Urban Climate Informatics (UCI)

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The SHaDE Lab

Sensable Heatscapes and Digital Environments

How does urban form, design, and landscaping impact heat* and the human experience of heat in cities?

*air temperature, land surface temperature, mean radiant temperature, heat index, WBGT, thermal comfort indices, etc.

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President, International Association for Urban Climate (IAUC), 2022 - 2026

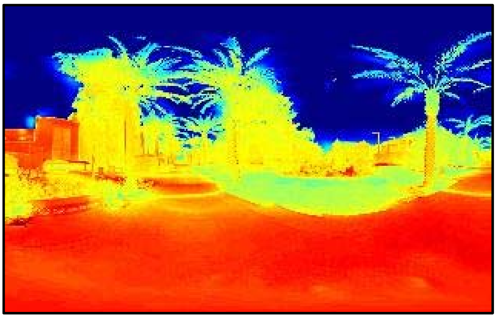
MaRTy, SHaDE Lab Assistant
Human-biometeorological cart
shade hunter, tree hugger, heat walker, thermal comfort expert
@ASUMaRTy

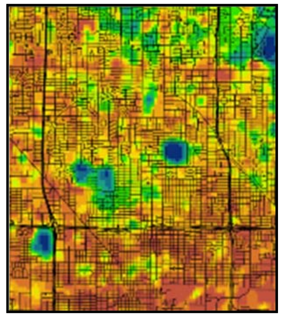
3 Dimensions of Heat

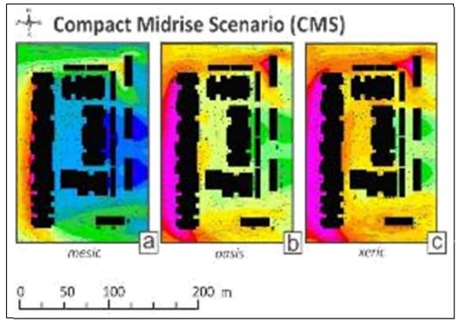
heatscapes sensed by instruments
microclimate observations and human-biometeorological observations (mobile, handheld, and stationary), thermal imagery, satellite imagery, etc.

heatscapes sensed by humans
MaRTy cart, surveys, sweating thermal manikin ANDI, etc.

digital modeling of heatscapes
ENVI-met, Rayman, SOLWEIG, Local Climate Zones, OpenMRT, PanoMRT, etc.







Urban Climate

Population growth and climatic changes threaten urban livability through

- urban overheating
- extreme weather
- hazardous air quality
- increased energy consumption

Numerous subfields of urban climatology have evolved over the last century to carefully document, examine, and model urban climate at various scales

- invention of the thermometer in the early 17th century enabled systematic recording of weather conditions
- first weather map with data from 22 stations was displayed at the World Exhibition in London in 1851
- first weather satellite TIROS was launched in 1960
- Stewart, I. D. (2019). Why Should Urban Heat Island Researchers Study History? *Urban Climate* 30, 100484. doi:10.1016/j.uclim.2019.100484

Despite tremendous technological progress: lack of hyperlocal data, less consideration of human factors and mobility

“Urban Climate Informatics”

RUB

Urban Climate

concerned with interactions between a city and the atmosphere

Climate Informatics

research combining climate science with approaches from statistics, machine learning, and data mining

Urban Climate Informatics

exploration and understanding of complex urban climate systems and human environment interactions through new technological, methodological, and systems thinking approaches

Middel, A., Nazarian, N., Demuzere, M., & Bechtel, B. (2022). Urban Climate Informatics: An Emerging Research Field. *Frontiers in Environmental Science*, 532.

Advances in Sensors

- Advances in wireless data transmission
- Low power design (reduced static/dynamic consumption)
- Reduced size
- Location awareness
- Higher resolution

- Internet of Things (IoT), Web of things (WoT), Internet of Everything (IoE)
- Secure data transmission and system protection
- Real-time data integration in dashboards and digital twins

Advances in Digital Infrastructure

- Cloud computing
- Edge computing
- Increased computational power and efficiency
- Increased storage capacity
- Improved communication networks

- Humans as sensors
- Novel non-obtrusive smart devices and applications
- New sensing methods (e.g., mobile, body-worn, garments, drones, CubeSats, LIDAR, MLS)
- Methods across scales

Increased Accessibility

UCI Applications

- Climate-sensitive urban design and planning
- Development of adaptation and mitigation strategies for urban climate challenges (such as heat and air quality)
- More comprehensive vulnerability and inequity analyses
- Improving human health and wellbeing through human-centric approaches

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- On-demand cloud computing and APIs (e.g., AWS, Azure)
- Real-time data analytics
- Public/scientific cloud computing, visualization, and analytics platforms (e.g., Google Earth Engine)
- Cloud-based climate modeling
- Digital twins of Earth/urban atmosphere

Novel Data Sources

- Government or commercial urban data (3D building models)
- Community generated and curated data
- Incidental data (social media, consumer data)
- Public domain data (web scraping)

- Proxy calculation and modeling using novel data sources (e.g., Google Street View)
- Pattern recognition of environmental impacts based on open data sources (e.g., Facebook/Twitter)
- Novel open-source data formats and standards (e.g. CityGML)

Advances in Analytical Algorithms & Platforms

- Artificial intelligence (including machine and deep learning)
- Augmented data management
- Procedural, predictive, and agent-based modeling
- Image processing

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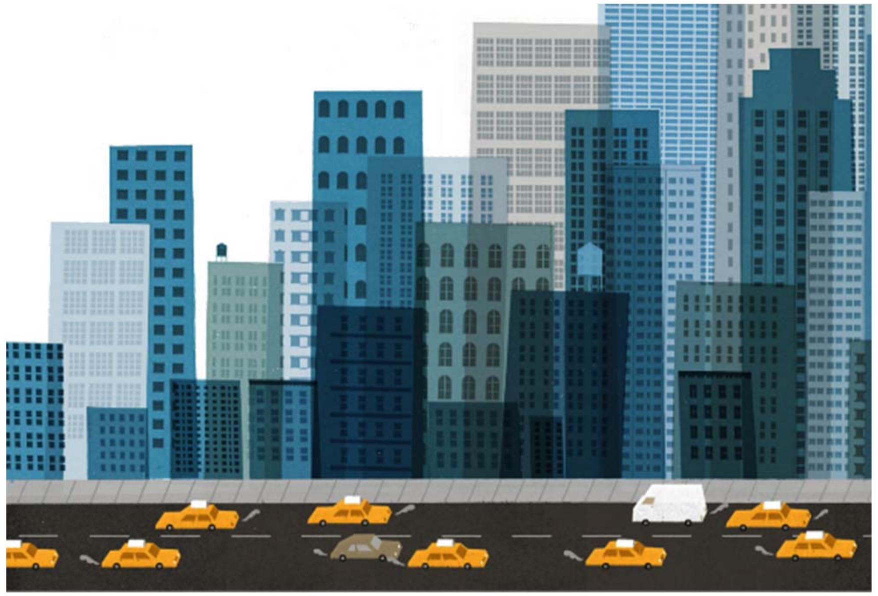
Paradigm Shift

UCI changes "how" we do science and expands research questions directed at the urban atmosphere and its residents

- human-environment interactions at fine spatial and temporal scales
- challenges of the Anthropocene
- intra-urban hazard distribution and human thermal exposure assessments
- low-cost sensing
- interdisciplinary teams
- solutions-oriented science
- new visualization tools, better communication



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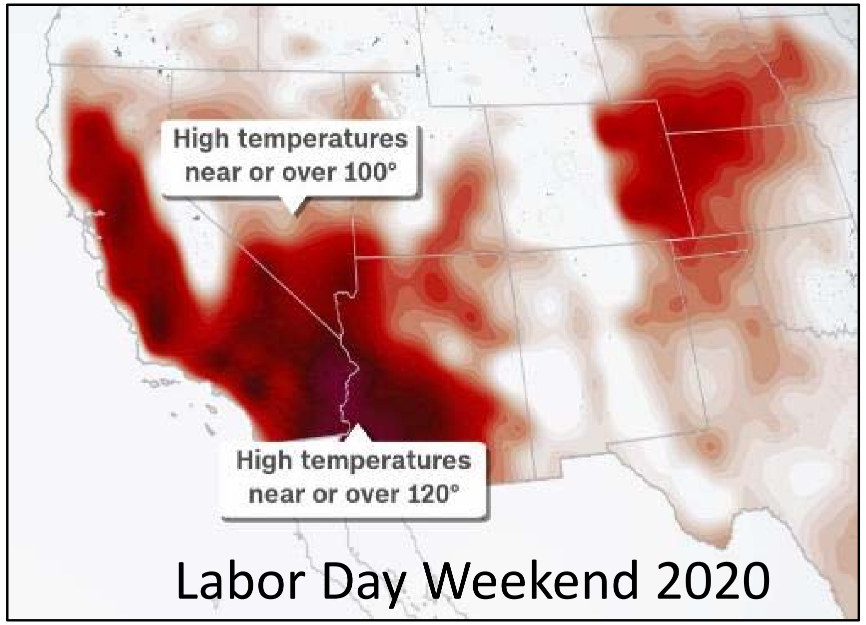
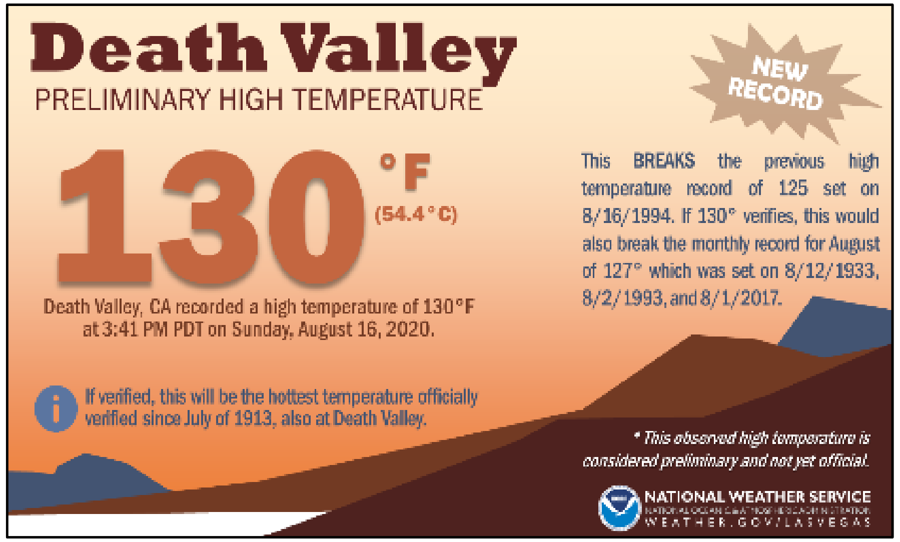
10 UCI Examples

School of Arts, Media and Engineering

US Southwest Heat Records

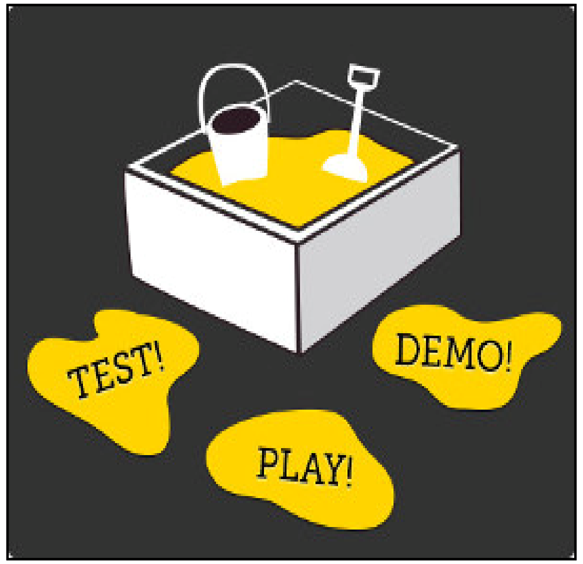




Phoenix, Arizona: The Living Laboratory

Phoenix's extreme climate and rapid urbanization patterns have rendered the metropolitan area a *perfect testbed* to investigate heat

- Average high temperatures over 38°C from June to August
- Phoenix conditions could become the new normal in other parts of the world
- City officials and researchers are actively seeking to understand the impacts of heat on urban infrastructure and the Phoenix population



Advances in Sensors: MaRTy

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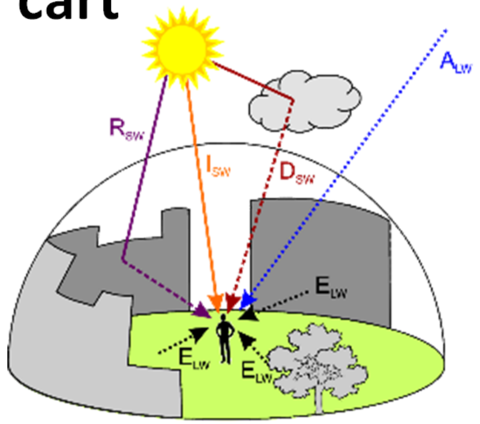
Human thermal exposure can be measured using Mean Radiant Temperature (MRT)

- MRT summarizes the heat load the human body is exposed to
- Synthetic parameter that summarizes the long- and shortwave radiation
- MRT an be 30°C higher in the sun than corresponding air temperature

MaRTy is a human-biometeorological “garden cart” to measure MRT

- MaRTy can observe how the thermal environment is experienced by a pedestrian
- Follow him at @ASUMaRTy



Ariane Middel, E. Scott Krayenhoff. (2019). Micrometeorological determinants of pedestrian thermal exposure during record-breaking heat in Tempe, Arizona: Introducing the MaRTy observational platform, STOTEN, 687:137–151.

50 Grades of Shade

Shade is crucial to improve thermal comfort/reduce heat exposure in hot desert cities

- Cities face infrastructure challenges to meet tree canopy goals outlined in urban forestry plans
- No actionable information is available that can help cities make well-informed decisions on viable shade alternatives

What is the most effective shade type depending on urban context and function of space?

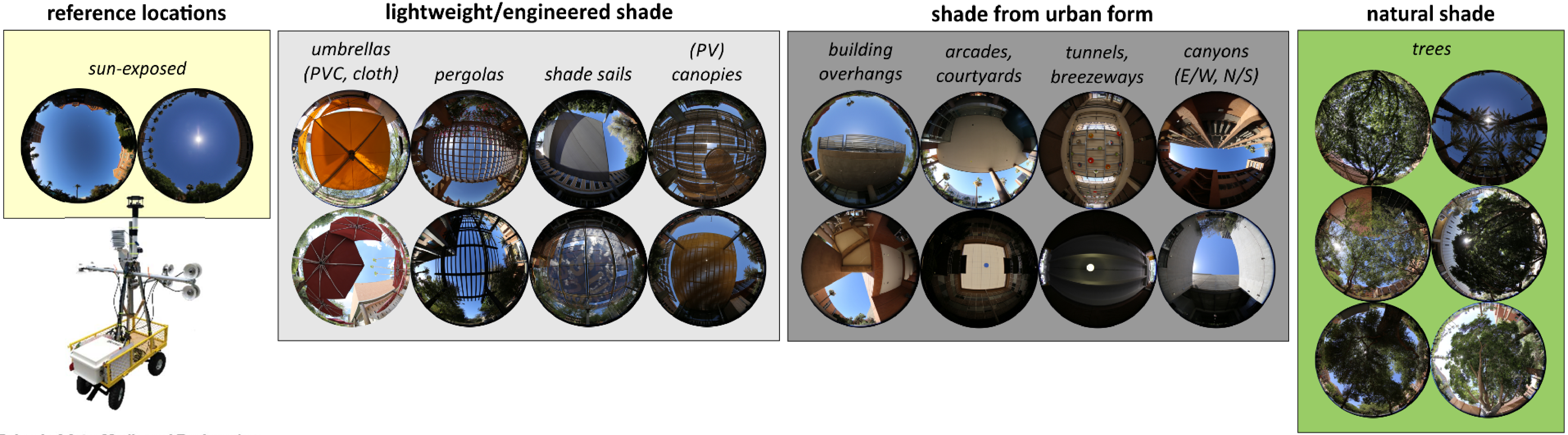
- Right Shade in the Right Place?

Middel, A., AlKhaled, S., Schneider, F.A., Hagen, B., Coseo, P. (2021) 50 Grades of Shade. *Bulletin of the American Meteorological Society (BAMS)*. https://doi.org/10.1175/BAMS-D-20-0193.1

Field Measurements

MaRTy observed shaded and sun-exposed reference locations in Tempe, Arizona

- Hourly transects from 8:00 AM to 9:00 PM on hot, sunny summer days between 2016 and 2019
- 159 unique locations and ~2000 observations



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Shade Performance

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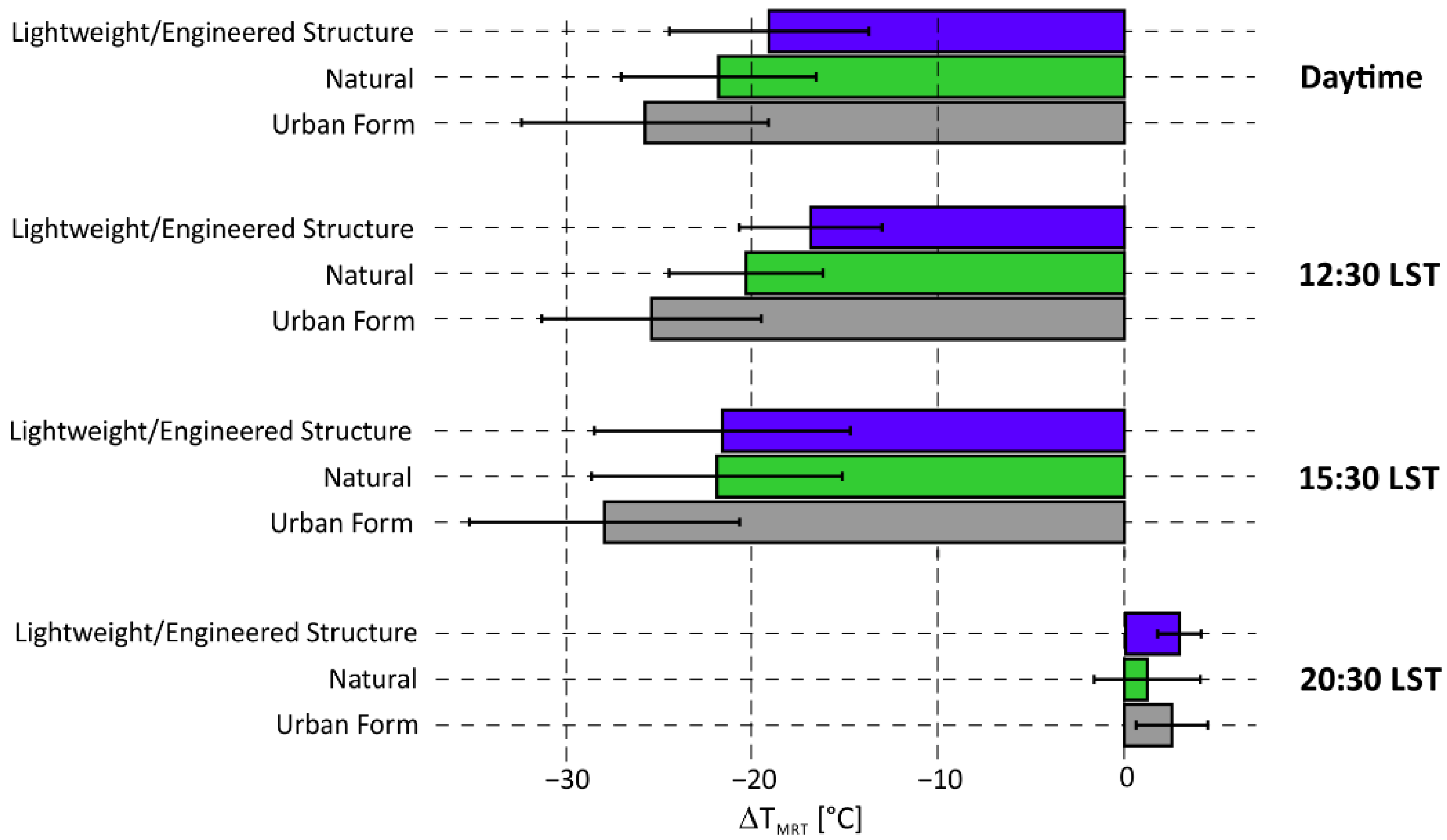
Shade Performance: The Difference in MRT between an exposed site and the shaded site



All shade is great!

Middel, A., AlKhaled, S., Schneider, F.A., Hagen, B., Coseo, P. (2021) 50 Grades of Shade. *Bulletin of the American Meteorological Society (BAMS)*. https://doi.org/10.1175/BAMS-D-20-0193.1

Results

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All Shade Is Great!

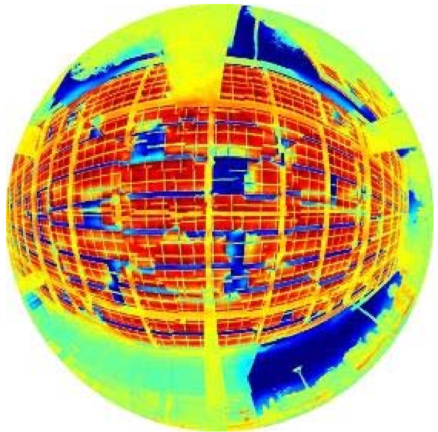
Shade from urban form/structures was most effective in reducing MRT and surface temperature

- Followed by trees and lightweight artificial structures such as umbrellas and shade sails

Structural shade performed differently with changing orientation

Trees varied widely in performance

- Native trees and palm trees were least effective
- Pine trees and eucalyptus trees were most effective



Goal: Guidelines and best practices—grounded in local observational data—that can be incorporated into City of Tempe ordinances and plans

Middel, A., AlKhaled, S., Schneider, F.A., Hagen, B., Coseo, P. (2021) 50 Grades of Shade. *Bulletin of the American Meteorological Society (BAMS)*. https://doi.org/10.1175/BAMS-D-20-0193.1

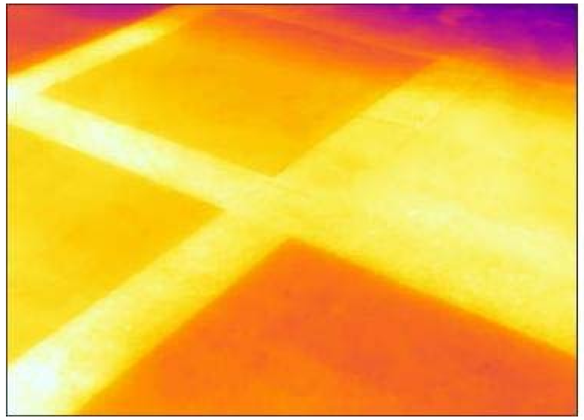
Cool Pavement

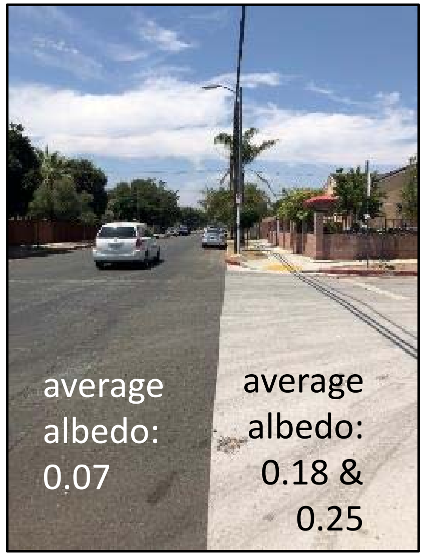
The Los Angeles Streets Department began piloting the use of solar reflective coatings on residential roads in 2017, the City of Phoenix began piloting in 2020

- Simple, low-cost solution with a demonstrated ability to reduce surface temperature

Less well understood is the effect of solar reflective coatings on radiant heat, which influences human thermal exposure

- What is the impact of cool pavement on pedestrians, considering various thermal performance metrics?





Middel, A., Turner, V. K., Schneider, F. A., Zhang, Y., & Stiller, M. (2020). Solar reflective pavements-A policy panacea to heat mitigation? *Environmental Research Letters*, 15(6). https://doi.org/10.1088/1748-9326/ab87d4

Results

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Surface Temperature T_s

- Highly reflective coating reduced T_s at all times
  - T_s was 10°C lower during midday, 4°C in the afternoon

Air Temperature T_a

- T_a was 0.5°C lower over cool pavement in the afternoon, but negligible after sunset

Mean Radiant Temperature

- T_{MRT} over cool pavement was 4°C higher during midday and 2°C higher in the afternoon compared to asphalt

Similar Findings in Phoenix in 2020

- MRT over cool pavement was increased at noon and afternoon by 3°C but overall similar to that experienced if walking over concrete
- Cool Pavement T_s was cooler than asphalt by 5°C at noon

https://www.phoenix.gov/streets/coolpavement

Middel, A., Turner, V. K., Schneider, F. A., Zhang, Y., & Stiller, M. (2020). Solar reflective pavements-A policy panacea to heat mitigation? *Environmental Research Letters*, 15(6). https://doi.org/10.1088/1748-9326/ab87d4

Conclusions

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Cool Pavements have benefits and disadvantages

- What is the goal/thermal metric that’s most important?

Cool Pavements provide important opportunities to learn how reflective coatings work in practice

- More “living laboratory” experiments are needed to investigate
  - Diurnal, seasonal, and inter-annual variability
  - Differences related to intervention scale, urban form, climatic context, and coating materials
  - Interactions with other heat mitigation measures (e.g., trees)

- *Open lots, not shaded* ☑
- *Low-rise residential*

- *Not in playgrounds or parks* ✗
- *Not in already very shaded locations*
- *Not in high-rise downtown areas*

MaRTy's Ongoing Adventures

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MaRTy the Shade Hunter (50 Grades of Shade)

- What is the most effective shade type depending on urban context and function of space?

Ariane Middel, Saud AlKhaled, Florian A. Schneider, Björn Hagen, Paul Coseo. (2021). 50 Grades of Shade. *Bulletin of the American Meteorological Society (BAMS)*, 102(9):E1805–E1820.

MaRTy the Tree Hugger

- What is the benefit of tree shade over time?

MaRTy takes to the streets

- What is the effect of cool pavement on pedestrians?

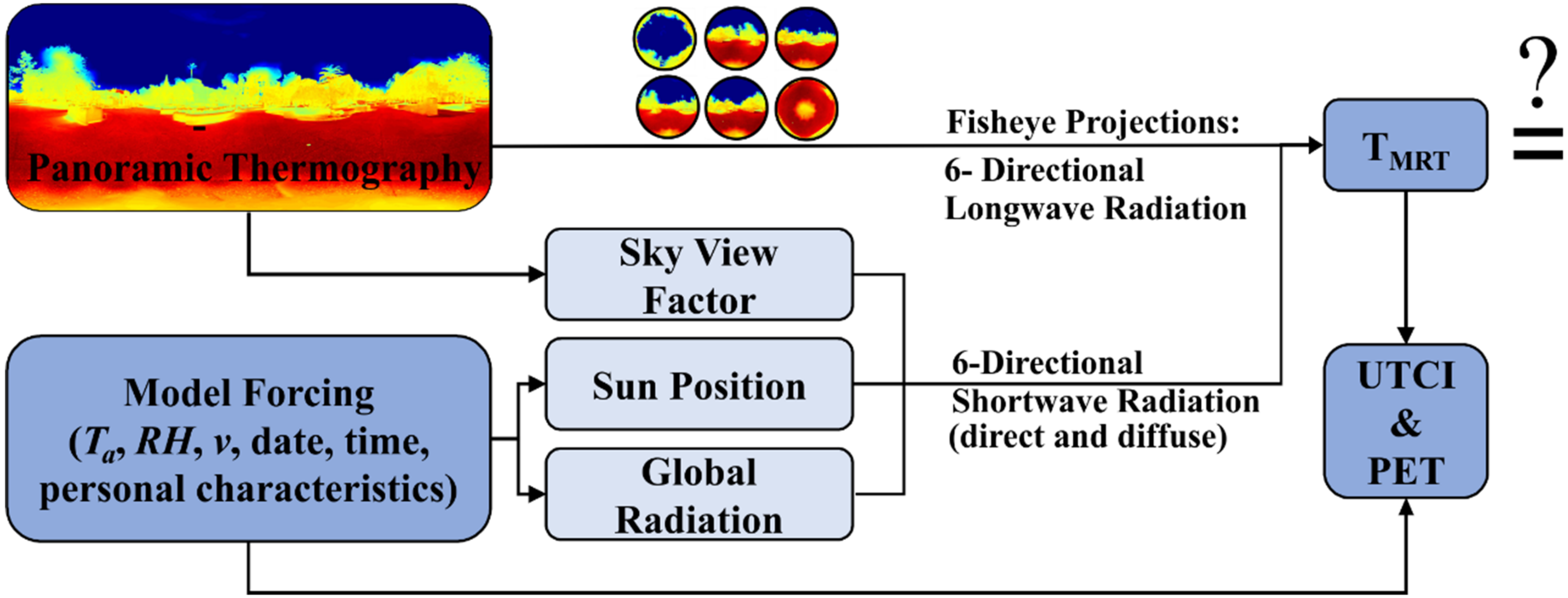
Ariane Middel, V. Kelly Turner, Florian A. Schneider, Yujia Zhang, Matthew Stiller. (2020). Solar reflective pavement – A policy panacea to heat mitigation? *Environmental Research Letters*, 15:064016.

MaRTy the Heat Walker

- What is the impact of neighborhood redesign on thermal comfort? Edison Eastlake, Cool Kids…

Advances in Sensors: PanoMRT

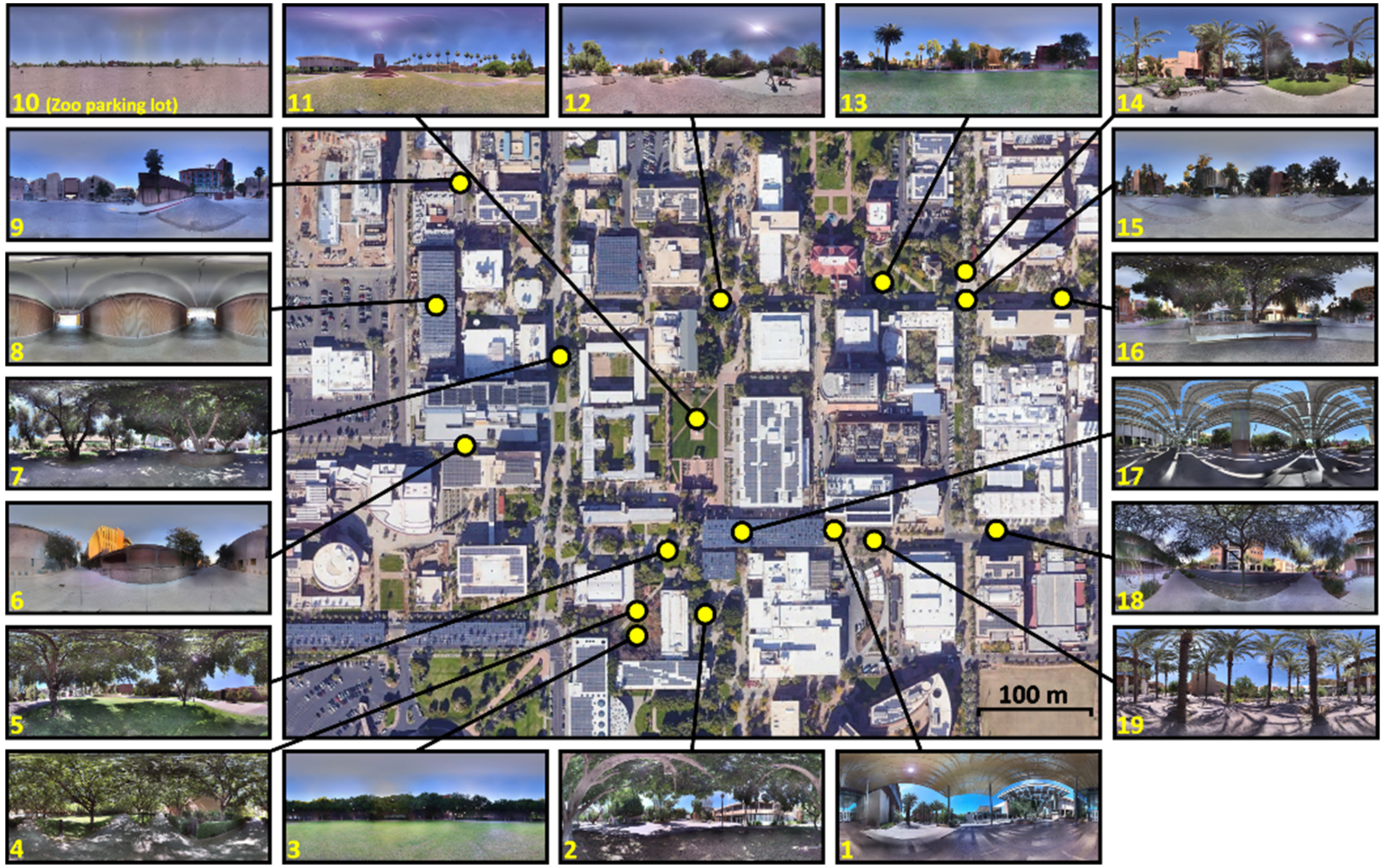
RUB

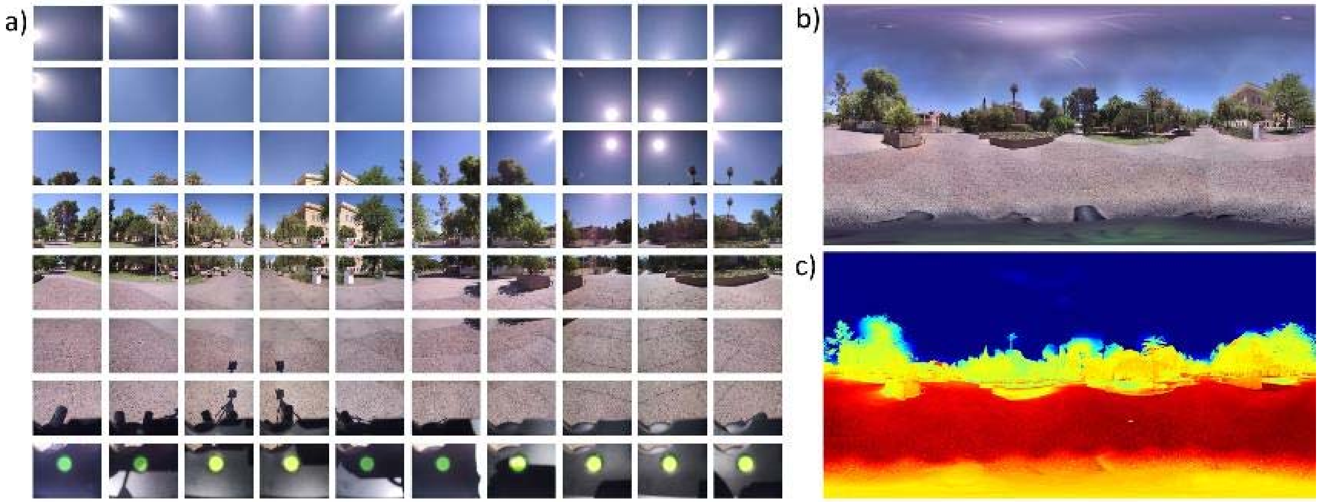


Ariane Middel, Matthew Huff, E. Scott Krayenhoff, Florian A. Schneider, Ananth Udupa. (under review). PanoMRT: Panoramic infrared thermography to model human thermal exposure and comfort, Science of the Total Environment

Advances in Sensors: PanoMRT

RUB





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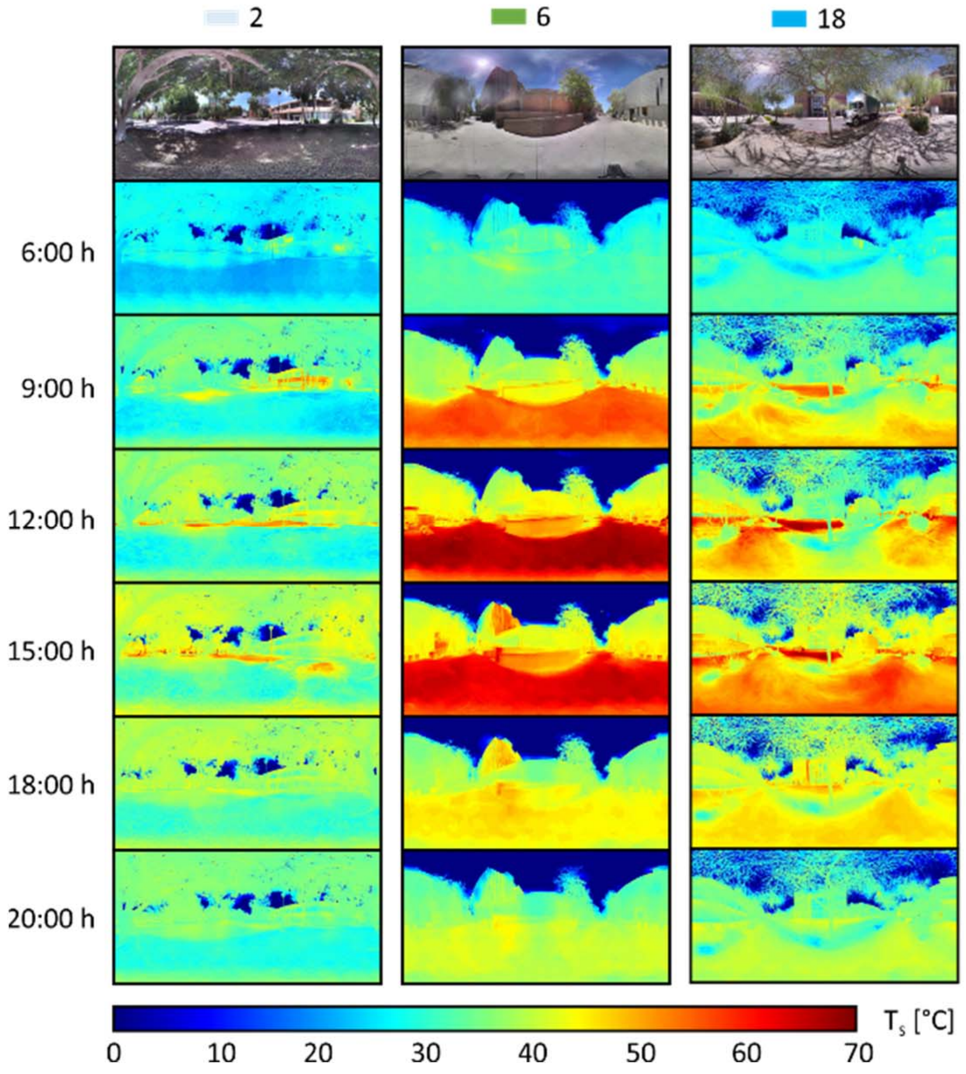
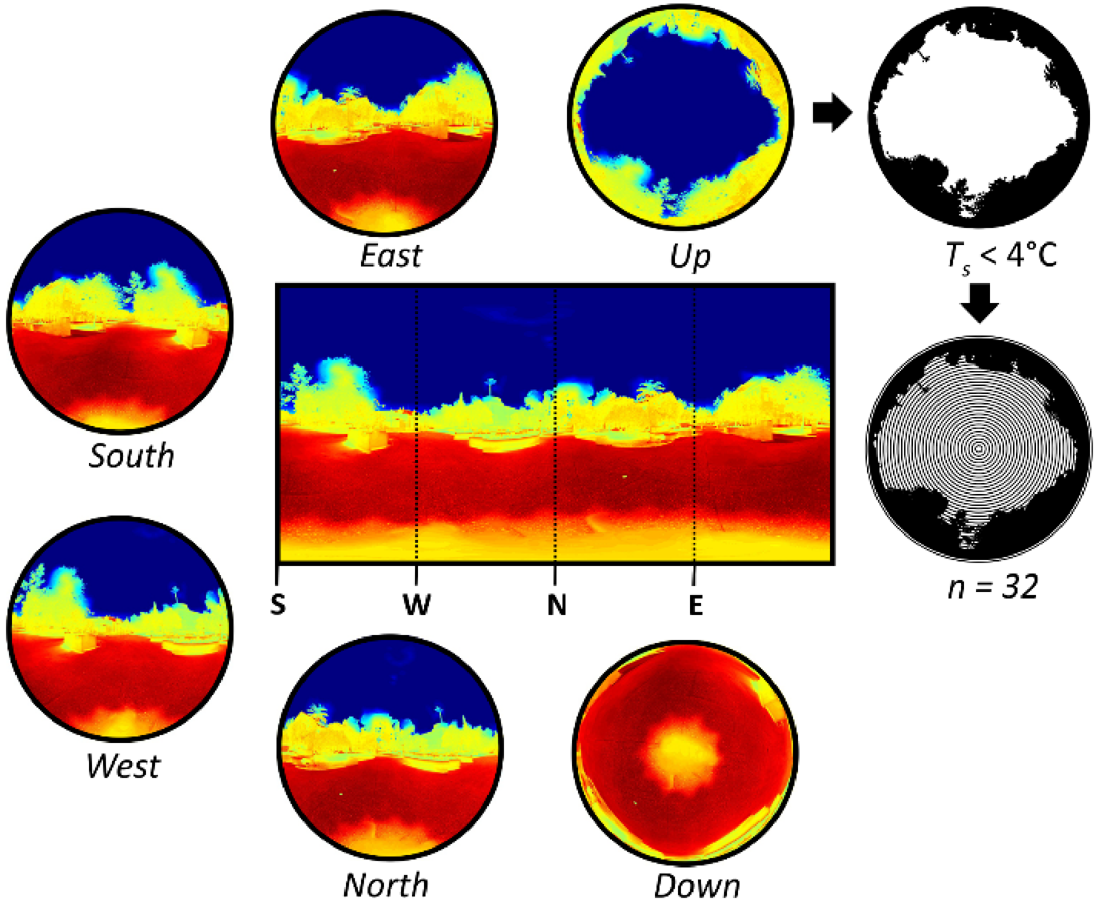
Advances in Sensors: PanoMRT





School of Arts, Media and Engineering

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Advances in Sensors: Thermal Manikin

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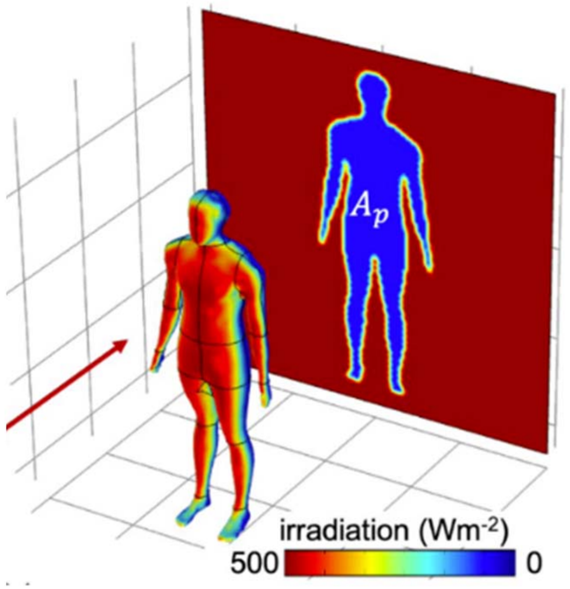
ASU ANDI is coming to Tempe in Fall 2022!

- Custom thermal manikin for studying human thermal exposure and safety in hot climates led by Prof. Rykaczewski, Vanos, Middel, Sailor, and Kavouras



anisotropic radiation source modeling for computational thermal manikin simulations

PhD position open at ASU for Fall 2023 to work with the manikin!

Konrad Rykaczewski, Jennifer K. Vanos, Ariane Middel. (2022). Anisotropic radiation source models for computational thermal manikin simulations based on common radiation field measurements, Building and Environment, 208: 108636.

Advances in Dig. Infrastructure: MaRTiny

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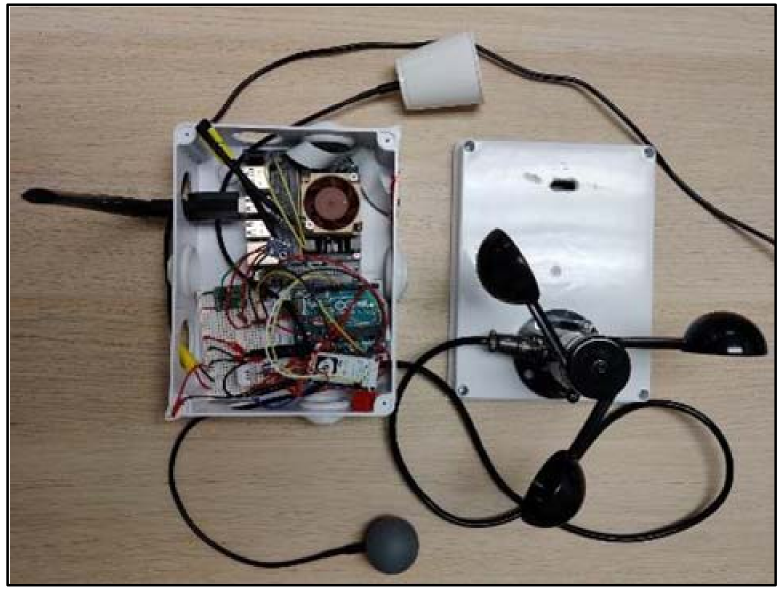
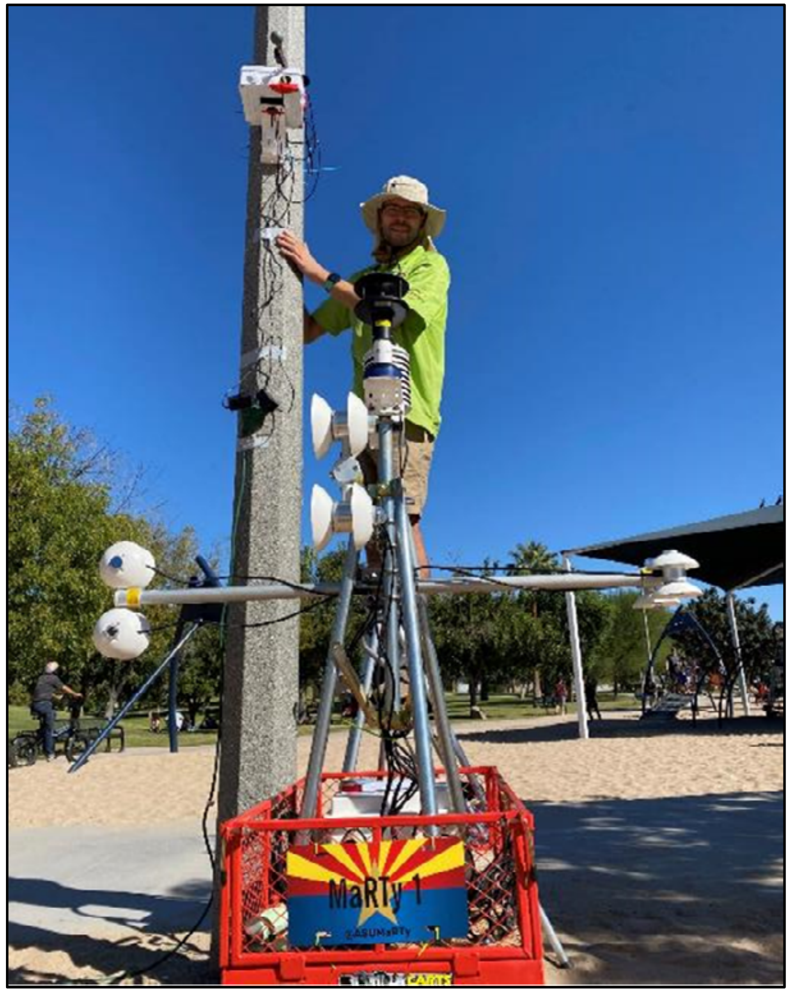
MaRTiny

- Low-cost IoT enabled human-biometeorological weather station
- Measures grey globe temperature, air temperature, relative humidity, wind speed, UV
- Counts people in the shade and sun
  - Image processing on AWS server
  - Data stored in MungoDB





Kulkarni, K. K., Schneider, F. A., … Middel, A. (2022). MaRTiny—A Low-Cost Biometeorological Sensing Device With Embedded Computer Vision for Urban Climate Research. *Frontiers in Environmental Science*, 550.

Novel Data Sources

The Internet of Things (IoT)

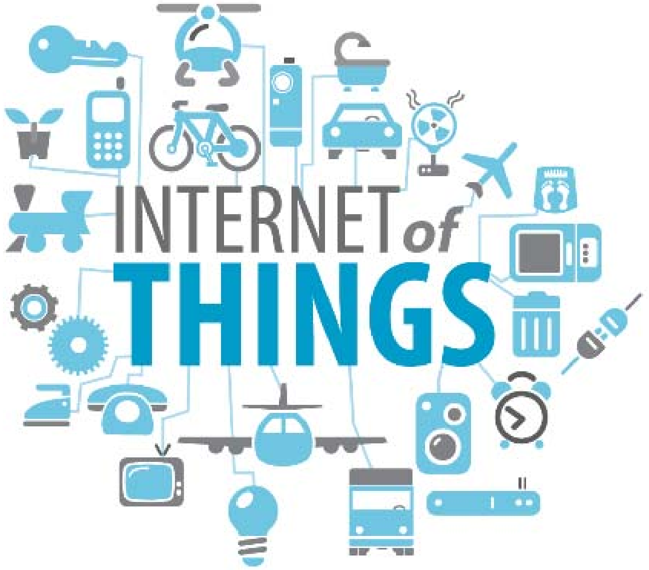
- interconnection via the Internet of computing devices embedded in everyday objects
- things that collect information and then send it
- things that receive information and then act on it
- things that do both

Social media

- Facebook
- Twitter…

Street View Imagery

- Google
- Mapillary
- Baidu…



temperature sensors
motion sensors
moisture sensors
air quality sensors
…

Ariane Middel, Negin Nazarian, Matthias Demuzere, Benjamin Bechtel. (2022). Urban Climate Informatics – an emerging research field, *Frontiers in Environmental Science*, 10:867434.

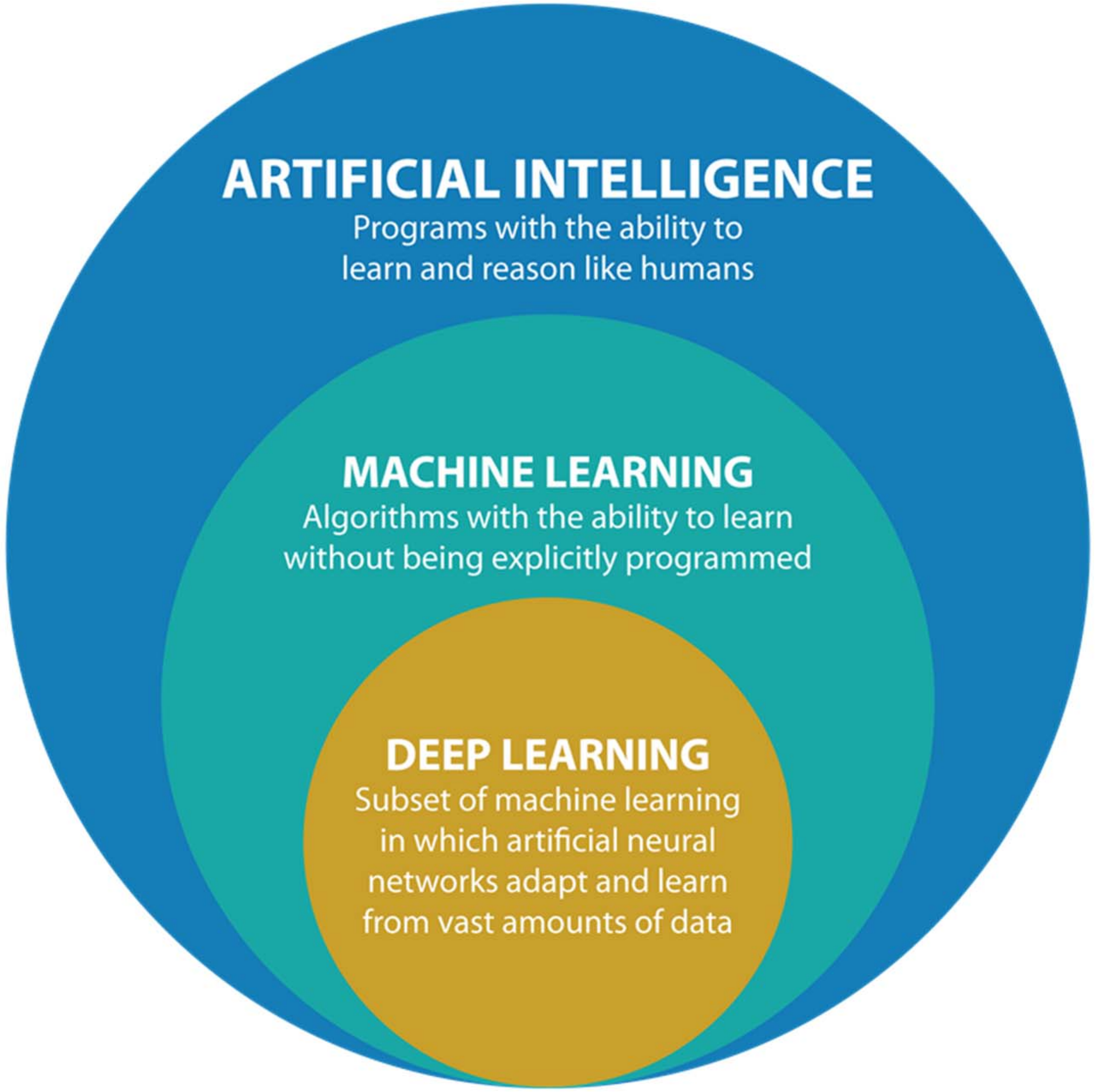
Novel Data Sources

Big data – often repurposed!

- unprecedented amount of data
- not collected to answer urban climate questions

Data processing

- machine Learning
- deep Learning (convolutional neural networks)



Street View imagery

Google Street View coverage

- High-resolution Street View images are increasingly available for cities around the globe
- Unprecedented opportunity to extract fine-scale 3D data to describe the form, materials, vegetation, and function of cities

Street View Applications

Virtual street/neighborhood audits

- way to evaluate the quality of streets and neighborhoods from the viewpoint of the people who use them, rather than those who manage them

  - in-situ vs. automated audits
  - walkability
  - bikeability
  - accessibility
  - traffic safety
  - obesity
  - physical activity

Characterizing the Built Environment

- greenery
- building floor count
- crosswalks
- building age
- urban land use classification
- sky view factors
- urban form and composition of street canyons

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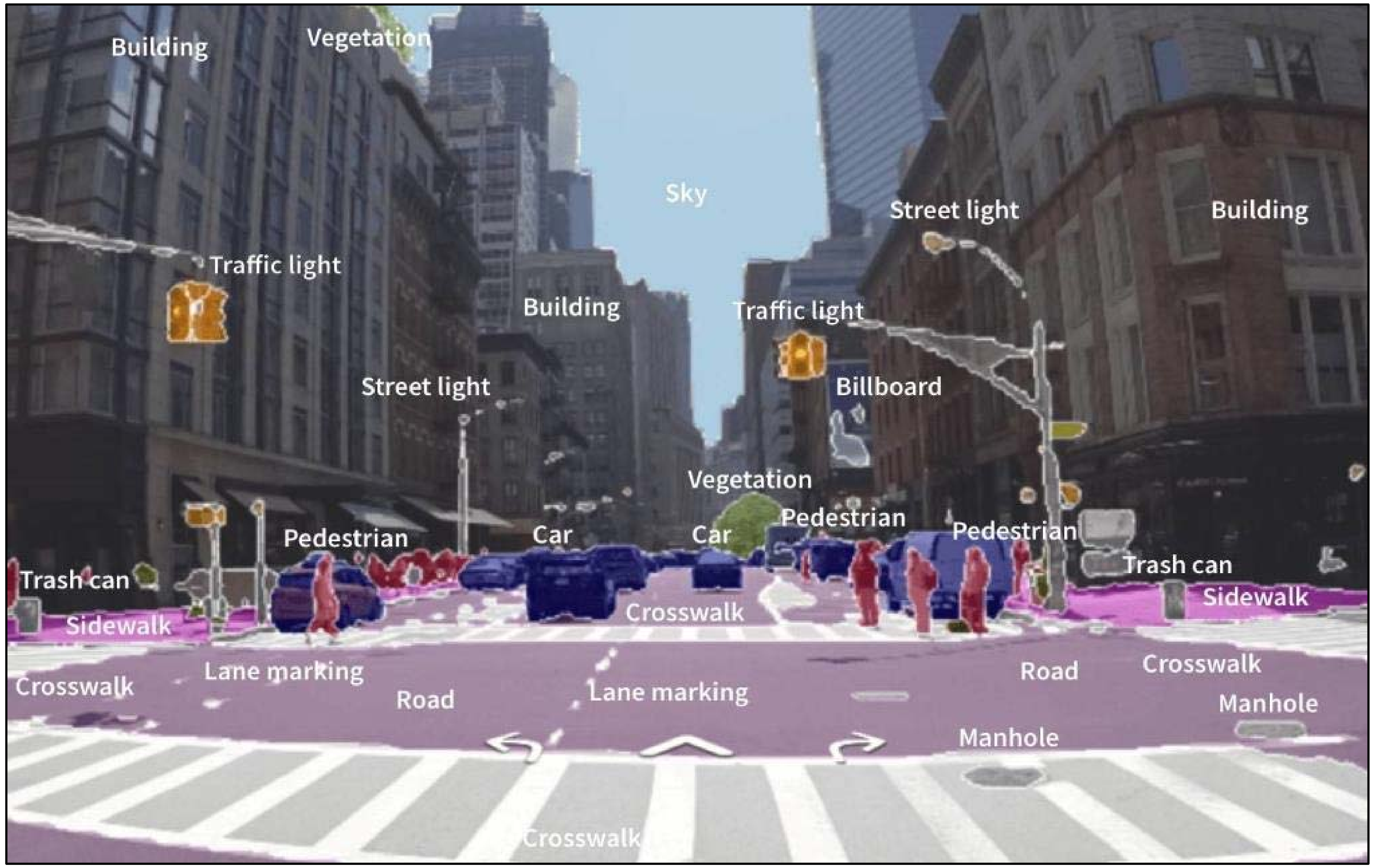
Street View Applications

Characterizing the Built Environment

Example of a Mapillary photo that has been digitized to train autonomous vehicles



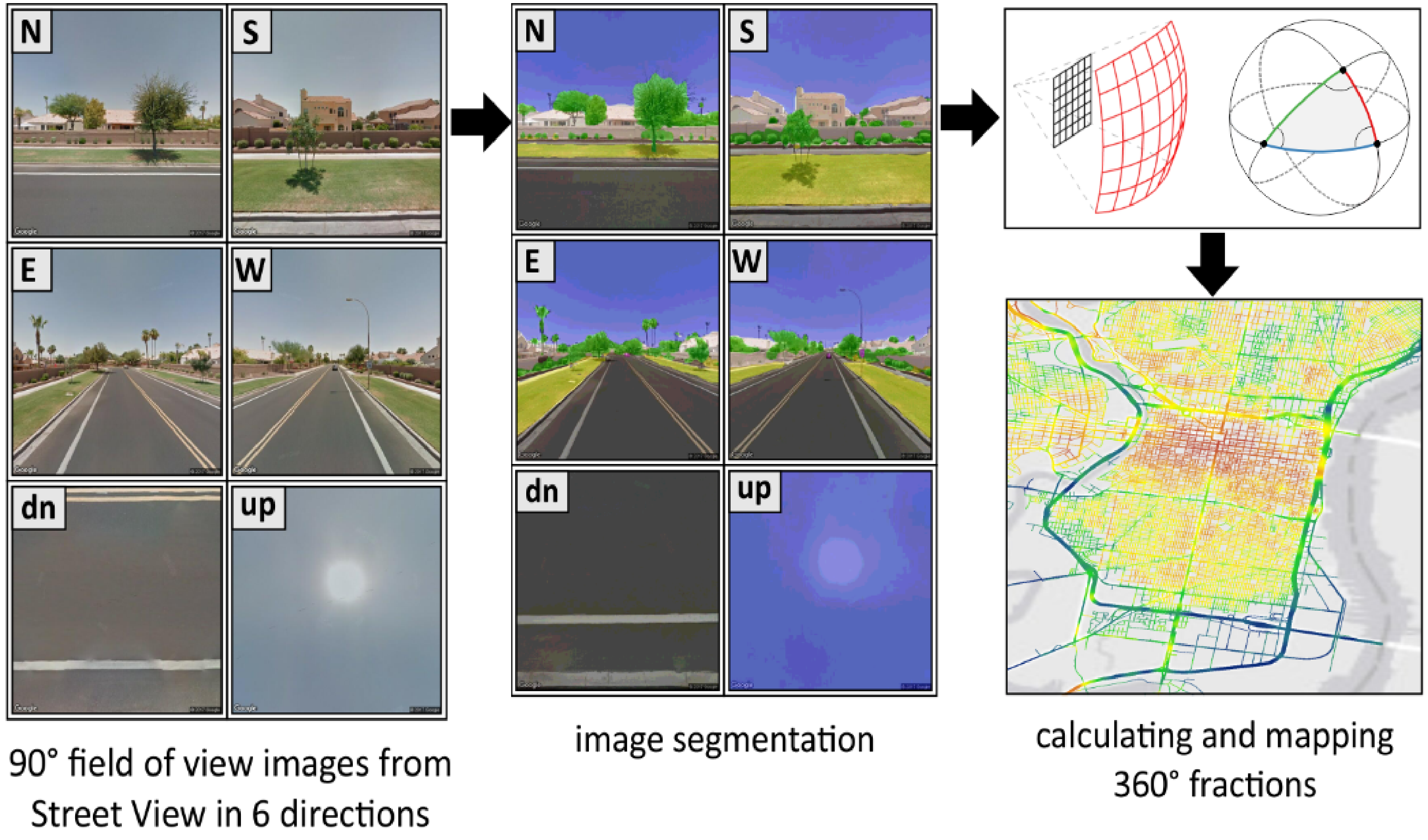
Urban form and configuration
from Street View

1. Street View image acquisition
- Javascript, Node.js
- Google Street View API

2. Image segmentation
- Fine-tuned fully convolutional neural network

3. Sky View Factor Calculation
- Modified Steyn

4. Calculation of urban fractions
- 360° fractions of trees, buildings, pervious and impervious surfaces, sky, and non-permanent objects



Middel, A., et al. (2019). Urban form and composition of street canyons: a human-centric big data and deep learning approach. *Landscape and Urban Planning*, *183*, 122-132.

Image Segmentation

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Deep Learning using fully convolutional neural network (Caffe framework)

- Aggregation of 33 original categories into six classes:
  buildings, trees, impervious and pervious surfaces, sky, movable objects

Fine-tuning the network

- Manual segmentation of 2,634 Google Street View images from around the world

Separate networks for three view directions

- Up, down, lateral

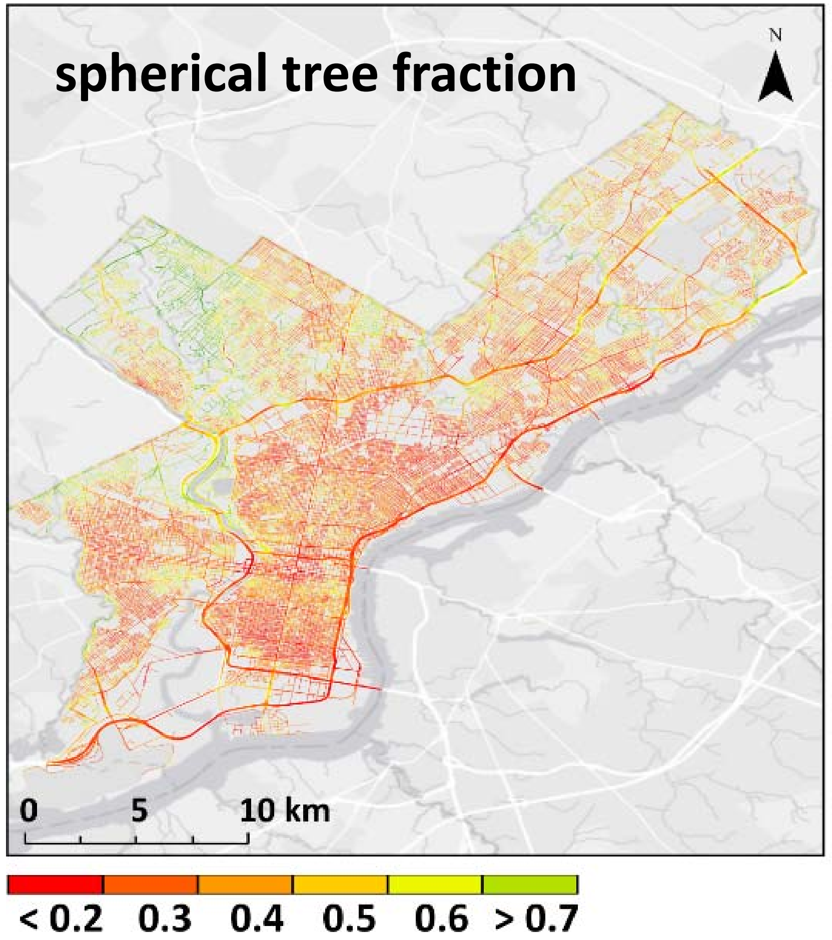
Training, testing, and segmentation performed on single NVIDIA TITAN X Pascal graphics card

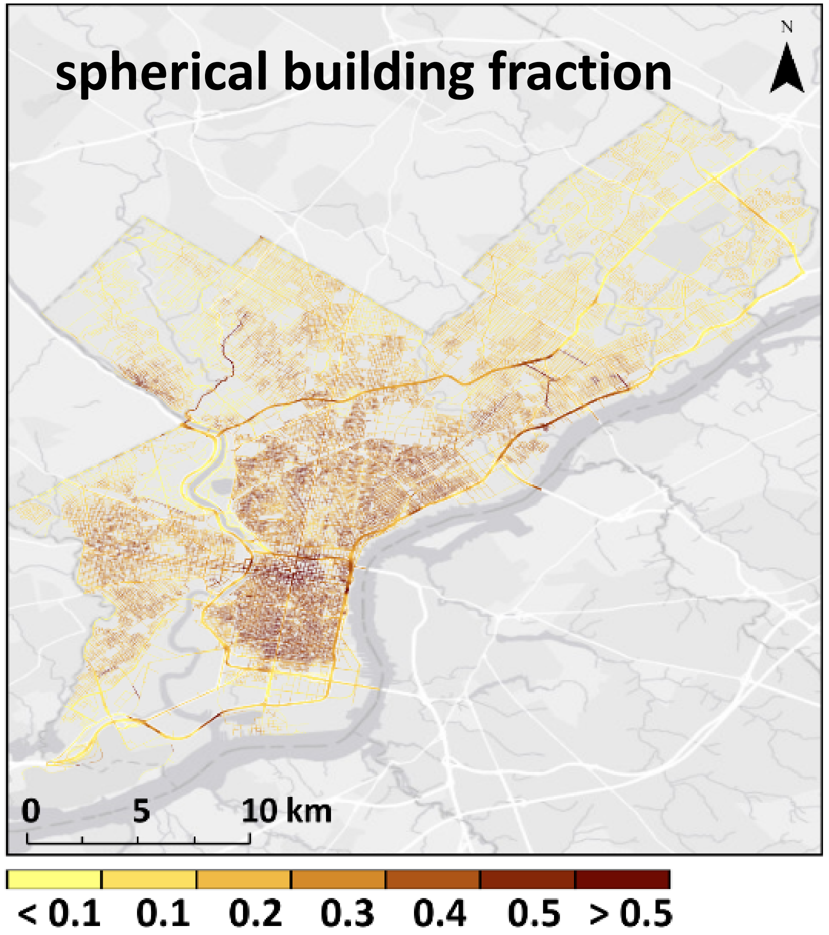
- Mean segmentation accuracy
  - Lateral: 0.919
  - Down: 0.971
  - Up: 0.992

Middel, A., et al. (2019). Urban form and composition of street canyons: a human-centric big data and deep learning approach. *Landscape and Urban Planning*, *183*, 122-132.

Street Canyon Composition

936,231 Google Street View locations





SVF (average)
0.723

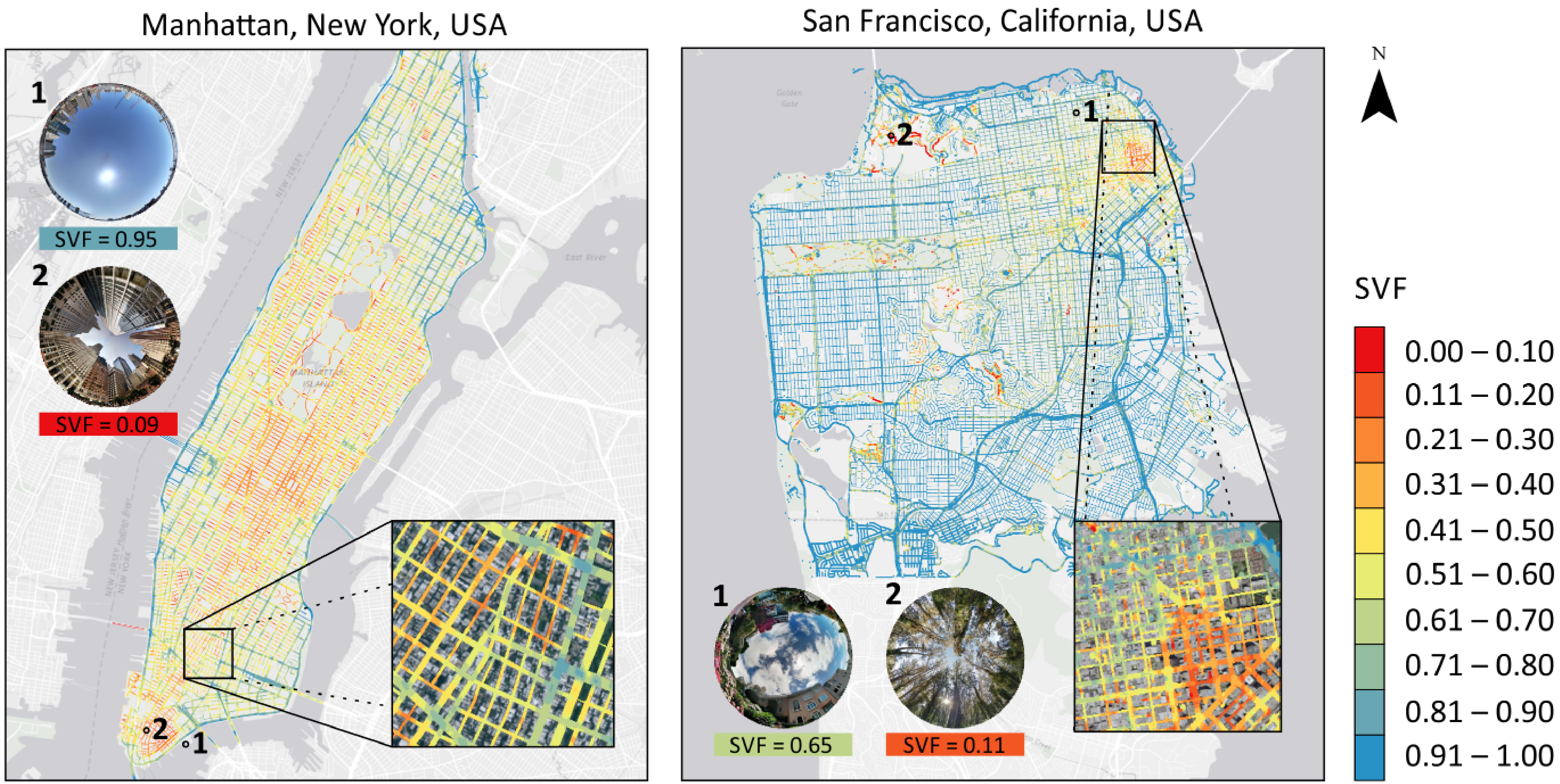
Sky Fraction	Tree Fraction
0.237	0.232

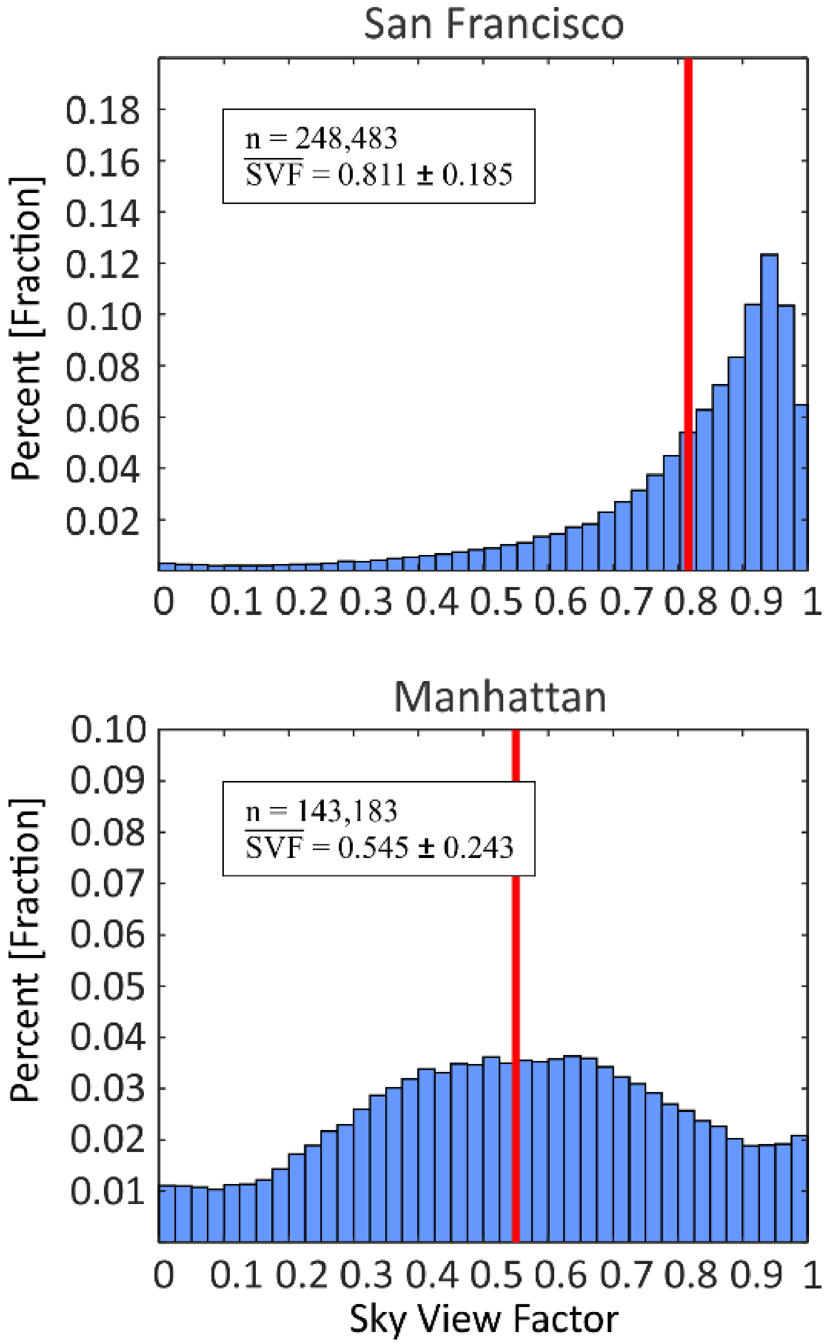
Building Fraction	Impervious Fraction
0.131	0.287

Pervious Fraction	Movable Objects Fraction
0.071	0.042

Middel, A., et al. (2019). Urban form and composition of street canyons: a human-centric big data and deep learning approach. *Landscape and Urban Planning*, *183*, 122-132.

Sky View Factor Footprints





Middel, A., Lukasczyk, J., Maciejewski, R., Demuzere, M., & Roth, M., (2018), Sky View Factor Footprints for Urban Climate Modeling. *Urban Climate*. 25, 120-134.

Spherical fractions and SVFs

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Urban Area		# Locations	SVF
Atlanta, GA	US	550,184	0.688
Baltimore, MD	US	523,709	0.786
Bangkok	TH	1779185	0.764
Barcelona	ES	602,645	0.709
Be'er Sheva	IL	57,608	0.898
Belgrade	RS	346,661	0.807
Bogotá	CO	694,329	0.776
Bonn	DE	57,861	0.749
Boston	US	466,158	0.705
Brussels	BE	285,059	0.698
Bucharest	RO	321,145	0.777
Budapest	HU	processing	
Buffalo, NY	US	349,676	0.824
Chicago, IL	US	processing	
Charlotte, NC	US	processing	
Cleveland, OH	US	352,365	0.757
Dallas, TX	US	processing	
Denver, CO	US	1,109,871	0.879
Detroit, MI	US	processing	

Urban Area		# Locations	SVF
Dubai	IE	609,301	0.921
Dublin	IE	427,071	0.835
El Paso	US	827,718	0.962
Frankfurt	DE	83,573	0.738
Fresno, CA	US	499,908	0.906
Gothenburg	SE	171,691	0.825
Hamburg	DE	253,958	0.702
Hong Kong	HK	625,136	0.548
Houston, TX	US	processing	
Istanbul	TR	1,629,574	0.714
Johannesburg	AF	472,900	0.804
Kampala	UG	145,989	0.873
Kiev	RU	450,163	0.764
Kuala Lumpur	MY	429,877	0.720
Las Vegas, NV	US	1,135,657	0.937
London	UK	2,396,172	0.774
Los Angeles metro	US	9,354,005	0.889
Lyon	FR	179,821	0.682
Madrid	ES	827,932	0.751

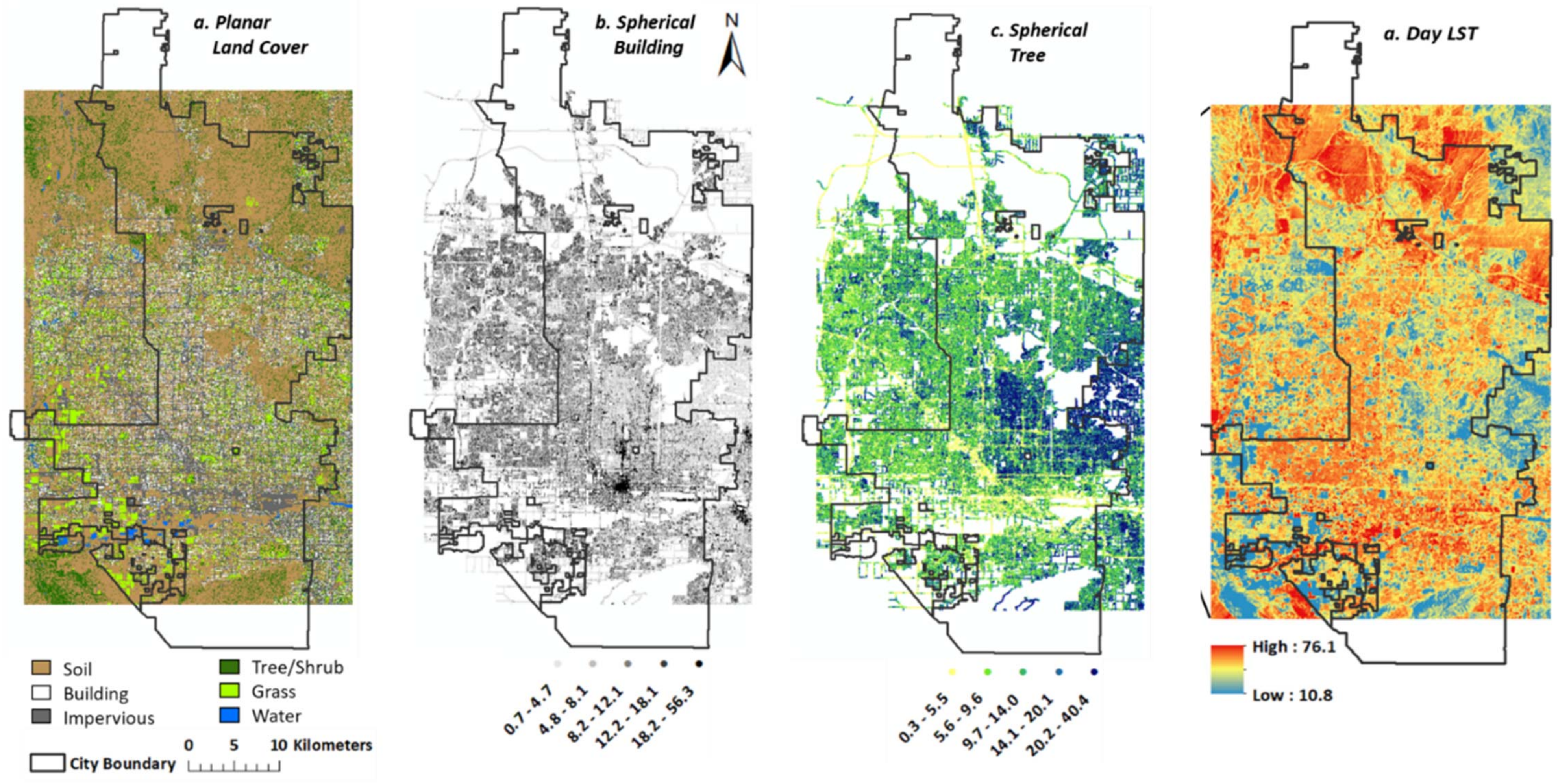
Urban Area		# Locations	SVF
Manhattan, NY	US	143,183	0.545
Mexico City	MX	1,950,105	0.761
Miami, FL	US	1,005,440	0.835
Minneapolis	US	592,037	0.742
Montreal	CA	1,345,423	0.826
Nantes	FR	203,440	0.812
New Orleans	US	631,122	0.846
New York, NY	US	6,142,813	0.722
Orlando, FL	US	872,359	0.809
Paris	FR	1,493,853	0.726
Philadelphia, PA	US	936,231	0.723
Phoenix metro	US	3,124,529	0.954
Portland, OR	US	processing	
Prague	CZ	processing	
Richmond, VA	US	321,193	0.703
Rome	IT	700,481	0.739
Salt Lake City, UT	US	689,701	0.907
San Antonio, TX	US	1,117,303	0.904
San Diego, CA	US	1,536,598	0.907

Urban Area		# Locations	SVF
San Francisco, CA	US	233,281	0.797
San Jose, CA	US	771,094	0.840
Santiago	CL	1,071,250	0.839
São Paolo	BR	2,559,340	0.787
Seattle, WA	US	405,276	0.765
Seoul	KR	processing	
Singapore	SG	948,674	0.685
Sofia	BG	311,971	0.786
Tampa, FL	US	693,181	0.772
Tel Aviv	IL	156,353	0.763
Tokyo	JP	3,736,082	0.693
Toulouse	FR	368,855	0.836
Tucson, AZ	US	565,825	0.956
Vancouver, BC	CA	693,193	0.781
Victoria, BC	CA	152,985	0.761
Warsaw	PL	601,920	0.755
Washington, DC	US	516,448	0.705
		64,608,441	

Jason Chinget al. (2019). Pathway using WUDAPT's Digital Synthetic City tool towards generating urban canopy parameters for multi-scale urban atmospheric modeling, Urban Climate, 28: 100459.

2D vs. 3D Surface Composition

RUB



Explaining Variation in Daytime and Nighttime Land Surface Temperature (LST)

Global Regression		Planar	Spherical	Planar + Spherical
Day LST	R^2	.31	.36	.46
	Adj. R^2	.31	.36	.46
Night LST	R^2	.31	.32	.43
	Adj. R^2	.31	.32	.42

Zhang, Y., Middel, A., & Turner, B.L., (2019), Evaluating the effects of vertical urban forms on diurnal land surface temperatures using Google Street View images. *Landscape Ecology*.

OpenMRT Heatscape Model

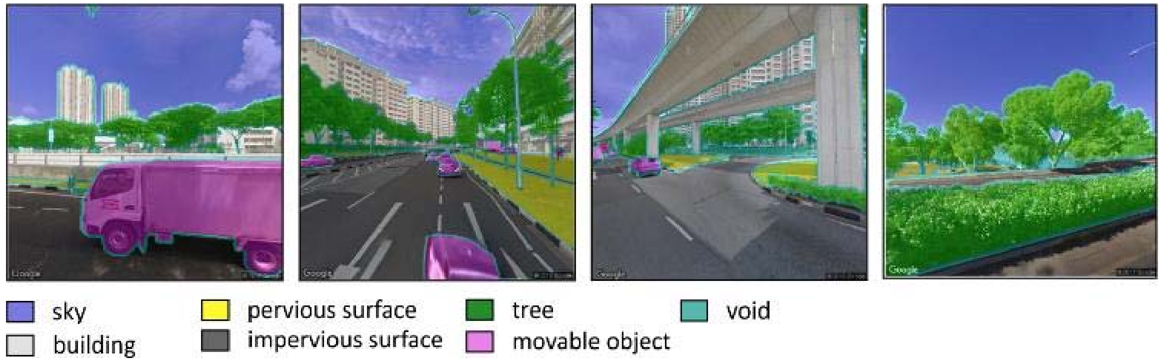
RUB

5-year NSF CAREER project

- Goal: advance understanding of how the built environment impacts heat and human thermal exposure in cities

OpenMRT Model calculates MRT based on

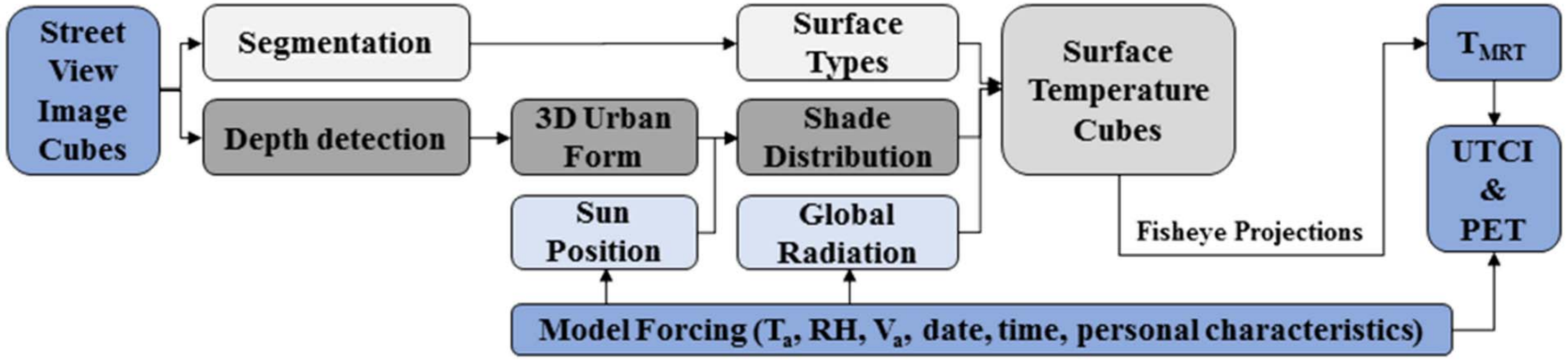
- Google Street View images
- Human-centric spherical surface fractions from image segmentation
- Shaded and sun-exposed urban surfaces from depth estimation
- Standard weather information as forcing



Assessment of model performance and refinement of parameters

- MaRTy's field observations
- Human-Biometeorological database

PhD position open at ASU for Fall 2023 to help advance model!



Advances in Analytical Platforms: LCZ map of Europe

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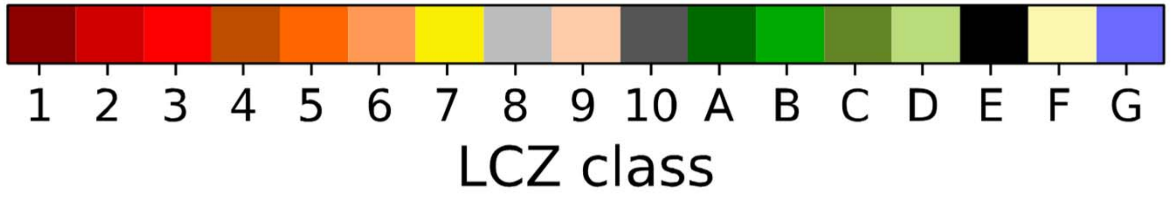
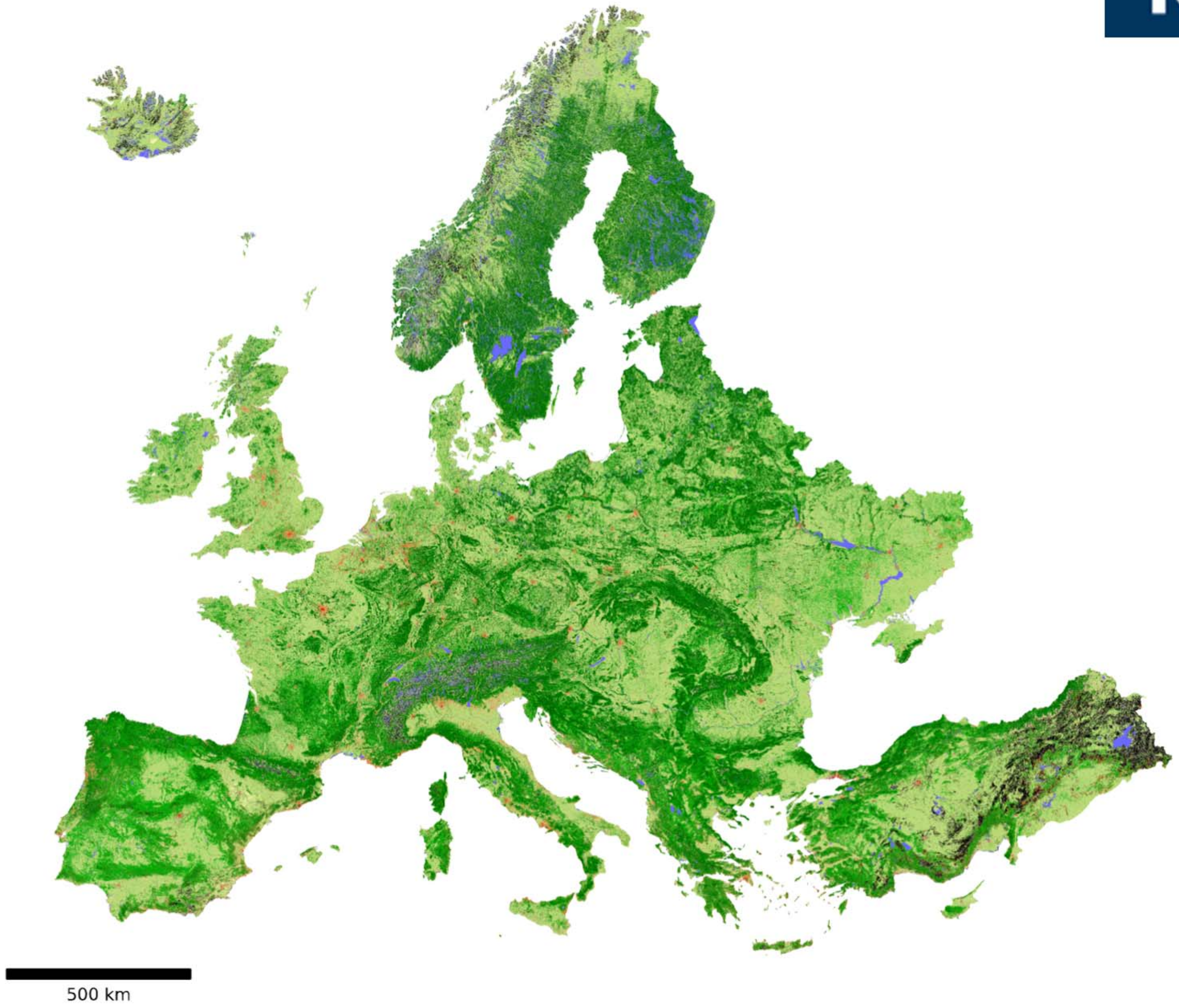
Crowdsourcing
Google Earth Engine
Machine Learning
Google Street View derived urban form





School of Arts, Media and Engineering

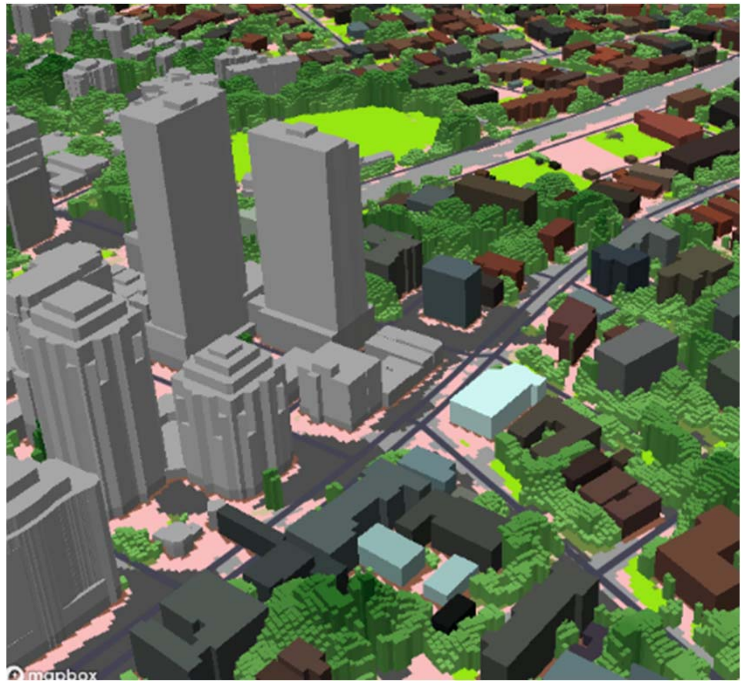
Matthias Demuzere, Benjamin Bechtel, Ariane Middel, Gerald Mills. (2019). Mapping Europe into Local Climate Zones, *PLoS ONE*, 14(4):e0214474. https://doi.org/10.1371/journal.pone.0214474

11

Australian city-descriptive data for urban climate models

Mathew Lipson, Negin Nazarian, Melissa Hart, Kerry Nice, Brooke Conroy

Restricted high-resolution 3D data → Fully open lower resolution (~100-300 m) derived data



Geoscape datasets (PSMA Australia):

- Buildings – shapefile with footprint and roof height data
- Surface cover – 2m resolution
- Trees – 2m resolution, canopy height

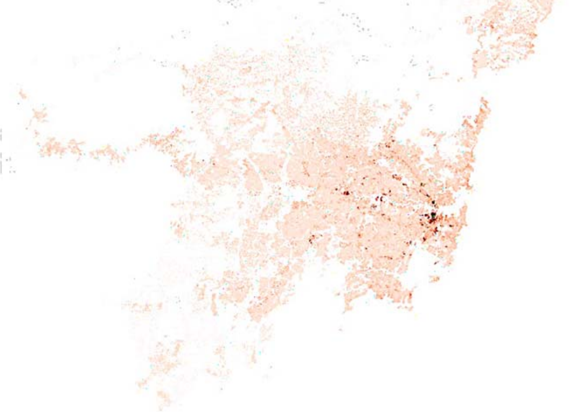
- Proprietary (restricted data)
- all urban areas in Australia (2 m resolution)
- all land in Australia (30 m resolution)

vegetation fraction

building fraction

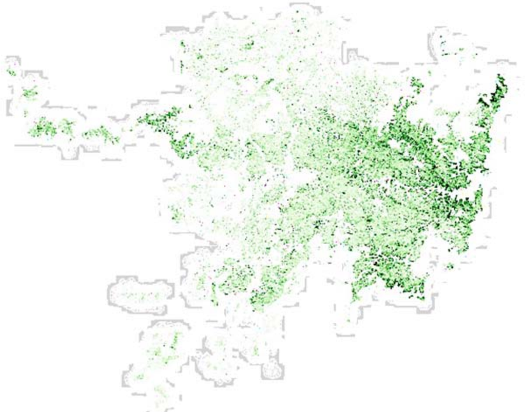
water fraction

mean building height



canyon height-to-width ratio

aerodynamic roughness

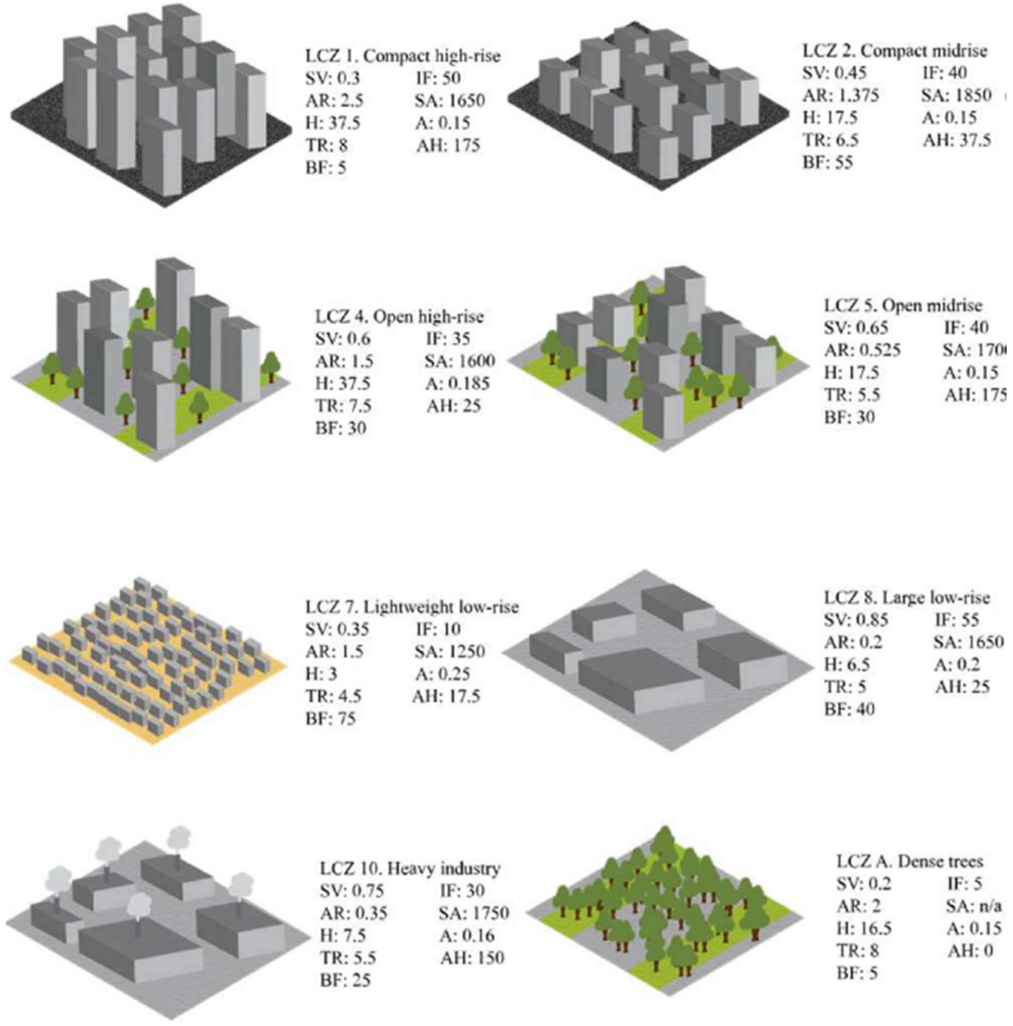


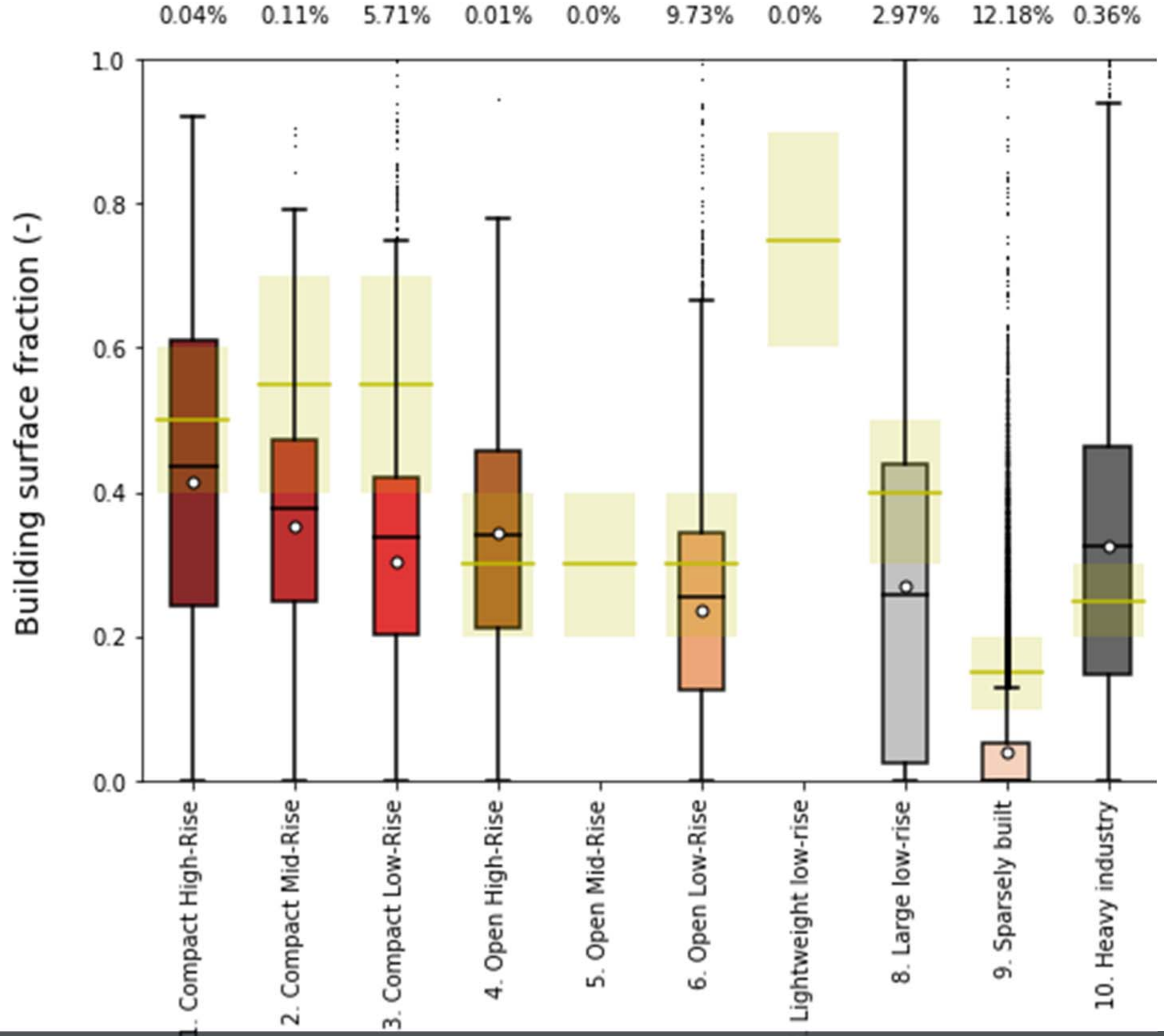
Lipson, M. J., Nazarian, N., Hart, M. A., Nice, K. A., & Conroy, B. (2022). A Transformation in City-Descriptive Input Data for Urban Climate Models. *Frontiers in Environmental Science*, 945.

Australian city-descriptive data for urban climate models

Mathew Lipson, Negin Nazarian, Melissa Hart, Kerry Nice, Brooke Conroy

Matching Local Climate Zone maps with detailed 3D Geoscape data to establish an open-source database for climate modelling in Australian cities





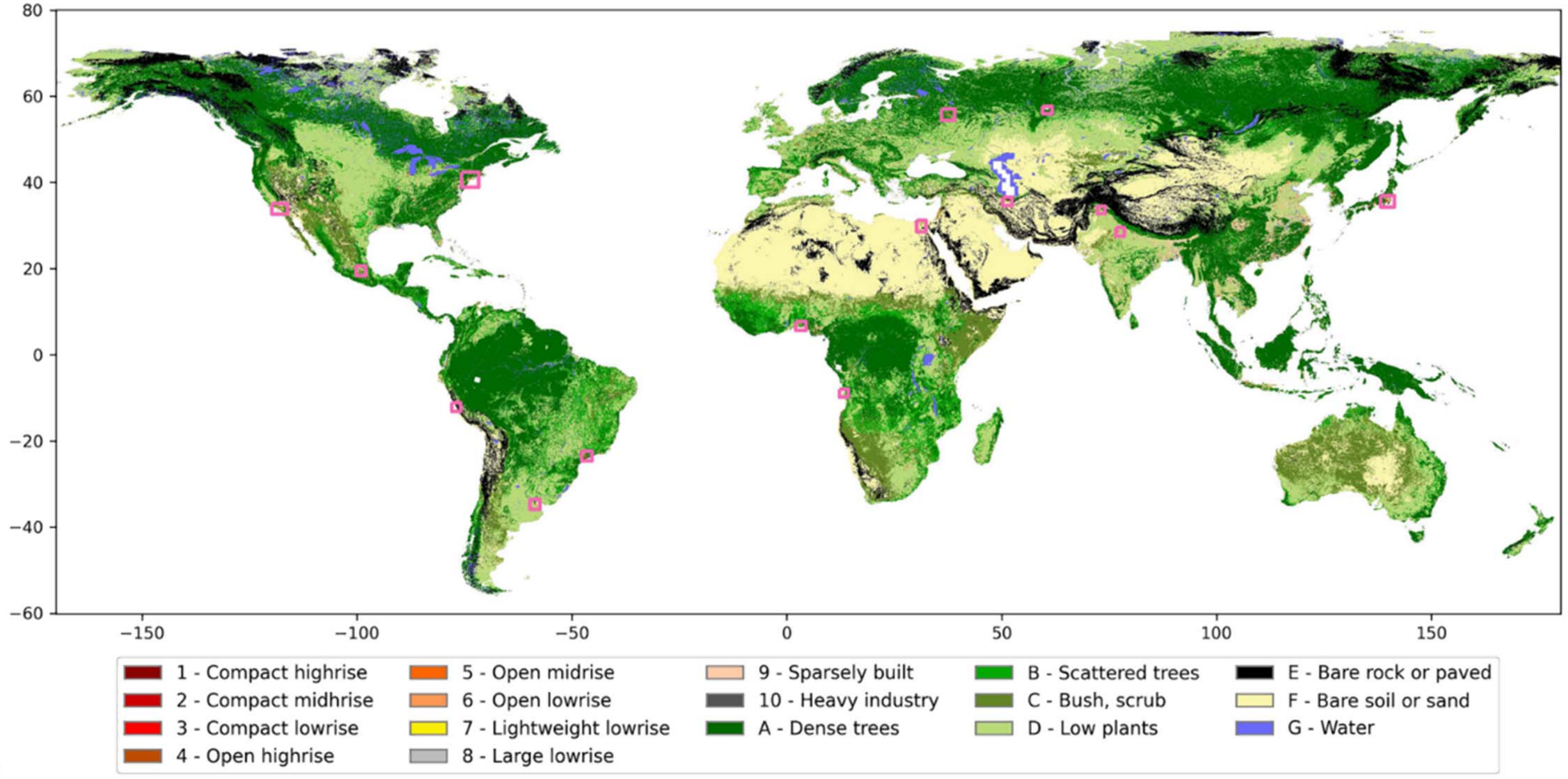
Lipson, M. J., Nazarian, N., Hart, M. A., Nice, K. A., & Conroy, B. (2022). A Transformation in City-Descriptive Input Data for Urban Climate Models. *Frontiers in Environmental Science*, 945.

Advances in Analytical Platforms: LCZ World map

RUB

This afternoon: Introduction to Google Colab, Google Earth Engine + Hands-on

Matthias Demuzere



Demuzere, M., Kittner, J., Martilli, A., ... & Bechtel, B. (2022). A global map of Local Climate Zones to support earth system modelling and urban scale environmental science. *Earth System Science Data Discussions*, 1-57.

Crowdsourcing Applications

Crowdsourcing weather information

- from smart phone batteries
- from citizen weather stations
- from wearable devices

Crowdsourcing urban form information

- WUDAPT
- NetAtmo

Next two speakers!

Frontiers Special Issue

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Julia Potgieter · Negin Nazarian · Mathew J. Lipson · Melissa A. Hart · Giulia Ulpiani · William Morrison · Kit Benjamin

3,677 views 4 citations

TECHNOLOGY AND... | 03 Dec 2021

CrowdQC+—A Quality-Control for Crowdsourced Air-Temperature Observations Enabling World-Wide Urban Climate Applications

Daniel Fenner · Benjamin Bechtel · Matthias Demuzere · Jonas Kittner · Fred Meier

2,217 views 3 citations

Conclusions

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- UCI embraces various scientific disciplines
- Shift from focusing on city-atmosphere interactions to tackling grand challenges of the Anthropocene
- Push boundaries of observational networks, model resolution, and domain size to yield unprecedented details on hazard distribution
- Digital Twins
- “Humans as sensors” and citizen science
- More integrated and human-centric assessments of urban climate challenges in future research and application
- Is the future of urban climate in the cloud?

THANK YOU!

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