MARL Multi-scale Archetype Representation Learning for Urban Building Energy Modeling

Paper, code and data available

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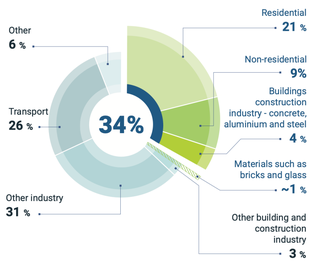
TLDR

We use **image reconstruction-based** framework to **automatically** construct representative building archetypes for building stock with **real-world building geometry** (footprint) with **downstream task** (building metadata such as vintage, programme) which has **transferability** be applied to any scale, any location.

MOTIVATION

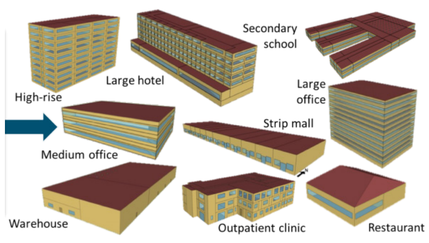
Climate change



Built environment contributes to 38% carbon emissions

Urban Building Eenergy Modeling

Current archetype for UBEM



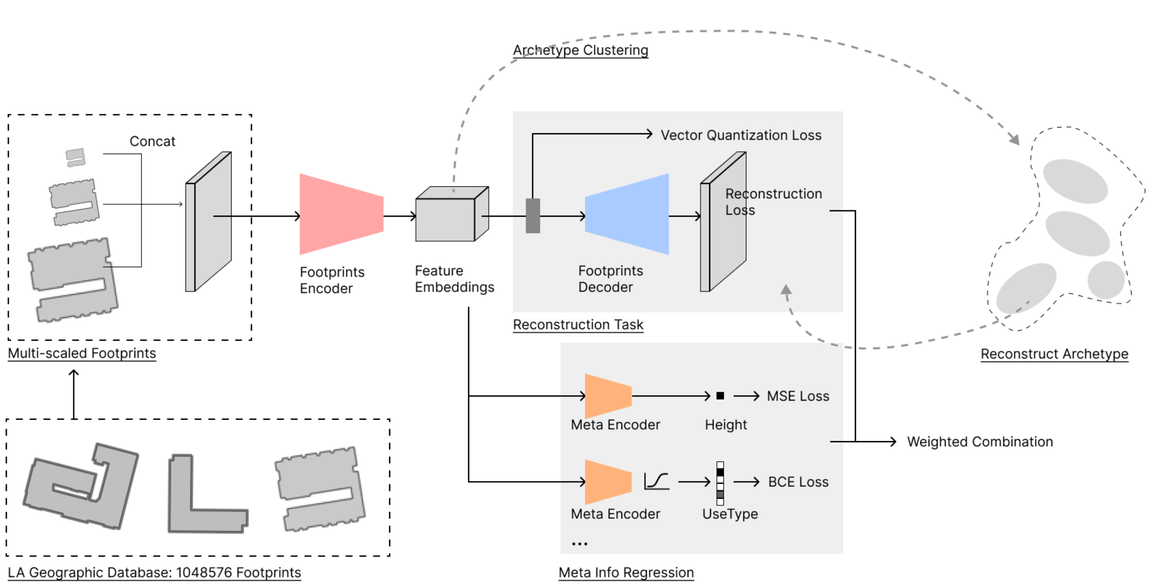
Prototype Building Models [1]

- Country/state scale
- Expert-reliant
- Overlook of real-world geometry.
- Computational demands exclude disadvantaged communities.

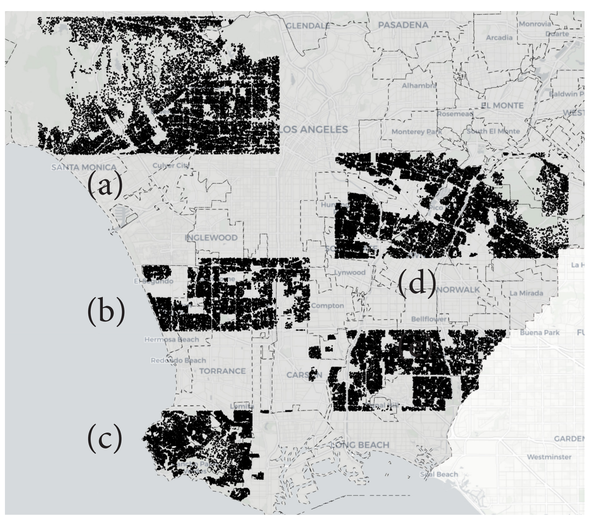
CONTRIBUTION

Automated representative building archetype generation given a building stock
Geometry integration for building archetypes
Methodology innovation: mage reconstruction-based framework.
Downstream task integration with building metadata (vintage, programme)
Transferability: Model effective in any urban settings.

MARL: Multi-scale Archetype Representation Learning



DATASET

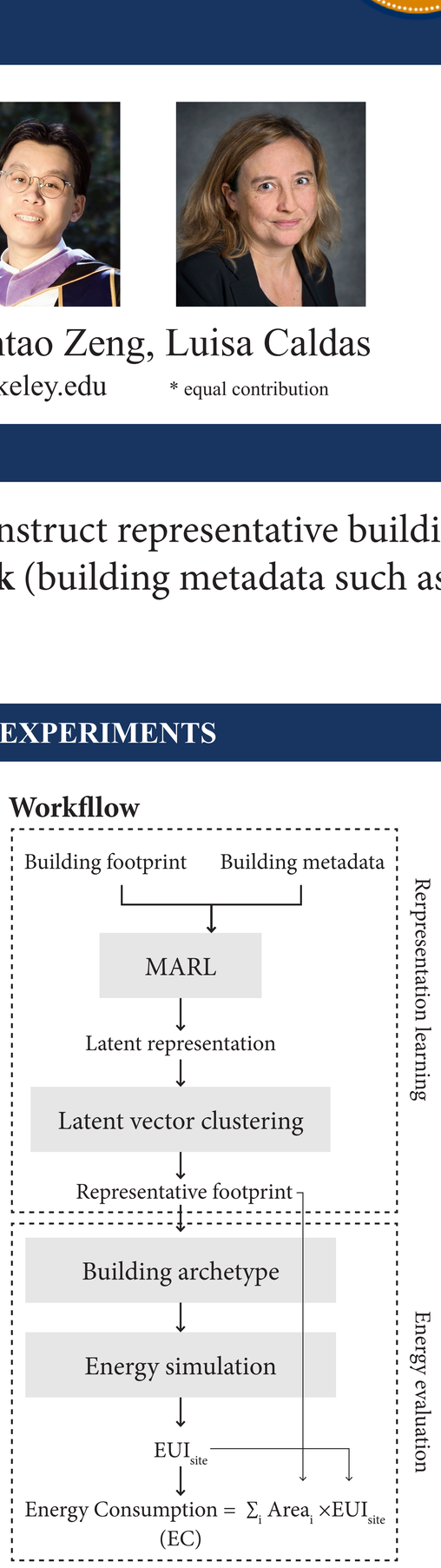


Five neighborhoods in Los Angeles county. Each contains over 6,000 residential buildings (single/multi family).

Example footprints

EXPERIMENTS

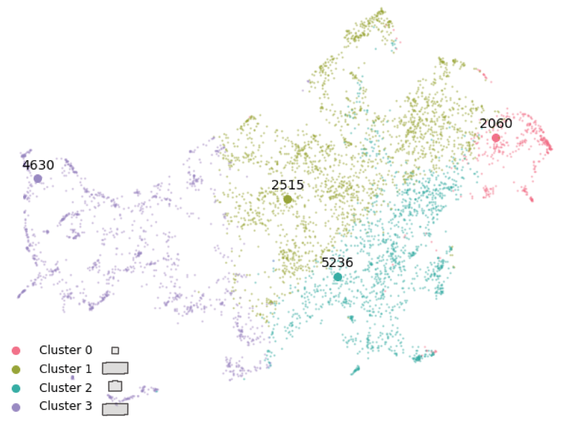
Workfllow



Ground truth Integrated Multisector Multiscale Modeling (IMMM) [2]

Baseline Prototype Building Models [1]

Metrics $Accuracy = 1 - \frac{|EC_{est} - Ec_{gt}|}{EC_{gt}}$



UMAP visualization of auto-generated building archetypes for Region (c)

Single archetype

Archetype offered by		EUI (kWh/m^2)	Building Area (m^2)	Energy (kWh)	Accuracy (%)
PBM [8]	MFH	75.14	861123.64	137344567	71.62
	SFH	60.79	1194889.74		
MARL (Ours)	MFH	89.3	861123.64	179539369	93.62
	SFH	85.9	1194889.74		
MARL + DTP (Ours)	MFH	92.5	861123.64	183609344	**95.74**
	SFH	87	1194889.74		
Energy Consumption GT [27]			2056013.38	191779982	/
Energy Estimation Accuracy Boosted by			**Our Reconstruction Task**		22.00 ↑
			Our Downstream Task		2.12 ↑

Multiple archetypes

Region	Energy Consumption GT[27](kWh)	PBM [8] (%)	MARL with Only Reconstruction Task (%)		MARL Restricted by DTP (%)	
Rncho Palo etc.	191779982	71.62	90.36	18.74 ↑	**91.08**	18.74 ↑ + 0.72 ↑
Long Beach etc.	104117941	73.10	**98.96**	25.86 ↑	97.58	25.86 ↑ - 1.37 ↓
Manhattan Beach etc.	121545524	70.51	90.43	19.92 ↑	**92.88**	19.92 ↑ + 2.45 ↑
SUM	417443447	71.66	92.52	20.86 ↑	**93.23**	20.86 ↑ + 0.70 ↑

Open Set

Region	GT[27] (kWh)	PBM [8]		MARL+DTP (Ours)	
		(kWh)	(%)	(kWh)	(%)
Downey etc.	187349182	144685496	77.23	201129362	**92.64**	15.42 ↑
Santa Monica etc.	211891201	151819183	71.65	192191917	**90.70**	19.05 ↑
SUM	399240383	296504678	74.27	393321279	**98.52**	24.25 ↑

SUMMARY

MARL: Automated, scale-adaptable building archetype construction with representation learning and downstream tasks, integrated with building geometry and building metadata.

Validation & Results: Benchmarked against conventional archetypes, MARL showcases superior energy estimation, especially in unseen neighborhoods.

Implications: Aid architects in making informed decisions on neighborhood configurations and morphologies. Emphasizes locale-specific designs, promoting energy efficiency.

[1] Department of Energy. Prototype building models, 2021. https://www.energycodes.gov/prototype-building-models, Accessed May 25, 2023
[2] Y. Xu, P. Vahmani, A. Jones, and T. Hong. A multi-scale time-series dataset of anthropogenic heat from buildings in Los Angeles county (version v1) [data set]. MSD-LIVE Data Repository, 2022. https://doi.org/10.57931/1892041