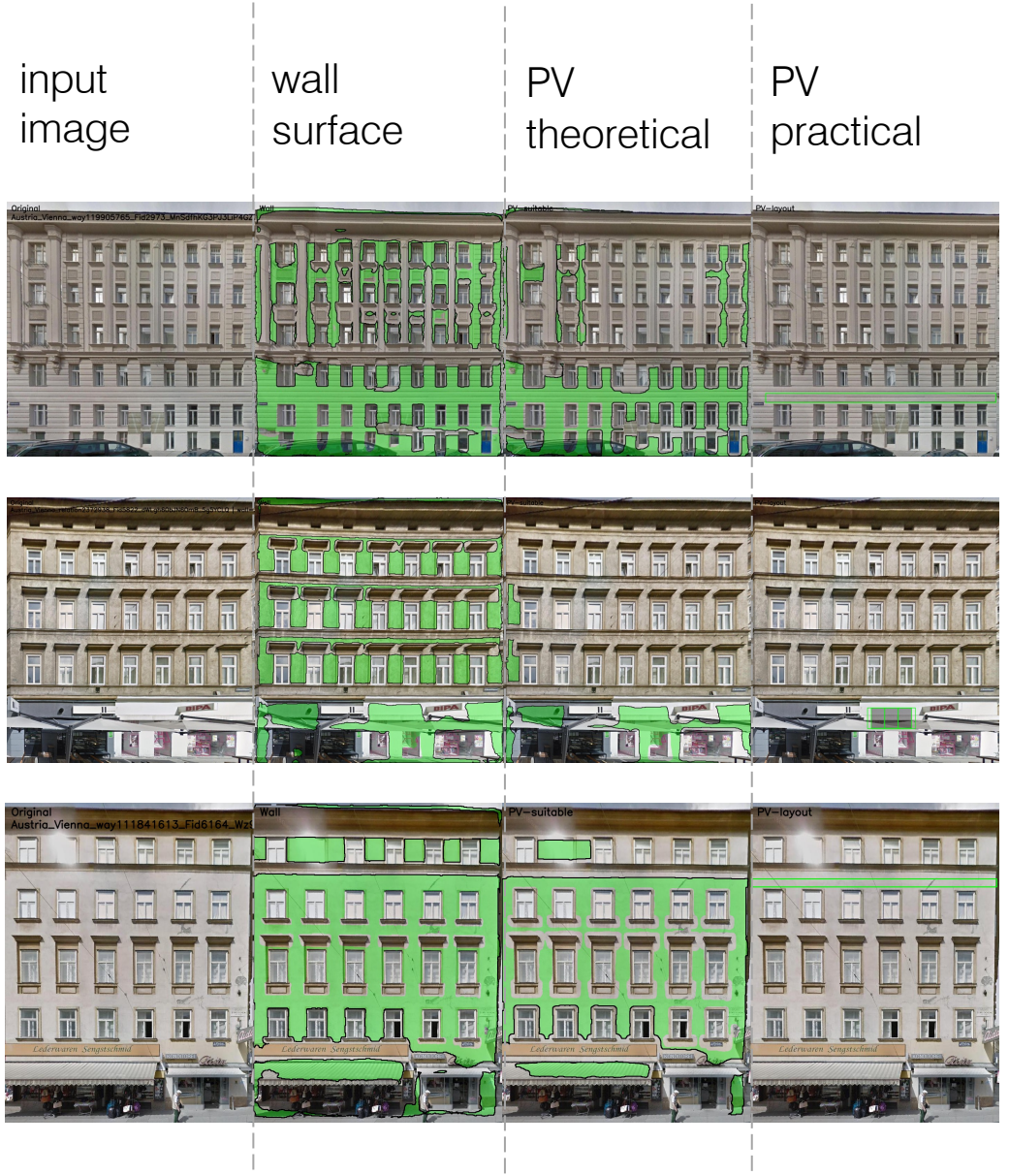
Application



Key Findings

Facade articulations can significantly **reduce installable PV potential**.

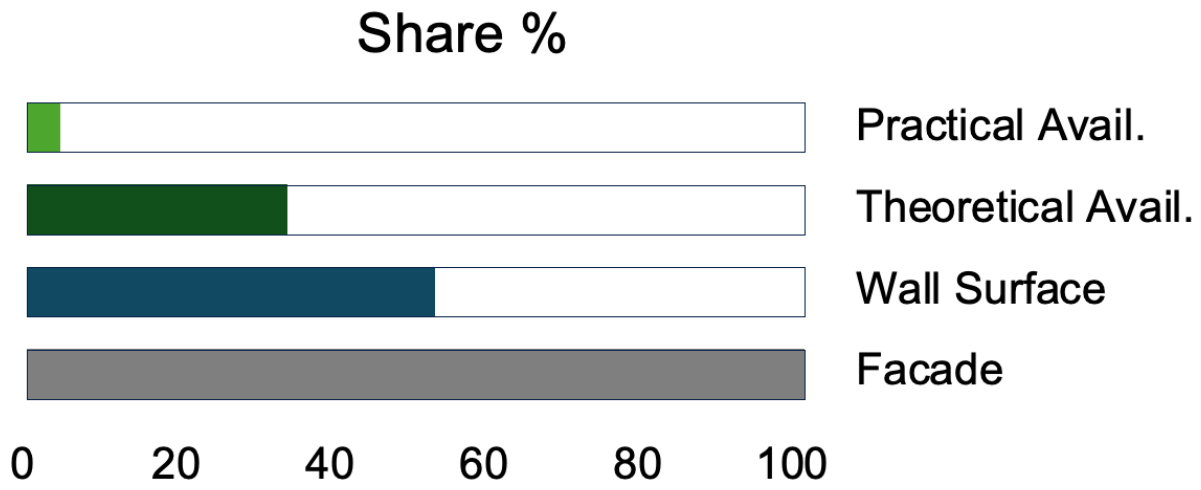
In total, 14 facades with $f_{PV,\ theoretical} > 0.30$ have zero panel count (*small**,1 size)



**small* = 720 × 875 mm, *large* = 935 × 1300 mm
[1] https://www.3s-solar.swiss/downloads-teraslate#systemeprodukte

Key Findings

Theoretical availability **overestimates** the installable capacity, particularly for highly articulated facades.



Conclusion

GitHub

An **automated pipeline** integrating **semantic segmentation** into practical **PV layout design.**

Scalable to **city-wide screening** using ortho-rectified street-level imagery for **retrofit planning**.

- **Retrofit prioritization and incentives**
- **Urban decarbonization plans**

Limitations and Future Work

The resulting PV layouts are based on common **BIPV panel sizes**.
Dependence on the **availability and quality of images.**

Improve segmentation performance for occluded and complex facades.
Generate **alternative layout** options with **multi-region packing**.
Integration into **more detailed** solar irradiation and shading analysis.

Thank you!