City Planning Systems for Pollution in Urban Canyons

Towards Cyber Integration for Societal Health: Improving Understanding of Urban Air Pollution Stakeholder Networks by Applied Systems Engineering

Janet K. Allen janet.allen@ou.edu

Wesley T. Honeycutt honeycutt@ou.edu

Farrokh Mistree farrokh.mistree@ou.edu

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The SYSTEMS REALIZATION LABORATORY @ OU

What’s an Urban Canvon?

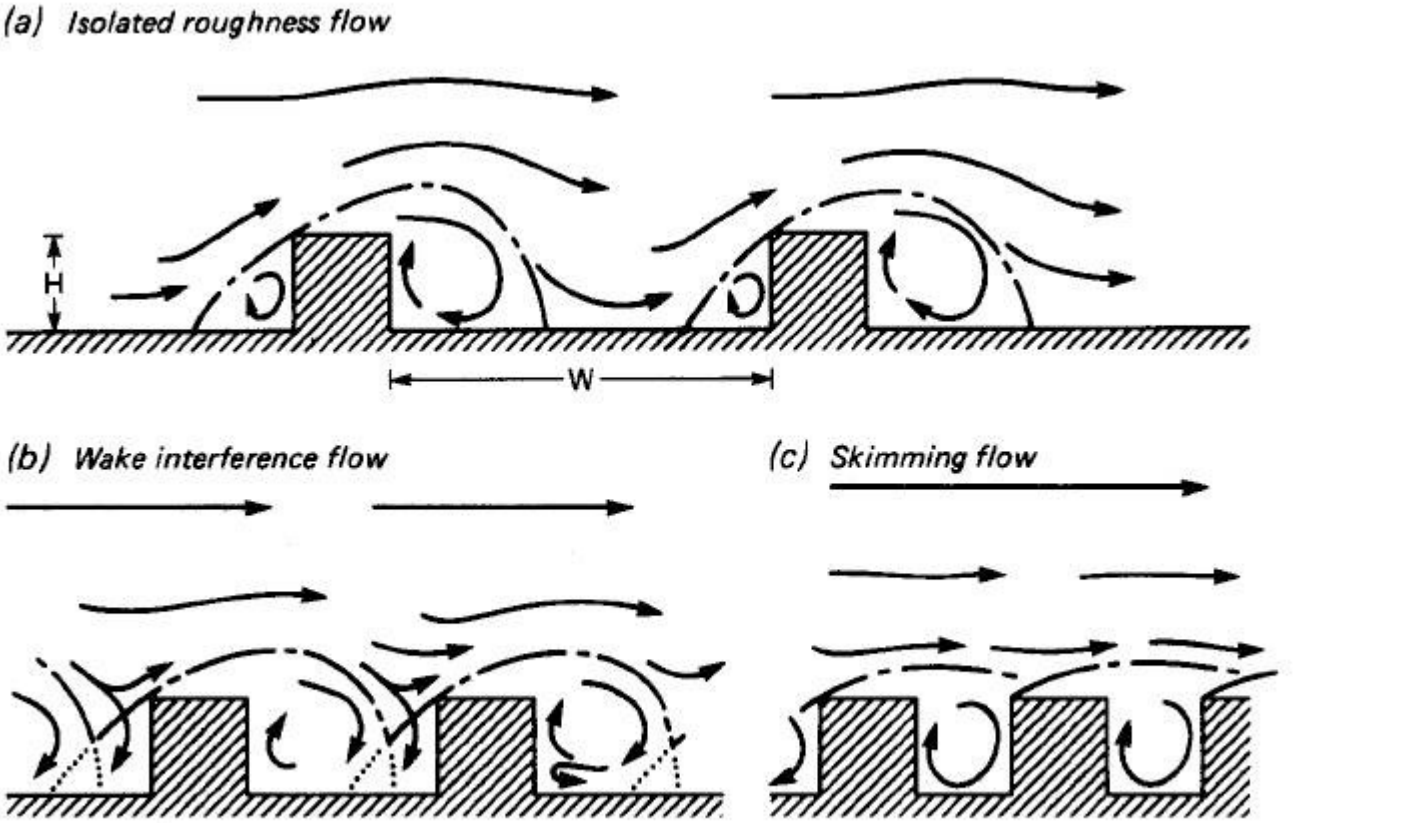
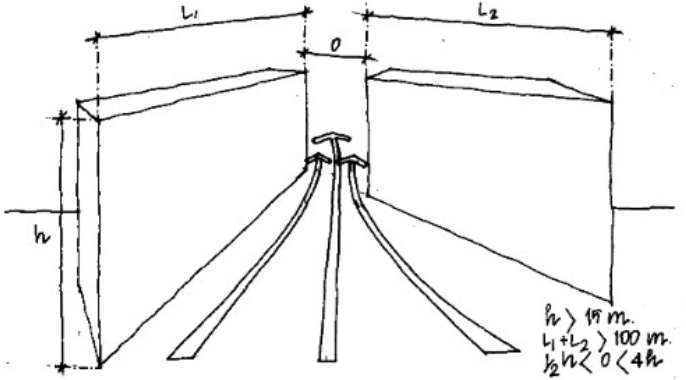


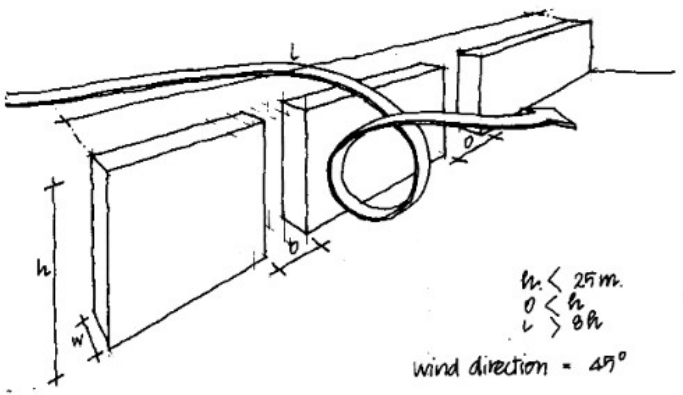
Fig. 1. The flow regimes associated with air flow over building arrays of increasing H/W.

Oke, T.R., 1988. Street design and urban canopy layer climate. Energy and Buildings 11, 103â€“113. https://doi.org/10.1016/0378-7788(88)90026-6

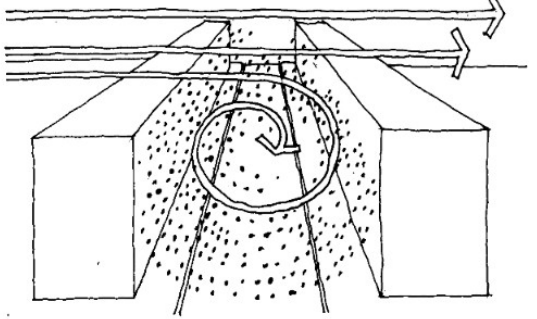
What's an Urban Canyon?

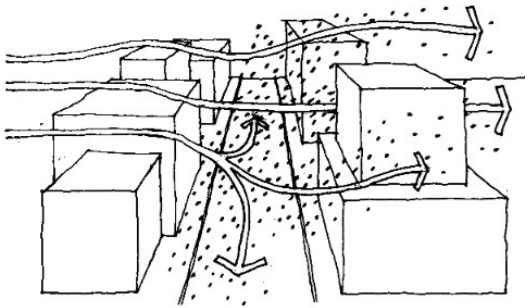


VENTURI EFFECT
(Source: Gandemer and Guyot, 1976)

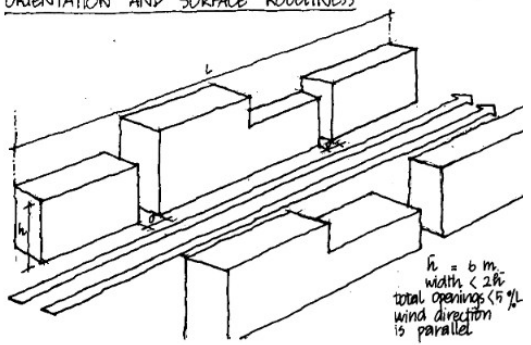


BAR EFFECT
(Source: Gandemer and Guyot, 1976)

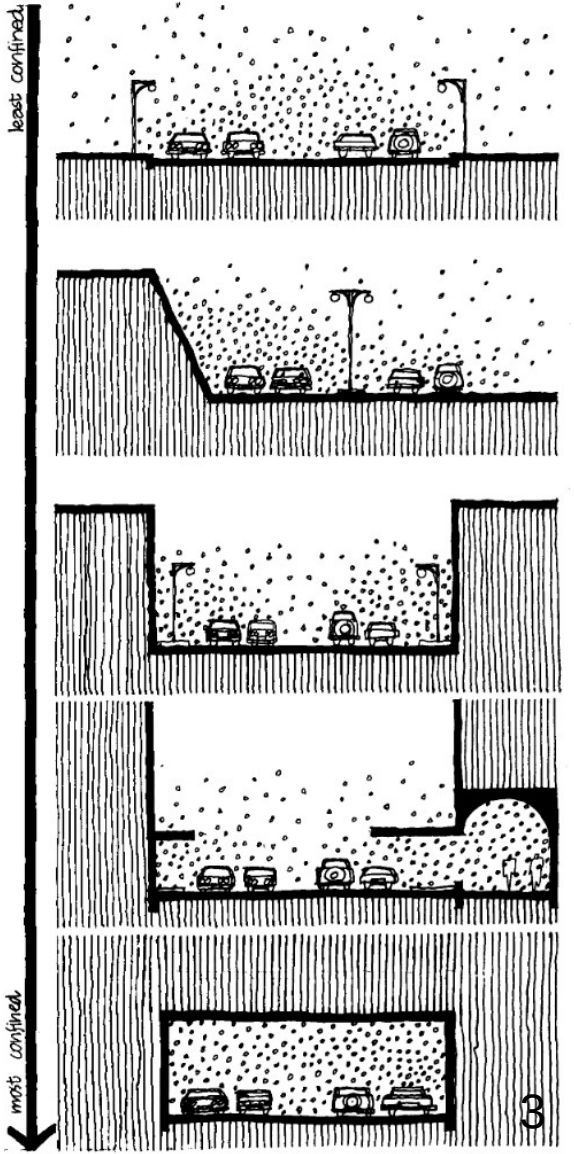




VARIABLES INFLUENCING AIR CIRCULATION: ORIENTATION AND SURFACE ROUGHNESS



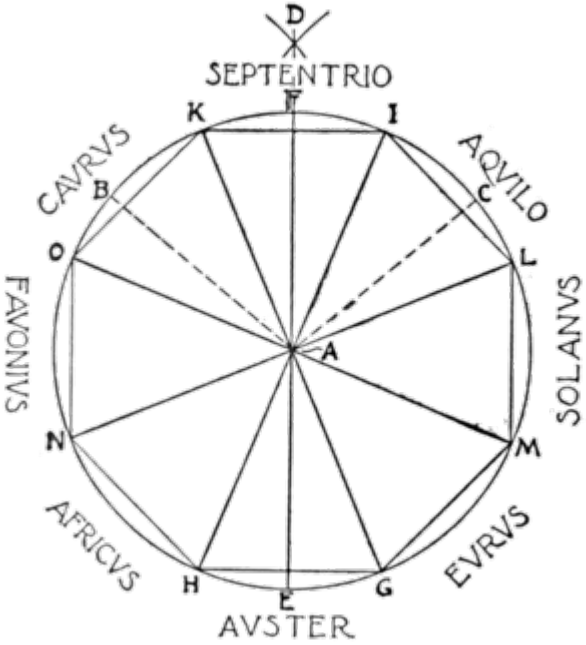
CHANNELIZATION EFFECT
(Source: Gandemer and Guyot, 1976)



Spirn, A.W., 1986. Air Quality at Street-Level: Strategies for Urban Design. Boston Redevelopment Authority, Boston, MA.

Vitruvius

"[The houses] will be properly laid out if foresight is employed to exclude the winds from the alleys. Cold winds are disagreeable, hot winds enervating, moist winds unhealthy. We must, therefore, avoid mistakes in this matter and beware of the common experience of many communities. [...]
Then let the directions of your streets and alleys be laid down on the lines of division between the quarters of two winds."



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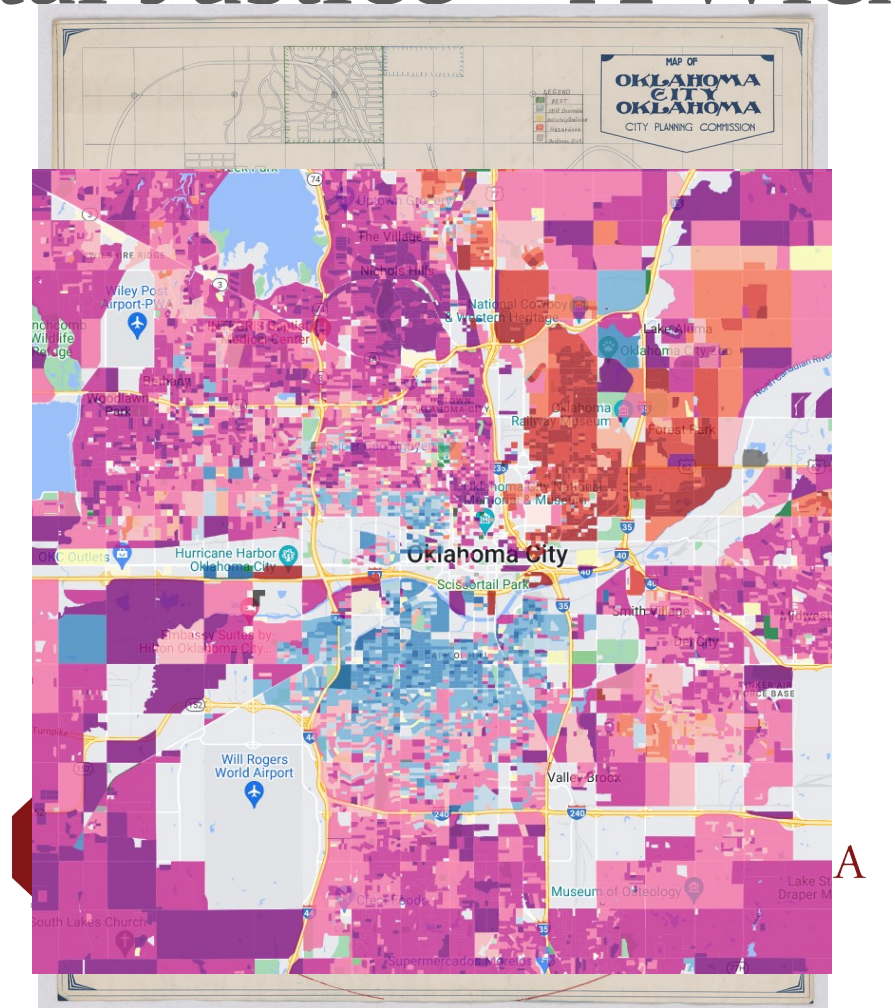
Morgan, M.H., Warren, H.L., others, 1914. Vitruvius: the ten books on architecture.

Environmental Justice – A Wicked Problem

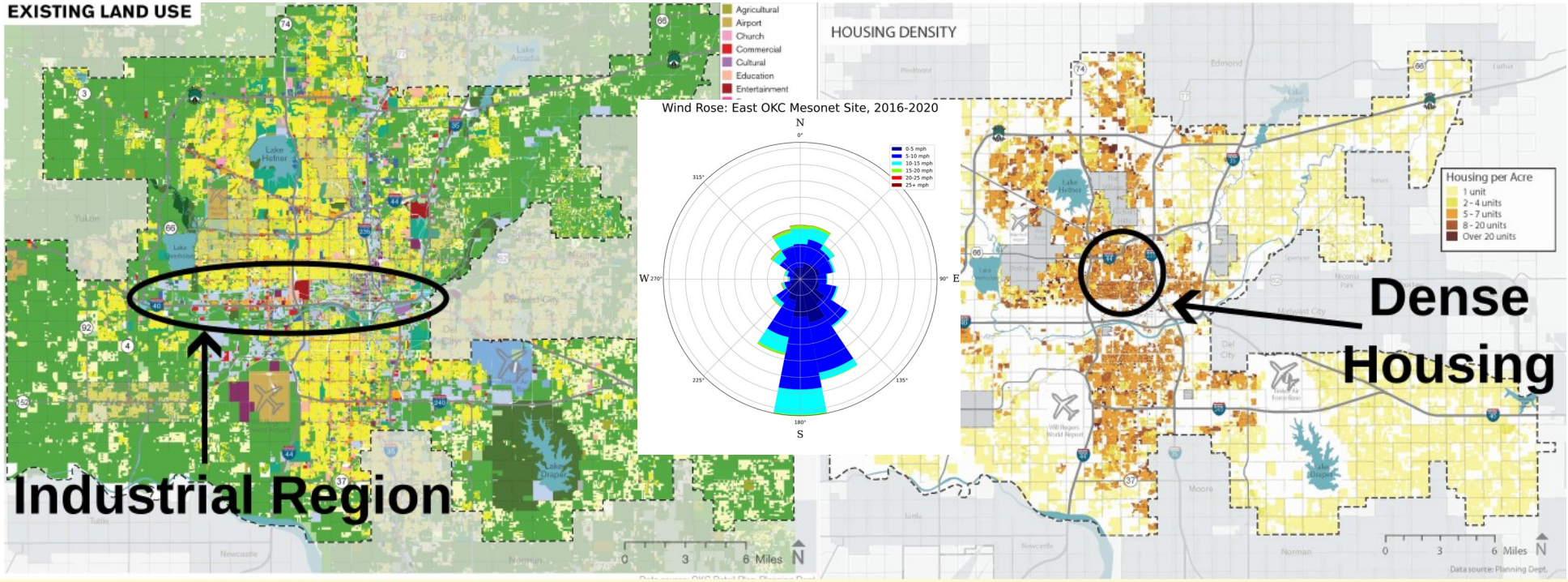


	<30%	30-50	50-70	70-90	90%+
American Indian					
Asian					
Black					
Hispanic					
White					
Ties					

Federal Home Loan Bank Board. Home Owners'™ Loan Corporation. 1933-7/1/1939, 1933. Map of Oklahoma City, Oklahoma, Series: Residential Security Maps, 1933 - 1989.

U.S. Census Bureau, 2020. Race and Ethnicity in the United States.

Health Outcomes, Housing, and Wind



Environmental Justice: How is a social problem of local weather uncertainty a mapped as a pollution system?

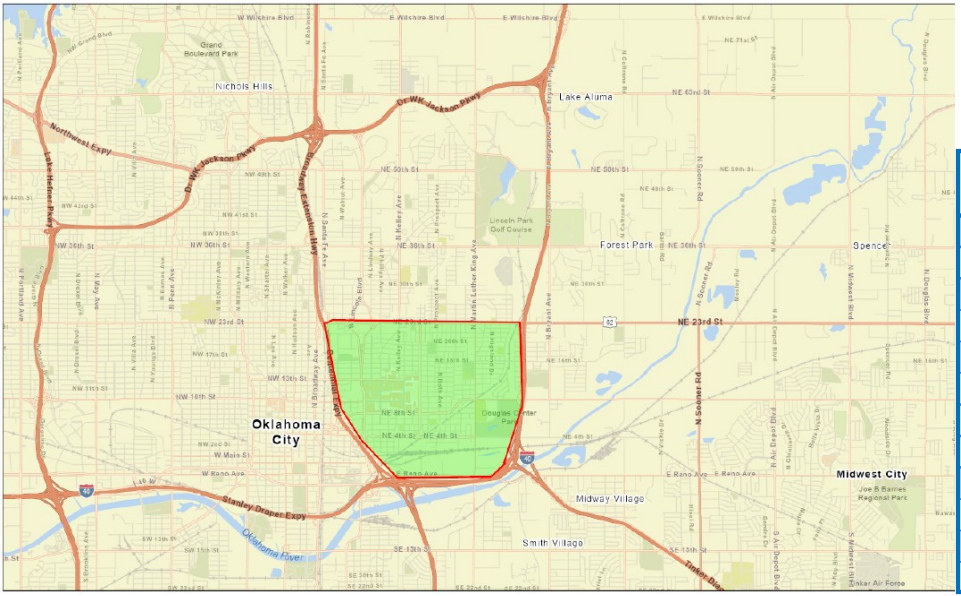
Basara, J.B., Hall Jr., P.K., Schroeder, A.J., Illston, B.G., Nemunaitis, K.L., 2008. Diurnal cycle of the Oklahoma City urban heat island. Journal of Geophysical Research: Atmospheres 113. https://doi.org/10.1029/2008JD010311

The City of Oklahoma City, 2019. Resolution of Intent of the Mayor and Council of the City of Oklahoma City Setting Forth a New MAPS Program to be Known as "MAPS"

Tierney, S., Petty, C., 2015. Gentrification in the American heartland? Evidence from Oklahoma City. Urban Geography 36, 439-456. https://doi.org/10.1080/02723638.2014.977038

Environmental Justice Index

$$I_{EJ} = I_{indicator} \times (I_{block} - I_{US}) \times Pop_{block}$$



the User Specified Area, OKLAHOMA, EPA Region 6

Approximate Population: 9,385

Input Area (sq. miles): 4.58

SDAT Study Area

Selected Variables	State Percentile	EPA Region Percentile	USA Percentile
EJ Indexes			
EJ Index for PM2.5	83	59	72
EJ Index for Ozone	84	61	74
EJ Index for NATA* Diesel PM	91	69	77
EJ Index for NATA* Air Toxics Cancer Risk	84	60	73
EJ Index for NATA* Respiratory Hazard Index	86	63	75
EJ Index for Traffic Proximity and Volume	93	75	78
EJ Index for Lead Paint Indicator	92	87	86
EJ Index for Superfund Proximity	91	72	77
EJ Index for RMP Proximity	85	64	76
EJ Index for Hazardous Waste Proximity	91	82	78
EJ Index for Wastewater Discharge Indicator	81	62	78

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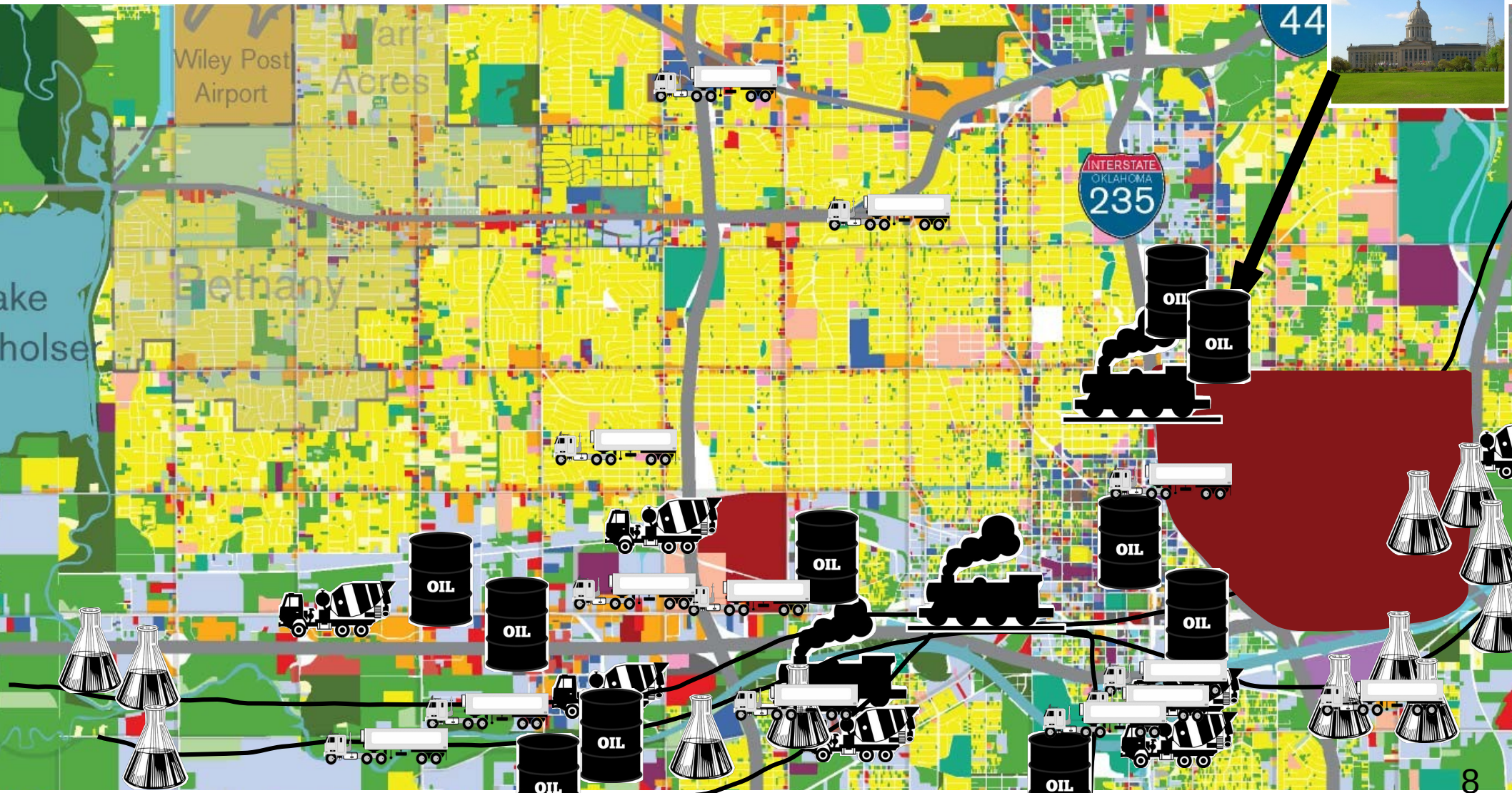
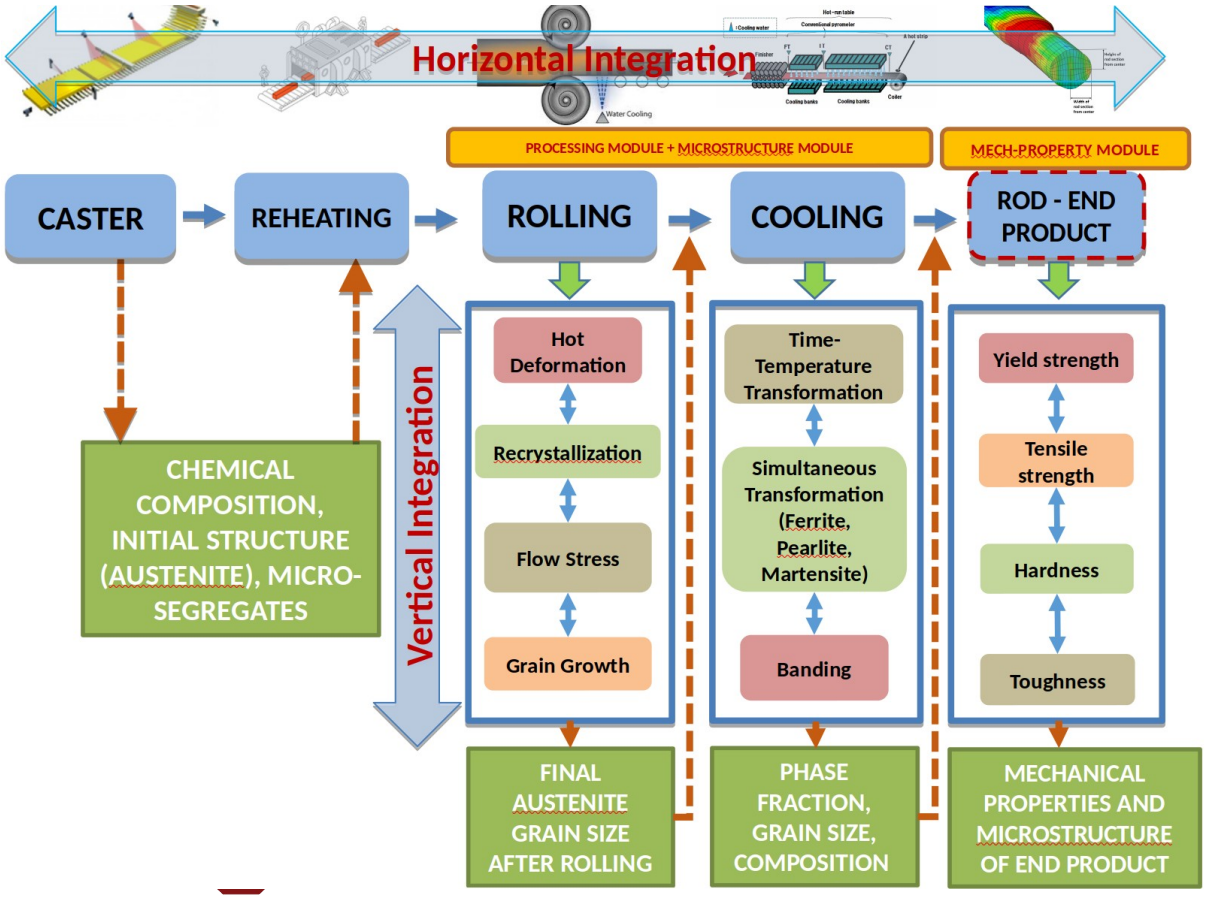
Courtesy of Lee Fithian, OU Gibbs College of Architecture


Wiley Post Airport
Bethany
INTERSTATE
OKLAHOMA
235
44
OIL

Currently, there are no tools to disentangle such a wicked problem.

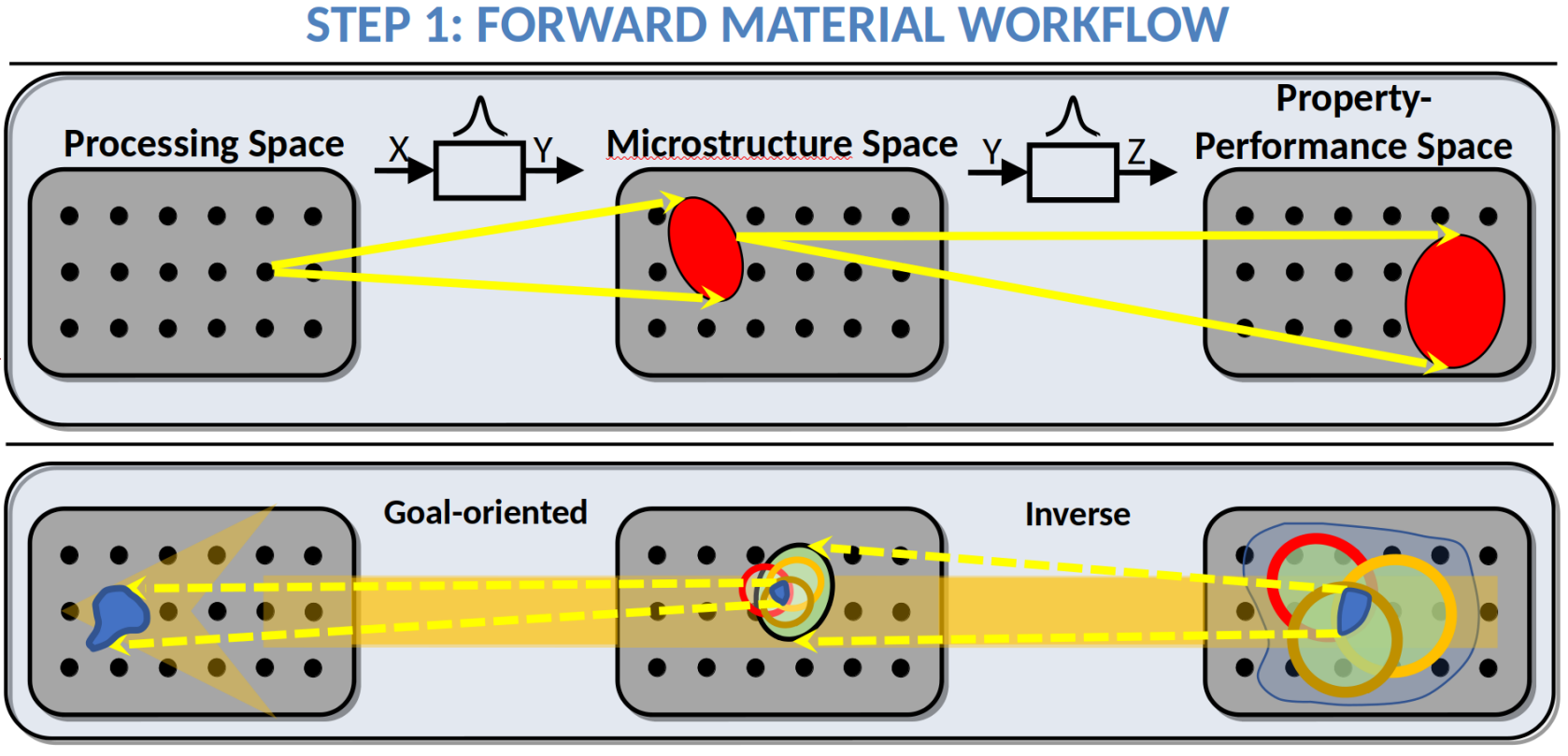
A Solution in Search of New Domain(s)



Nellippallil, A.B., Rangaraj, V., Gautham, B.P., Singh, A.K., Allen, J.K., and Mistree, F., 2018, " An Inverse, Decision-Based Design Method for Integrated Design Exploration of Materials, Products and Manufacturing Processes," *ASME Journal of Mechanical Design*. vol.140, no. 11, pp. 111403-111403-17.

A Solution in Search of New Domain(s)

This abstraction works well for engineered materials.



But can it be applied to systems issues?

Nellippallil, A.B., Rangaraj, V., Gautham, B.P., Singh, A.K., Allen, J.K., and Mistree, F., 2018, " An Inverse, Decision-Based Design Method for Integrated Design Exploration of Materials, Products and Manufacturing Processes," *ASME Journal of Mechanical Design*. vol.140, no. 11, pp. 111403-111403-17.

Research Overview

Research Questions	Tasks	Subtasks
Q1: How does mapping system from energy production regions relate to urban consumption regions?	**T1:** Define the network of gas production and consumption in the Oklahoma City transect in terms of vertically integrated elements with horizontally integrated, temporal cycles and events.	**T1.1:** Define the network of gas producers in OKC. **T1.2:** Define the network of gas consumers in OKC. **T1.3:** Determine the interconnection of the mapping based on wind patterns and operational cycles. **T1.x:** Continually reassess definition based on empirical results

The network of energy/economy

Discrete Project

How much data do we need in urban canyons?

How do trace pollutants get stuck between buildings?

Systems Engineering for social good?

What does OKC look like as a gas molecule?

Can we predict future harm at the city block scale?

Does cyber-* sensor data reflect the *-physical reality?

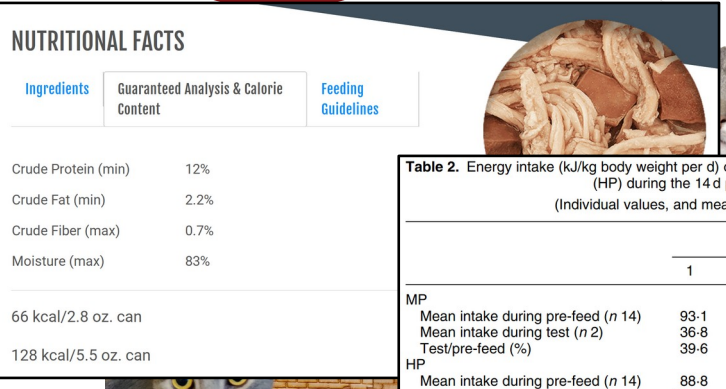
How connect. & What good can it do?

Mapping Energy/Pollution Systems

Material Input

Waste Output

Env. Impact



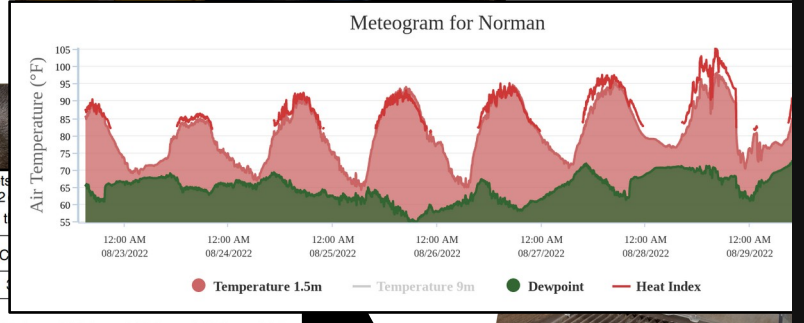
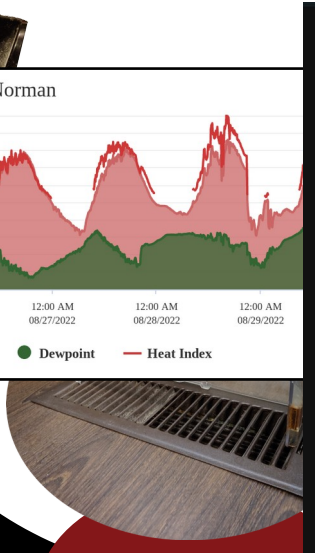
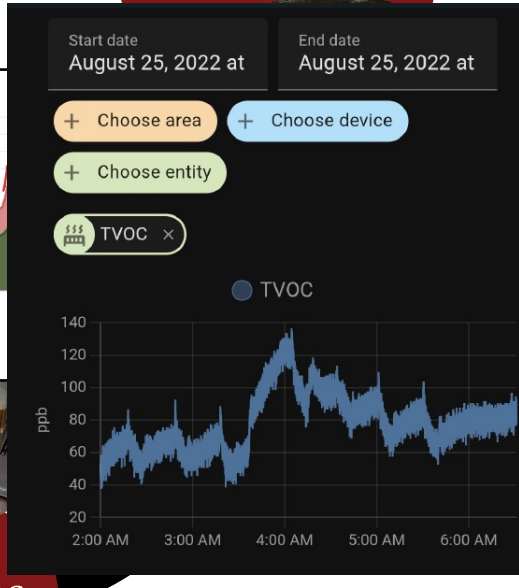


Table 2. Energy intake (kJ/kg body weight per d) of cats fed diets (HP) during the 14 d pre-feed and 2
(Individual values, and mean values with t

	1	2					
MP							
Mean intake during pre-feed (*n* 14)	93·1	66·7	195·1	111·1	102·9	113·8	21·7
Mean intake during test (*n* 2)	36·8	74·3	191·2	134·2	75·9	102·5	27·1
Test/pre-feed (%)	39·6	111·4	98·0	120·7	73·8	88·7	14·6
HP							
Mean intake during pre-feed (*n* 14)	88·8	161·7	196·4	129·1	236·3	162·5	25·6
Mean intake during test (*n* 2)	115·2	135·3	182·8	113·6	195·8	148·6	17·2
Test/pre-feed (%)	129·8	83·7	93·1	88·0	82·9	95·5	8·8
MP/HP during test phase (%)	32·0	54·9	104·6	118·1	38·8	69·7	17·6

* For details of diets and procedures see Table 1 and p. 30.





Air Patterns

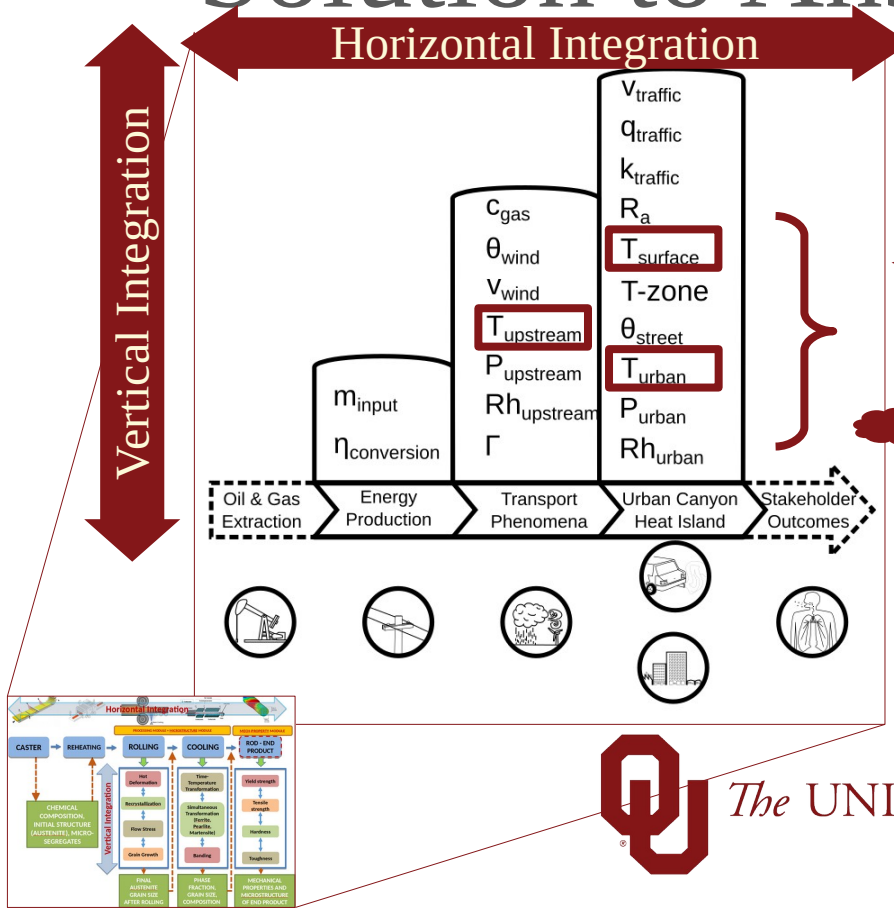
Tiki Cat® After Dark™ Chicken, n.d. . Tiki Pets. URL https://tikipets.com/product/tiki-cat/after-dark/chicken-2/ (accessed 8.29.22).25

Russell, K., Lobley, G.E., Millward, D.J., 2003. Whole-body protein turnover of a carnivore, Felis silvestris catus. British Journal of Nutrition 89, 29–37. https://doi.org/10.1079/BJN2002735

McPherson, R.A., Fiebrich, C.A., Crawford, K.C., Kilby, J.R., Grimsley, D.L., Martinez, J.E., Basara, J.B., Illston, B.G., Morris, D.A., Kloesel, K.A., Melvin, A.D., Shrivastava, H., Wolfinbarger, J.M., Bostic, J.P., Demko, D.B., Elliott, R.L., Stadler, S.J., Carlson, J.D., Sutherland, A.J., 2007. Statewide Monitoring of the Mesoscale Environment: A Technical Update on the Oklahoma Mesonet. Journal of Atmospheric and Oceanic Technology 24, 301–321. https://doi.org/10.1175/JTECH1976.1

Curry, J., Honeycutt, W.T., 2022. Gracie Particulate Matter Data Request (unpublished data).

How We Will Apply the Solution to Answer New Questions



- Divide holistic system into temporal elements; the result is a mapped system
- Each element is defined by measurable, physical constants
- We focus on the interconnected challenging part rather than the endpoints
- Much of the expertise/equipment needed exists at OU
- This not a static engineering problem; it is an EVOLVING system

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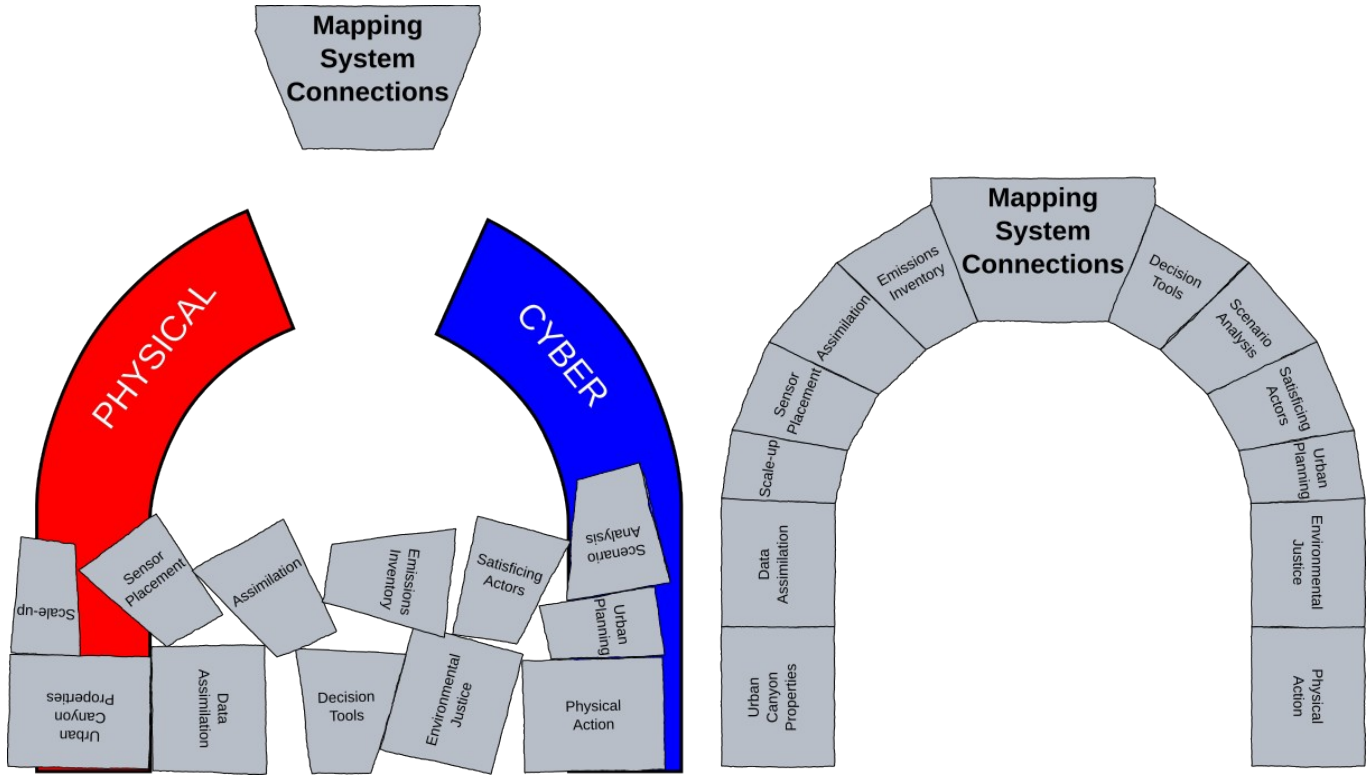
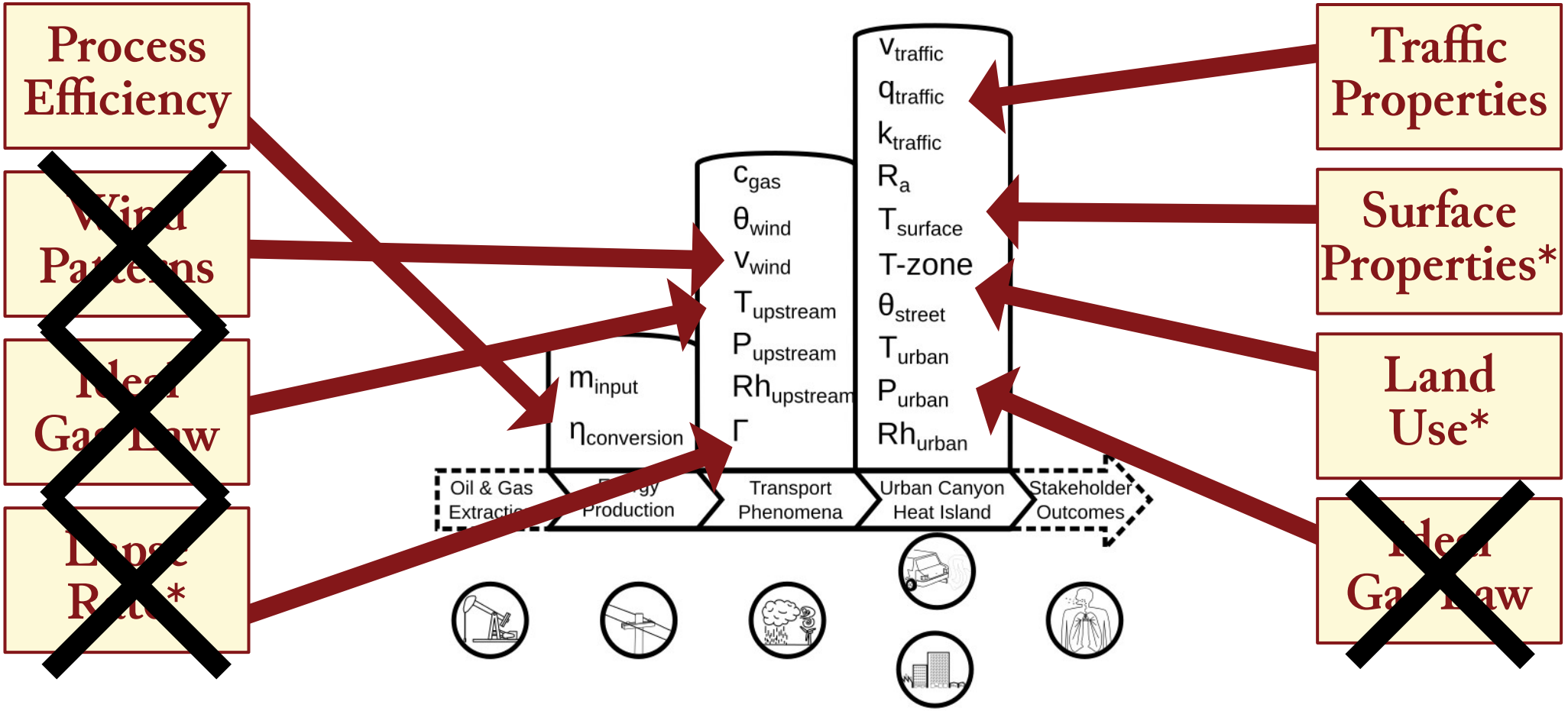


Find new ways to address uncertainty and risk in a complex, evolving environment.



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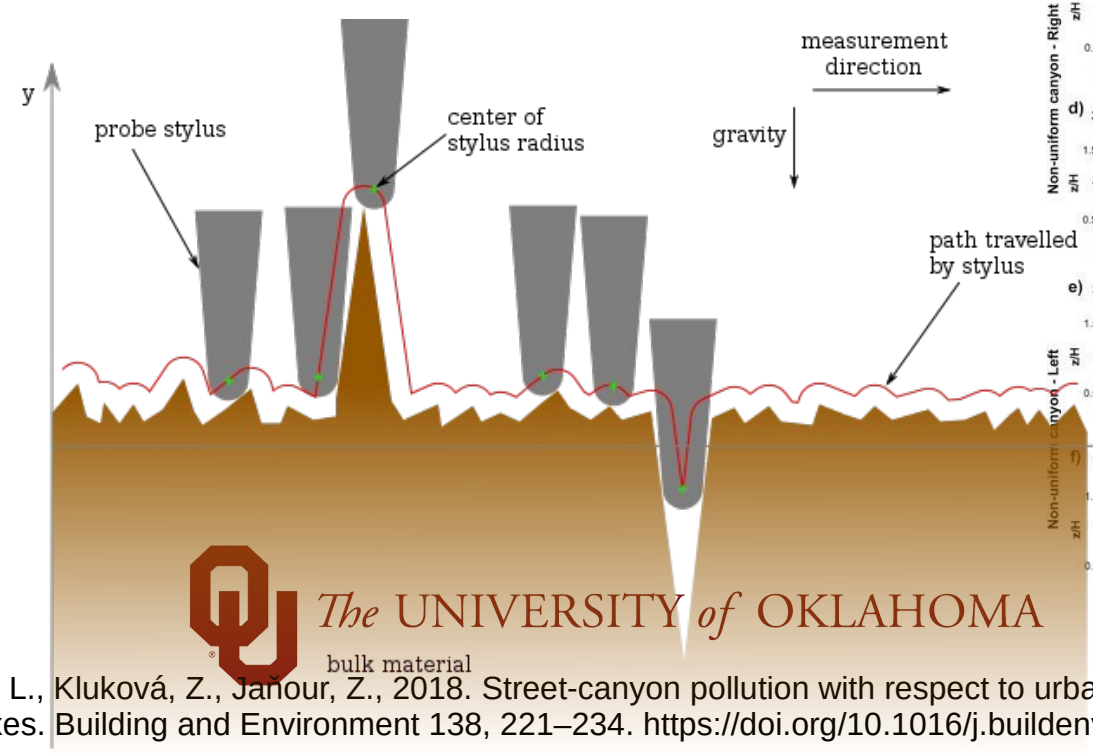
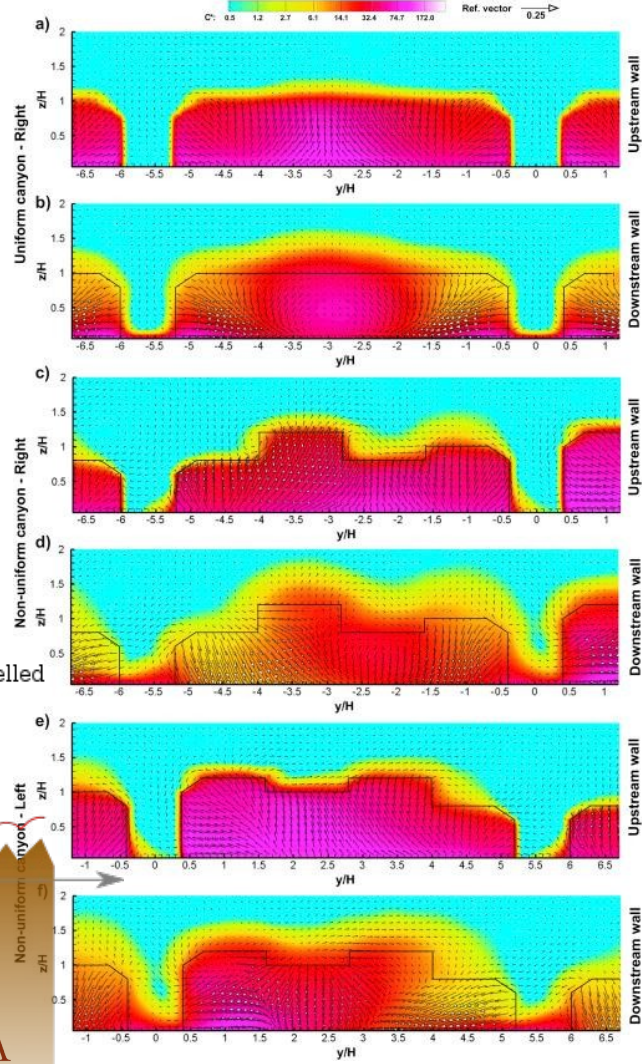
Ex: Surface Roughness Changes Eddy Upstream

$$Ra = \int_0^{\ell} |f(x)| dx$$





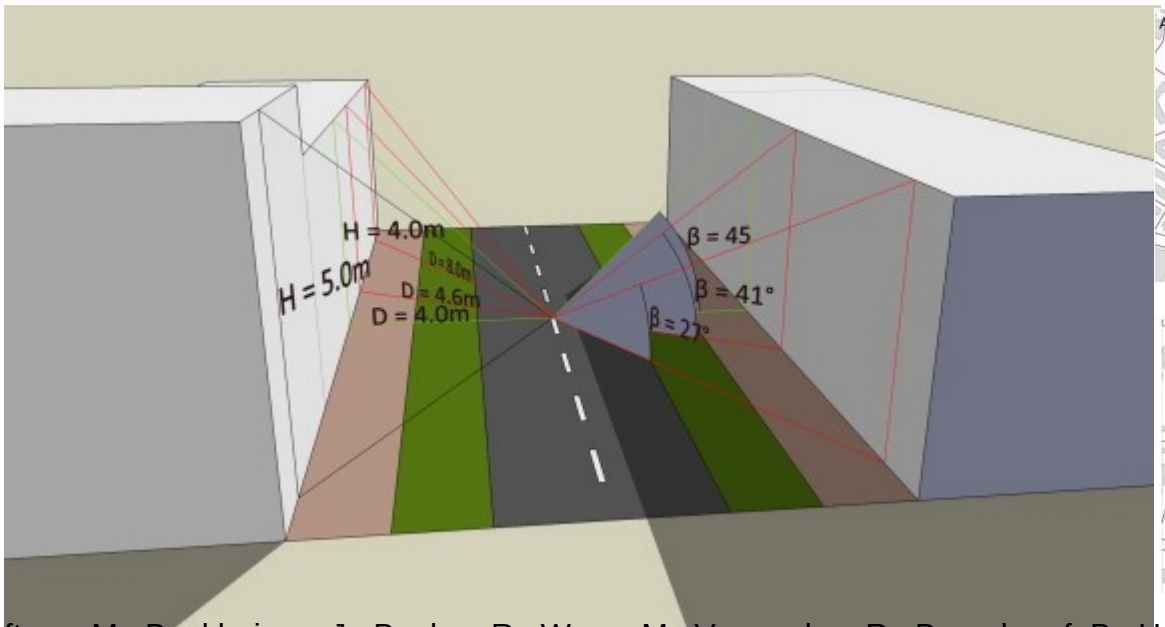
Nosek, Š., Fuka, V., Kukačka, L., Kluková, Z., Jaňour, Z., 2018. Street-canyon pollution with respect to urban-array complexity: The role of lateral and mean pollution fluxes. Building and Environment 138, 221–234. https://doi.org/10.1016/j.buildenv.2018.04.036

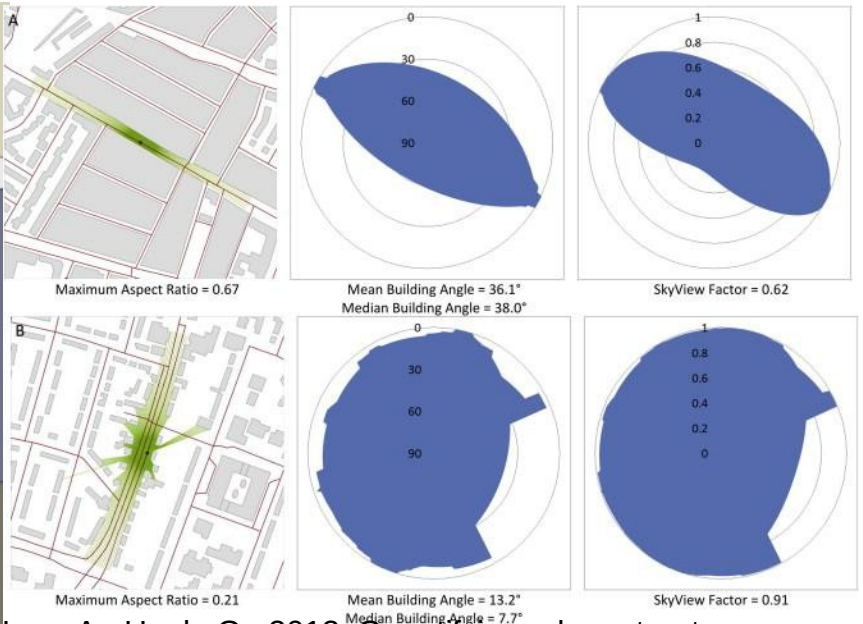
Ex: Surface Temperature Depends on “SkyView”

$$SVF = \sum_{\alpha=0}^{359} \beta_\alpha \times \left(\frac{1}{360}\right)$$

where

$$\beta_{\alpha,i} = \arctan \frac{H_{\alpha,i}}{D_{\alpha,i}}$$





Eeftens, M., Beekhuizen, J., Beelen, R., Wang, M., Vermeulen, R., Brunekreef, B., Huss, A., Hoek, G., 2013. Quantifying urban street configuration for improvements in air pollution models. Atmospheric Environment 72, 1–9. https://doi.org/10.1016/j.atmosenv.2013.02.007

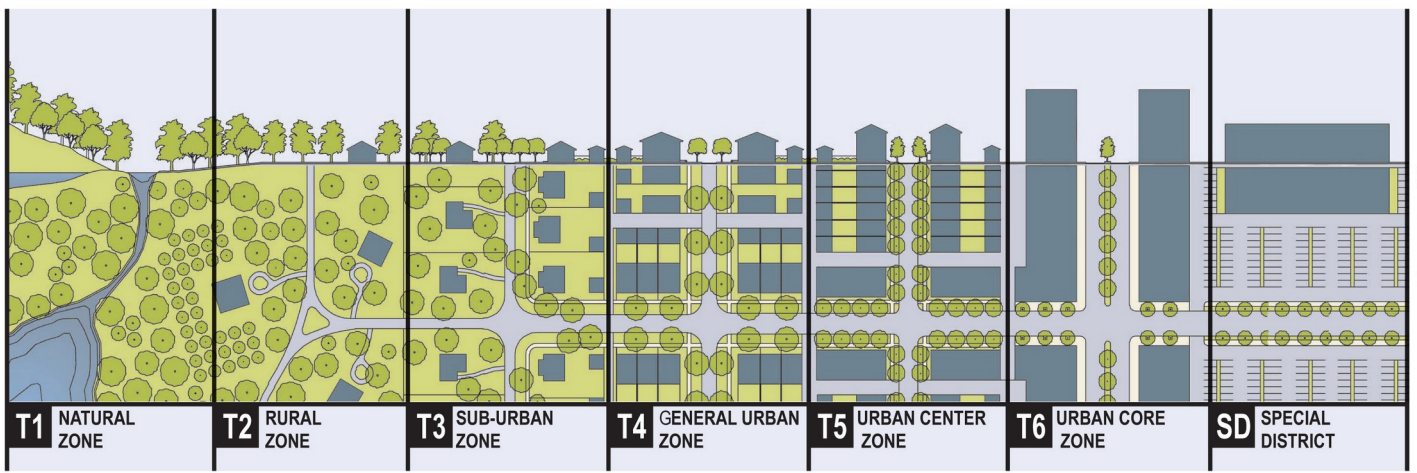
Ex: Land Use Impacts Spectral Radiance, Temperature

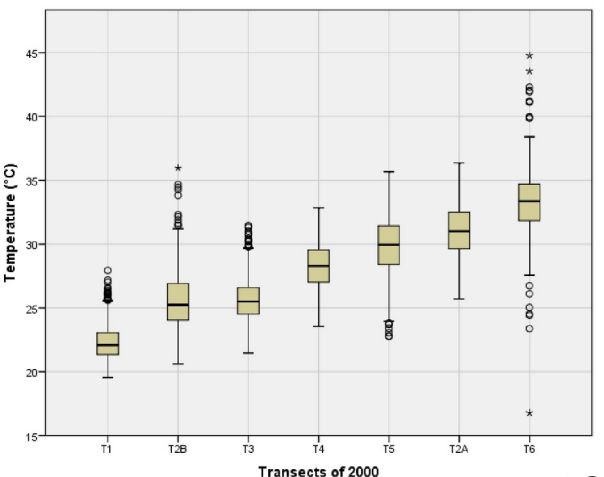
$$T_{\text{sensor}} = \frac{K_2}{\ln\left(\frac{K_1}{L_{rad}} + 1\right)}$$

$$T = \frac{T_{\text{sensor}}}{1 + \frac{\lambda T_{\text{sensor}}}{\hbar \frac{c}{k_B}} \ln(\varepsilon)}$$

where

$$K_1 = 607.76 \frac{\text{W}}{\text{m}^2 \text{sr} \, \mu\text{m}} \text{ and } K_2 = 1260.56 \text{ K}$$

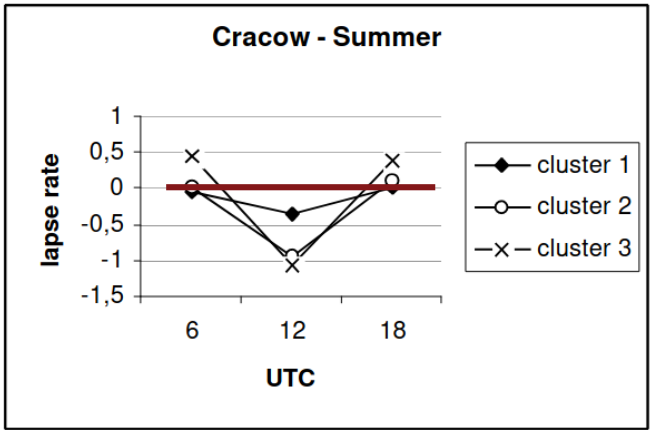


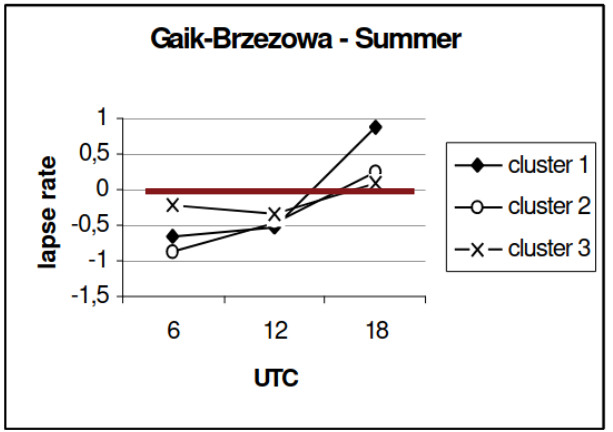


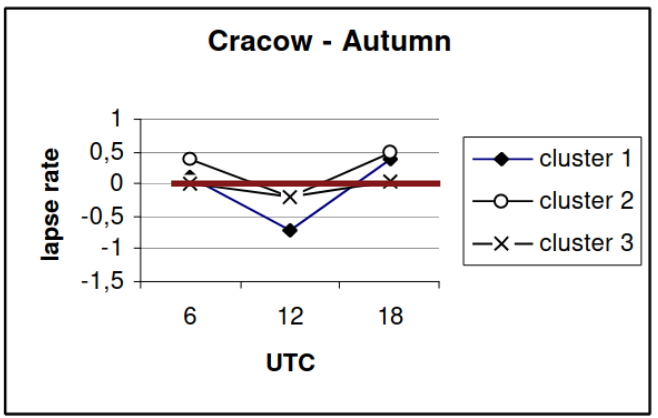
Duany, A., Sorlien, S., Wright, W., 2009. SmartCode Version 9.2. Ithaca: New Urban News Publications Inc.
Jahan, K.N., 2013. Spatial Analysis of Transect Zone and Land Surface Temperature: A Case Study on Hamilton County, Ohio. University of Cincinnati.

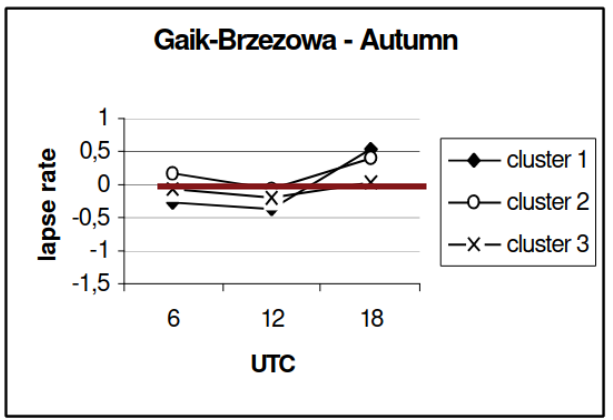
Ex: T-Zone and Lapse Rate Inversion

$$\Gamma = \frac{dT}{dz}$$





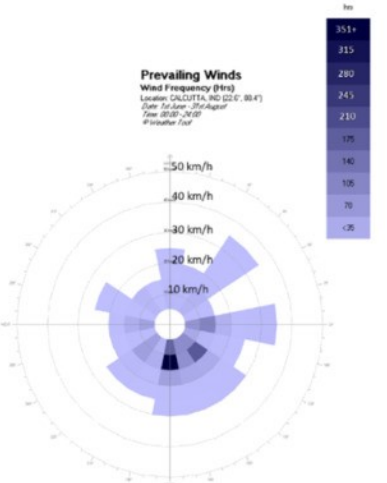


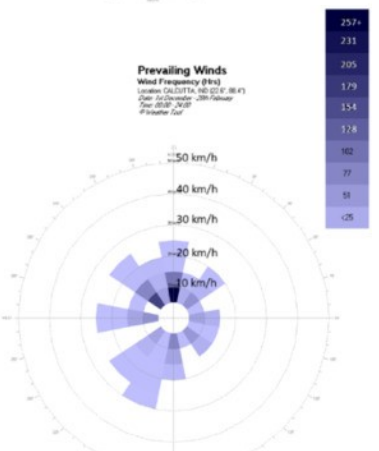


Bokwa, A., 2015. Temperature Lapse Rates in the Air Near the Ground in Urban and Rural Areas. http://nargeo.geo.uni.lodz.pl/~icuc5/index.html.

Thermal Comfort Studies

Eastern Kolkata





De, B., Mukherjee, M., 2018. Optimisation of canyon orientation and aspect ratio in warm-humid climate: Case of Rajarhat Newtown, India. Urban Climate 24, 887-920. https://doi.org/10.1016/j.uclim.2017.11.003

Background Literature

Selection of Urban Design Parameters Influencing Urban Climate
- Orientation
- Canyon Aspect Ratio

Selection of Study Area

Selection of Meteorological Factors Influencing Urban Climate
- Air Temperature
- Wind Speed
- Mean Radiant Temperature

Generation of First Order Scenarios Varying the orientation angle
- Scenario A1
- Scenario A2
- Scenario A3
- Scen

Selection of Thermal Comfort

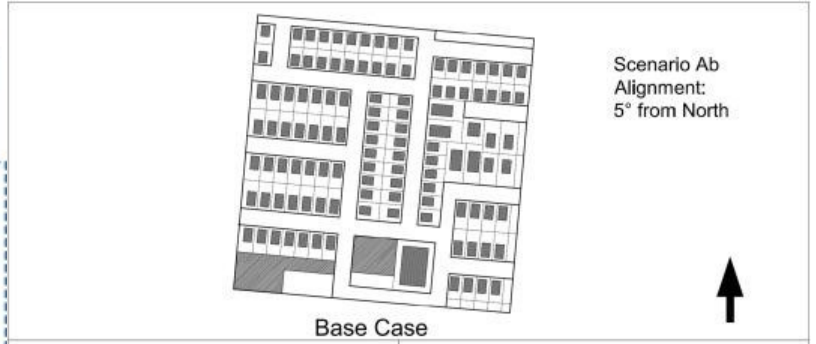
Selection of the Bes
with the optimum ar

Combine the orient
scenario with differ
ratios to generate se
- Scenario A3H1
- Scenario A3H2
- Scenario A3H3
- Scenario A3H4

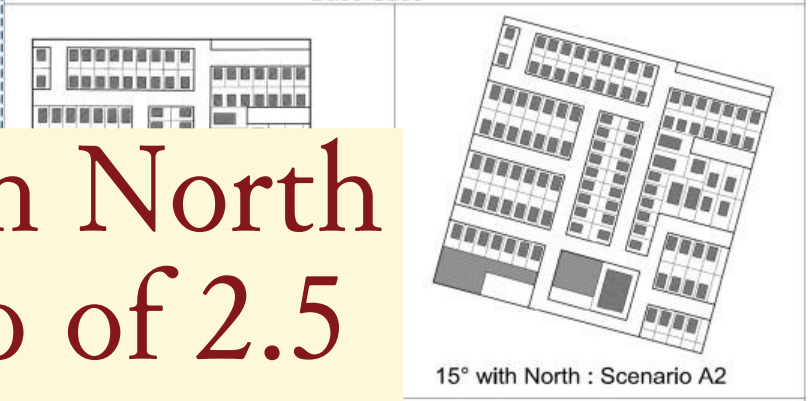
Selection of the **Best Performing** Scenario with the optimum **Canyon Aspect Ratio**

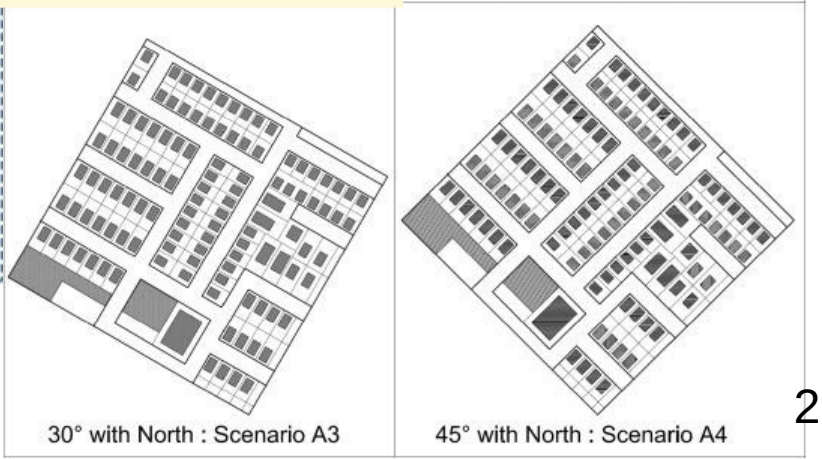
Recommendation for optimum **Orientation** and **Canyon Aspect Ratio** for Rajarhat-Newtown, Kolkata, India

30 – 60° from North Aspect Ratio of 2.5



Base Case


15° with North : Scenario A2


30° with North : Scenario A3

45° with North : Scenario A4

What we need:

A modern Vitruvius to guide city planning to reduce impacts of dense cities INTEGRATED with sensing tools for modern surveillance.

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That’s cool, but who will fund such a project?

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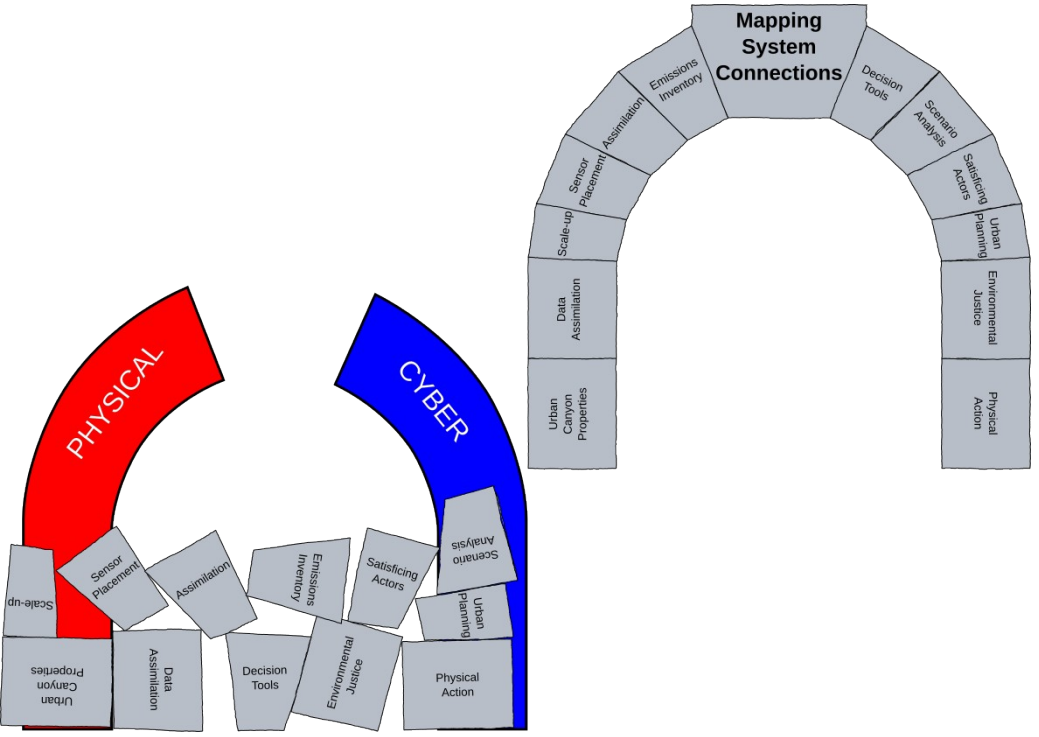
EAGER Keystone and Ramifications



- **Potential Outcome**
  - Integrates several fields with a mapped system approach to link together a future cyber-physical tool
  - Asks fundamental questions about how we define our urban landscape

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EAGER Project Applicability

- This project is/will:
  - A discrete project with High Reward deliverables
  - Transdisciplinary, not confined to a single field
  - High Risk
    - Conceptually – bridges diverse fields
    - Academically – uses bleeding-edge theory
- This project is/will NOT:
  - Have a predetermined outcome
  - An “application”
  - Proof-of-concept or fact-finding
  - Conceptually non-transferable

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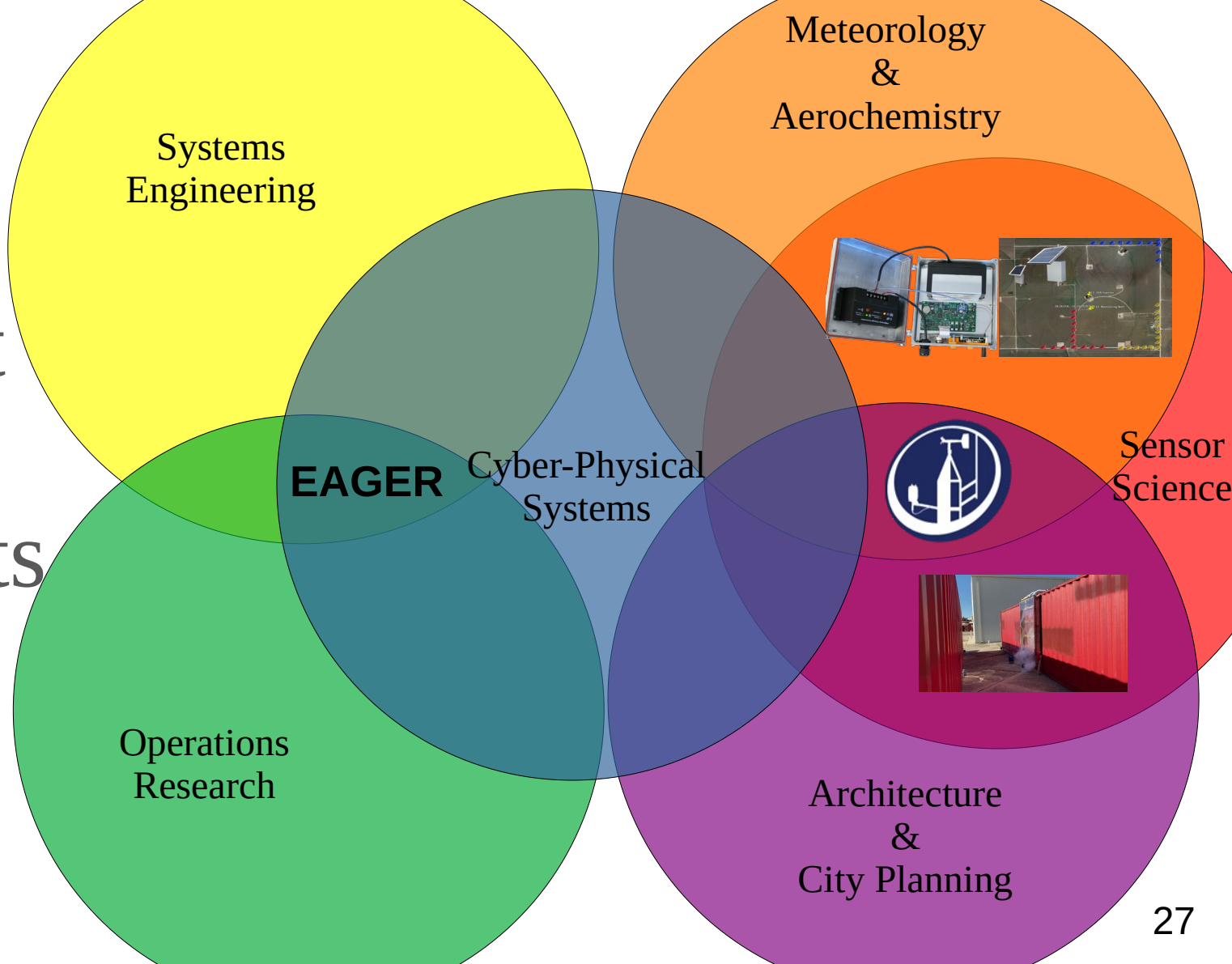
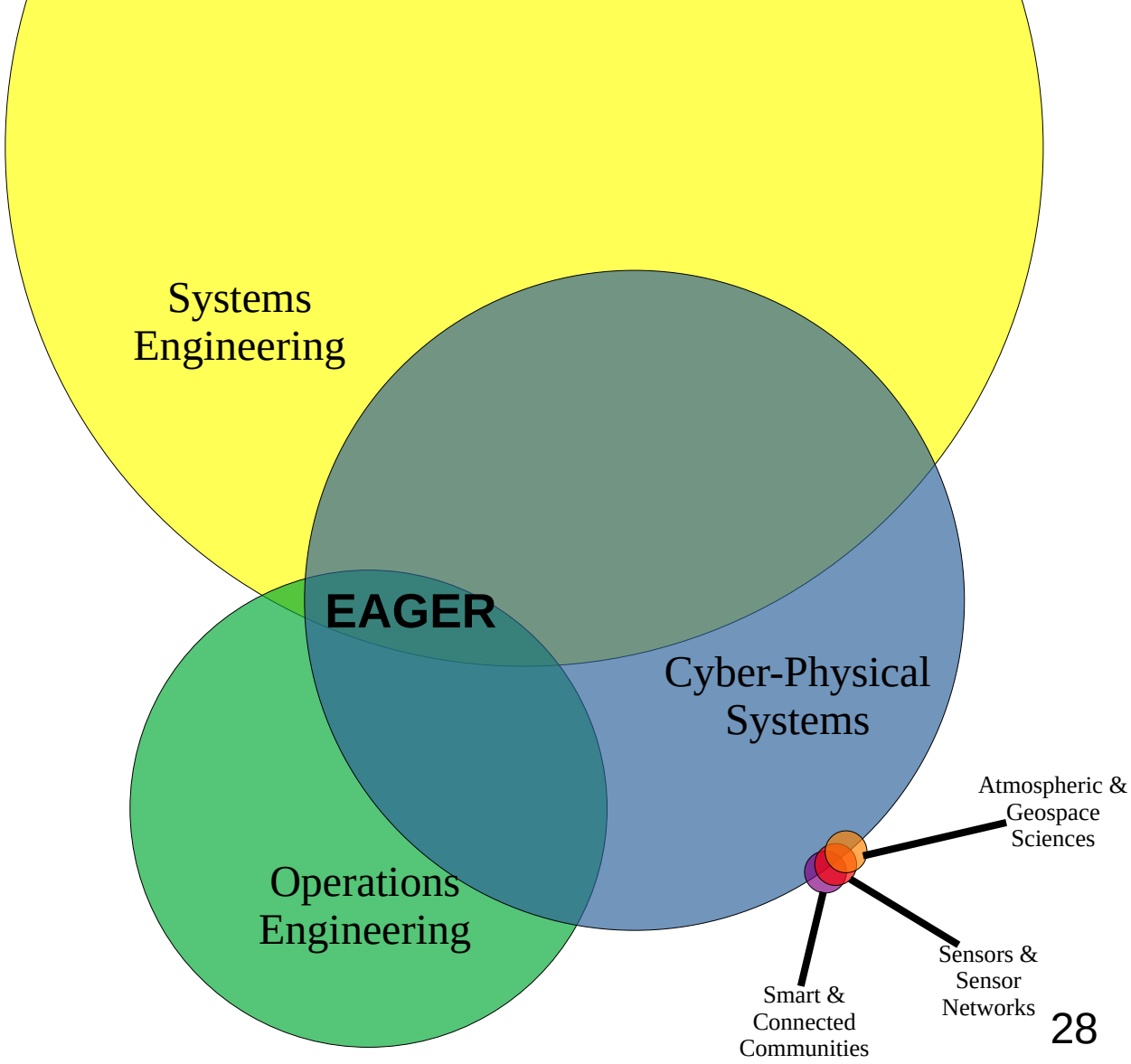
Full Project Team Requirements



EAGER Project as NSF Programs



Thanks

- Claire M. Curry
- Paula M. Cimprich
- Jim Curry
- Gram
- Gracie
- Janet & Farrokh
- Lee Fithian

X-GEM
Community Sustainability
Emission Monitoring

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