BUILDING INNOVATION
Conference

Decarbonizing the Built Environment

Digital Twin Capabilities for Resiliency & Energy Assurance

Pat Wallis

AICP | LEED AP | AIA Assoc. | GISP

Esri Built Environment Innovation Lab

Decarbonizing the Built Environment

Project Datasheet

- **Impacted Users**
  - Architects & Engineers | Building Owners | Planners & Developers | Policy Makers & Executives
- **Problem**
  - Impacted users cannot see the long-term cumulative impact of decisions and actions regarding the built environment.
- **Impacts**
  - Poorly designed and energy inefficient infrastructure-buildings account for 40% of carbon emissions

Solution

- Provide impacted users digital twin capabilities to decarbonize infrastructure using building, solar, and weather physics.
- Reduce the carbon footprint of the built environment and promote sustainability.

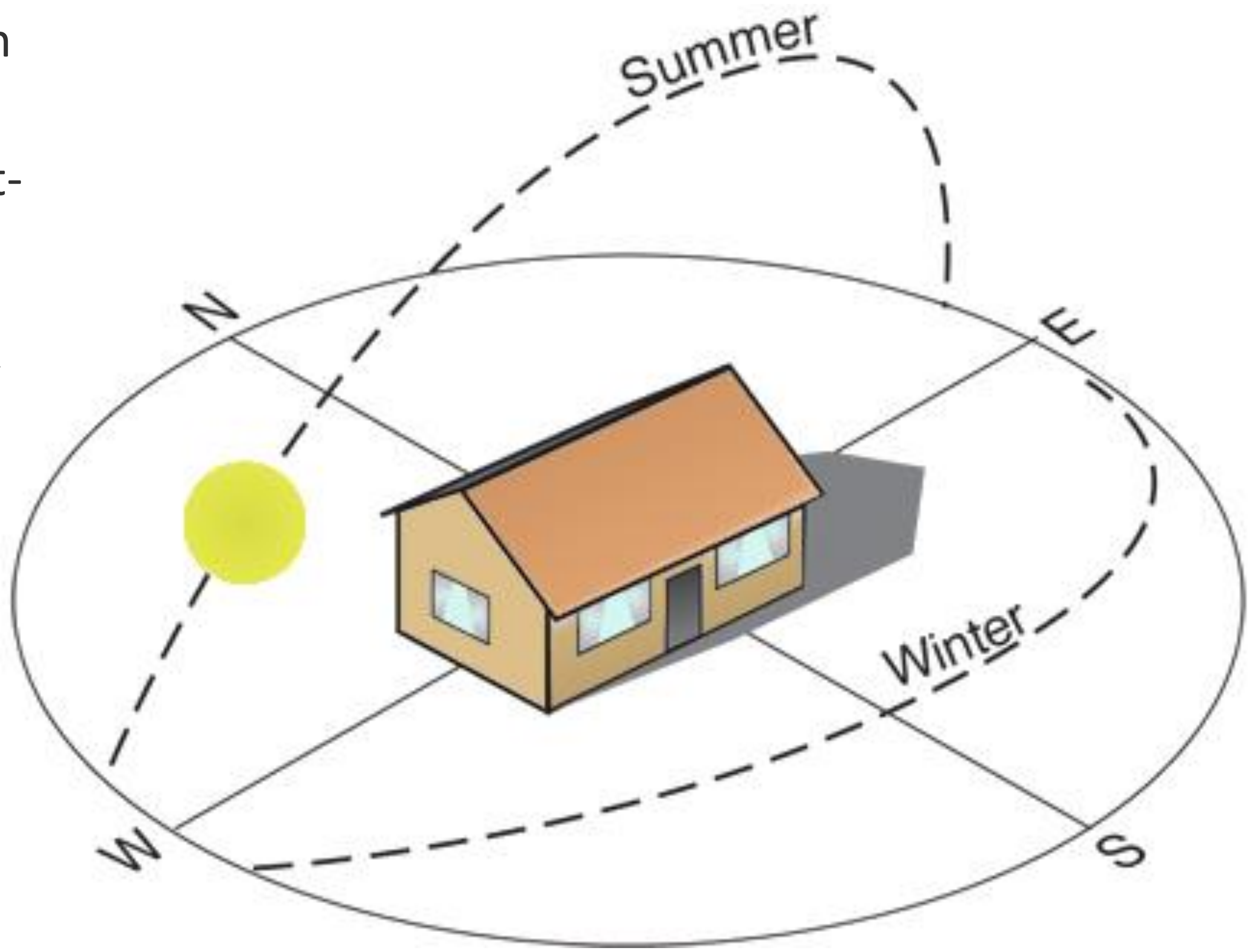
Technology Outcomes

- Tools to analyze building form and estimated additional carbon generation, works at building and urban scale
- Solar energy tools to calculate solar insolation for all building faces.
- AI and Physics-based Heat Transfer tools to calculate conductive, radiative, and convective heat transfer.

Decarbonizing the Built Environment

Premises and Assumptions: Solar Orientation

- Accurate building orientation is fundamental in passive energy use
- A rectangular house's ridgeline should run east-west to maximize the length of the southern side.
- Buildings oriented toward the Sun without any additional solar features save between **10%** and **20%** and up to 40% on heating



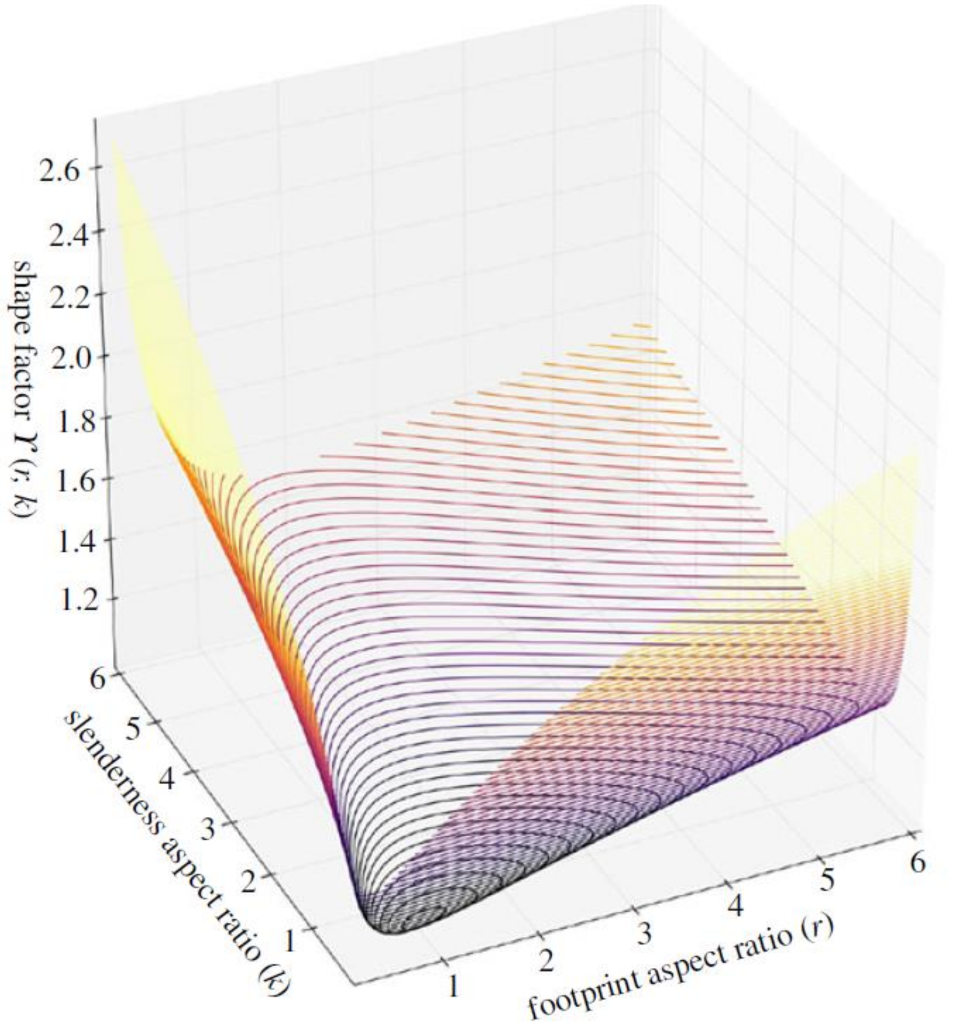
Decarbonizing the Built Environment

Premises and Assumptions: Surface / Volume

- Minimizing the surface area (S) for enclosed volumes (V) maximizes energy efficiency and lowers the embodied carbon from building materials

- There is positive correlation of heat gain with S/V was nearly linear with a slope of around 41.8 kWh/m2 /m−1

- Shape Factor g: S / S min is a scaleless factor that provide instant feedback to evaluate building design. ‘a rapid feeler for the ‘goodness’ of any building shape’



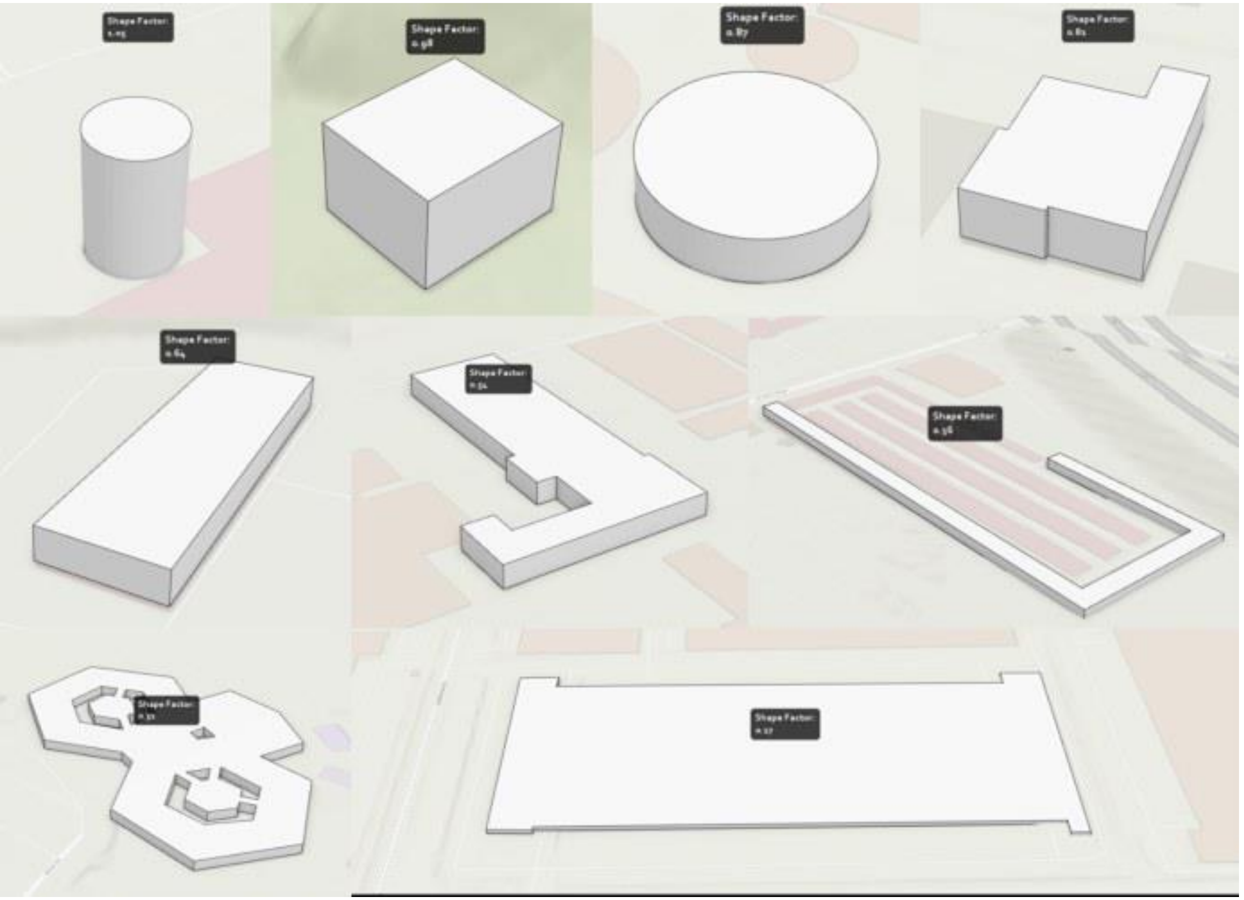
Decarbonizing the Built Environment

Premises and Assumptions: Surface / Volume

- minimizing the surface area (S) for enclosed volumes (V) maximizes energy efficiency and lowers the embodied carbon from building materials

- There is positive correlation of heat gain with S/V was nearly linear with a slope of around 41.8 kWh/m2 /m−1

- Shape Factor g: S / S min is a scaleless factor that provide instant feedback to evaluate building design. ‘a rapid feeler for the ‘goodness’ of any building shape’



Decarbonizing the Built Environment

Premises and Assumptions: Heat Transfer Model

- Conduction through Roofs, Window, Walls
- where Te is < Ti (cooler outside than inside)
- Qcd = A * ΔT / RSI

Where:

- Qcd is the energy from conduction (Watt-hours)
- A is the surface area (m2)
- ΔT = abs(Te – Ti)
- Te is the exterior ambient temperature (Celsius)
- Ti is the interior ambient temperature (Celsius)
- RSI is the heat transfer resistance coefficient recommended for roofs, walls and windows (m2·K/W)

Decarbonizing the Built Environment

Premises and Assumptions: Heat Transfer Model

- Conduction through Roofs, Window, Walls
- where Te is > Ti (warmer outside than inside)
- $Qcd = A * (Ts - Ti) / RSI$

Where:

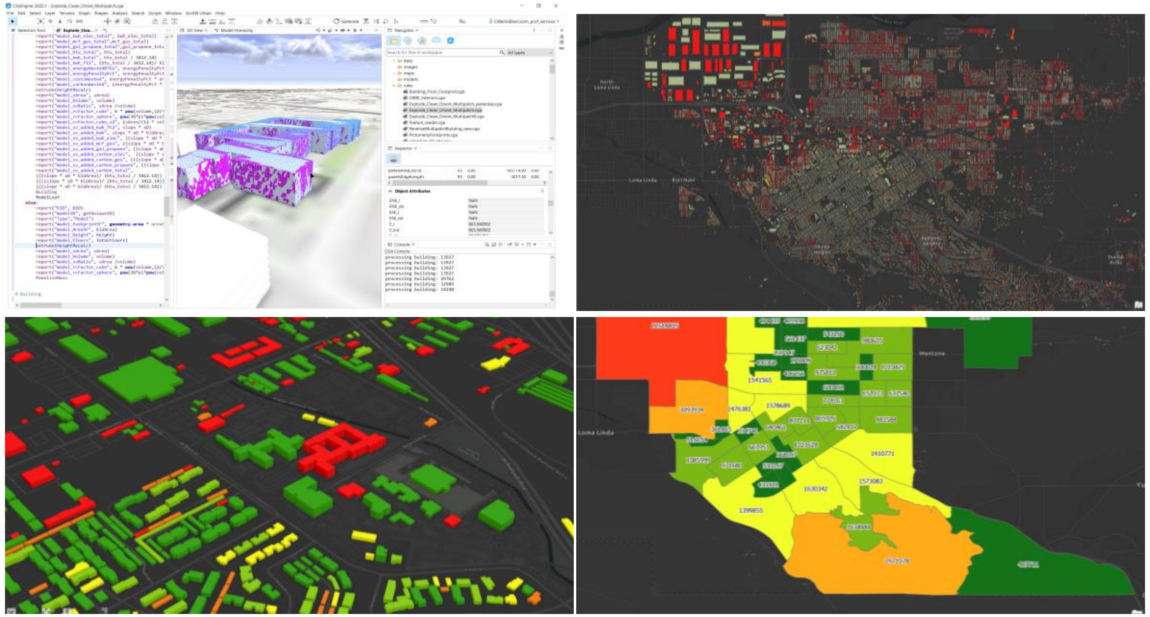
- Qcd is the energy from conduction (Watt-hours)
- A is the surface area (m2)
- Ts is the surface temperature (Celsius)
- Ti is the interior ambient temperature (Celsius)
- RSI is the heat transfer resistance coefficient recommended for roofs, walls and windows (m2·K/W)

Decarbonizing the Built Environment

Premises and Assumptions: Heat Transfer Model

- Conduction through Roofs, Window, Walls
- where Te is > Ti (warmer outside than inside)
- Qcd = A * (Ts - Ti) / RSI
- Ts is calculated from the plane of array global (poa_global) incident irradiation (W/h m2) to each building surface.

```
Ts = pvlib.temperature.faiman_rad(
    poa_global,
    Te,
    wind_speed=windspeed,
    ir_down=ir,
    u0=25 (default),
    u1=conv_ht_c,
    sky_view=1.0,
    emissivity=emissivity)
```

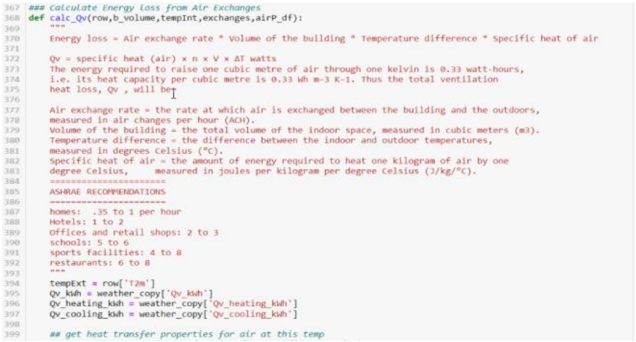


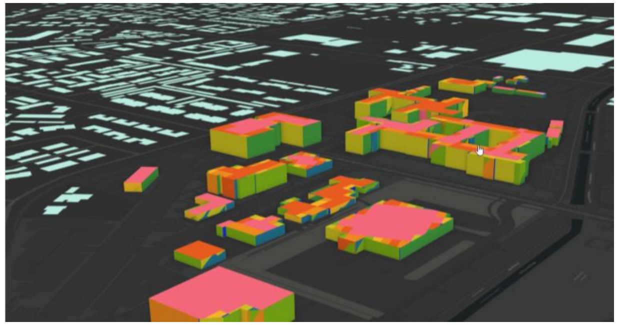
Basic

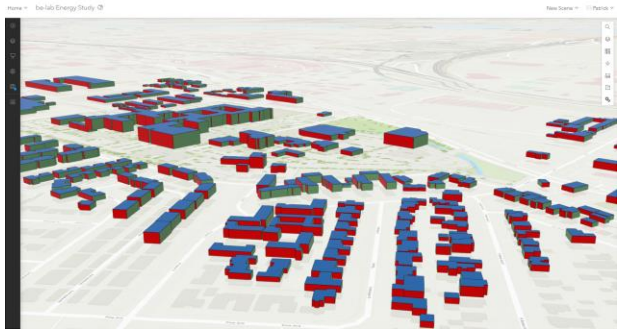
[procedural analysis, ‘atlas’ layers, dashboards, …]

Advanced

[basic+, solar analysis, & energy model, …]

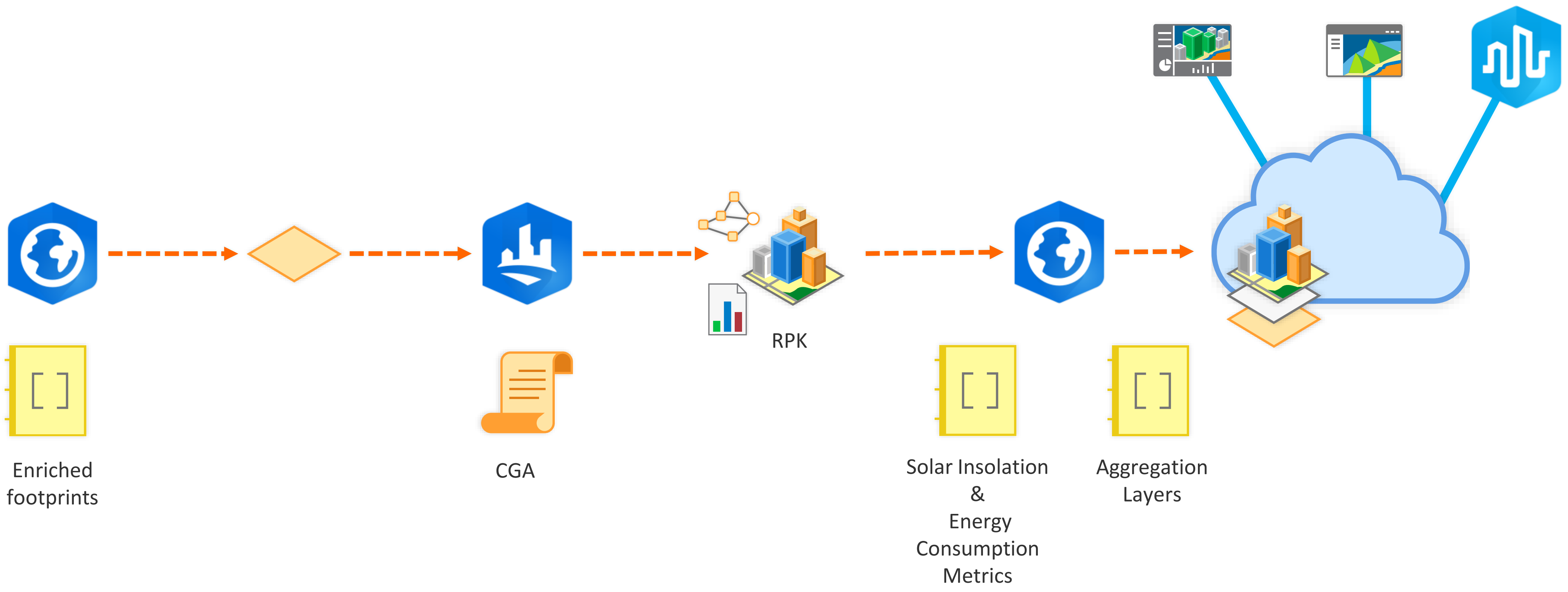






Solution Architecture

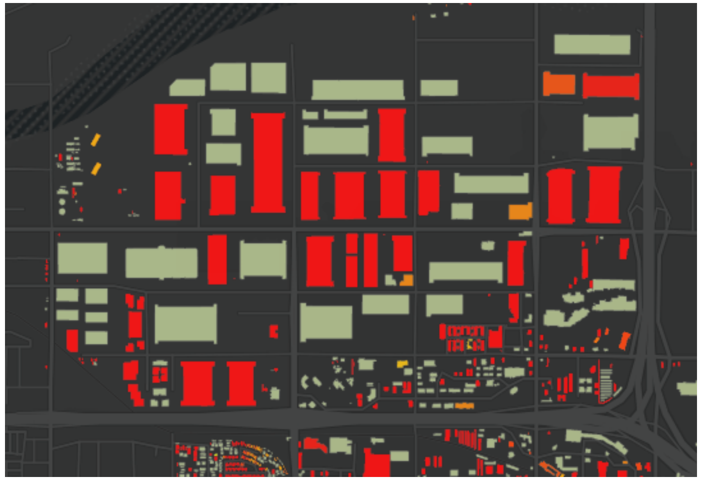
Decarbonizing the Built Environment



Multi-Scale FM

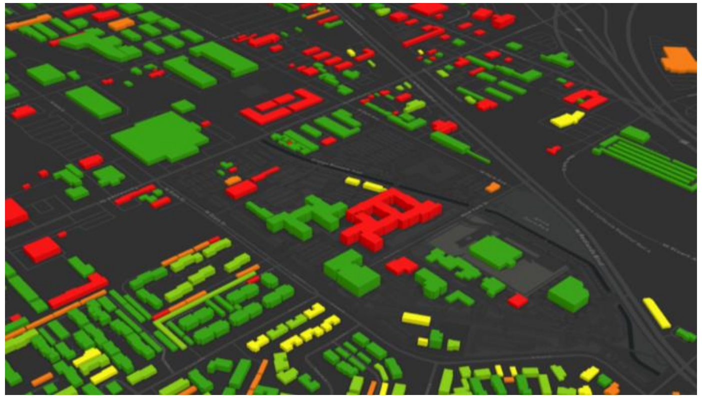
Where to Start

1. Input = Building Footprints OR 3d shell
   - Zoning (commercial or residential)
   - Elevation
   - Height



2. Procedural output = enriched building footprints, 3d shell, face panels, and panel points

'AreaSF', 'Bearing', 'EW_Length', 'EW_ldir_factor', 'E_Azimuth', 'E_Length', 'E_ldir_factor', 'EdgeLength', 'Floors', 'FootprintSF', 'Height', 'NS_Length', 'NS_ldir_factor', 'N_Azimuth', 'N_Length', 'N_ldir_factor', 'Perimeter', 'S_Azimuth', 'S_Length', 'S_ldir_factor', 'Volume', 'W_Azimuth', 'W_Length', 'W_ldir_factor', 'bldType', 'btu_total', 'carbonWasted', 'carbon_total', 'carbon_wasted_elec', 'compactness_PP', 'compactness_S', 'costsWasted', 'depth_Length', 'energyPenaltyPct', 'energyWastedBTUs', 'gal_propane_total', 'gal_propane_wasted', 'gas_wasted_elec', 'ideal_sa_cube', 'k_wh_ratio', 'kwh_elec_total', 'kwh_elec_wasted', 'kwh_ft2', 'kwh_total', 'lw_ratio', 'lw_ratio_NS_EW', 'mainAzimuth', 'mainDir', 'mcf_gas_total', 'mcf_gas_wasted', 'propane_wasted_elec', 'r_dw_ratio', 'rcFactor_cube', 'rcFactor_cube_v2', 'rcFactor_sphere', 'sArea', 'svRatio', 'sv_added_carbon_elec', 'sv_added_carbon_gas', 'sv_added_carbon_propane', 'sv_added_carbon_total', 'sv_added_gal_propane', 'sv_added_kwh', 'sv_added_kwh_elec', 'sv_added_kwh_ft2', 'sv_added_mcf_gas', 'width_Length'

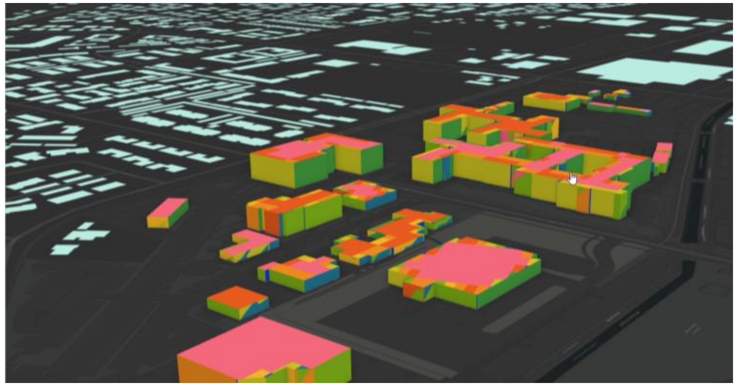


Multi-Scale FM

Where to Go – Advanced Capabilities

3. Use procedural output to tally solar insolation (kWh/m2)

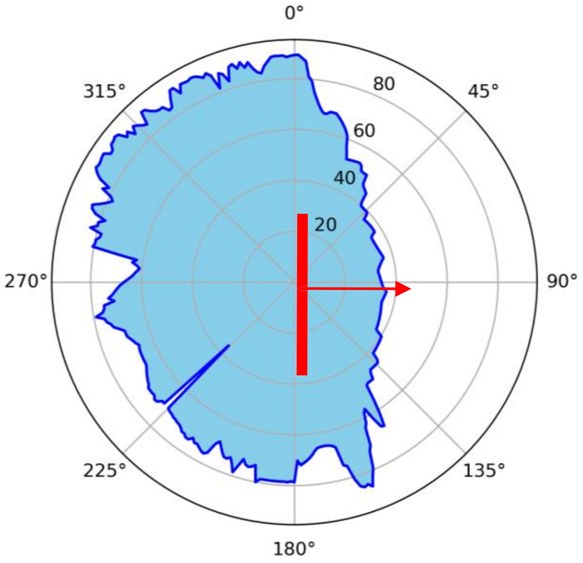
4. Use solar insolation and weather data to compute:
   - kWh heating and cooling using heat transfer model for all building faces - summarize by building
   - kWh savings & Carbon reduction for ideal form

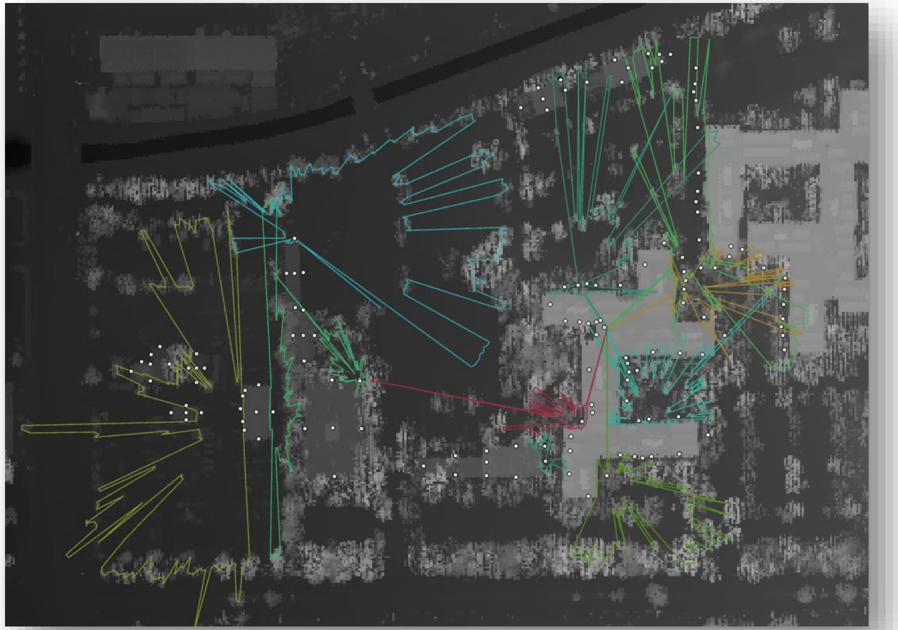


Multi-Scale FM

Where to Go – Advanced Capabilities

5. Use Skyline Analysis to account for shadow impacts on energy consumption calculations





el Diablo Buildings by Wasted Carbon - Dashboard

Patrick Wallis
CWallis@esri.com_prof_services

Facilities by Wasted Carbon

Search...

NFAEX003000182 Hospital
Total Wasted Carbon: 10125515.792494 pounds
Surface Area: 2995344.096162 sf
Floor Area: 13458914.612543 sf
Shape Factor: 0.658361
LW ratio: 1.957516
Main Direction: EW

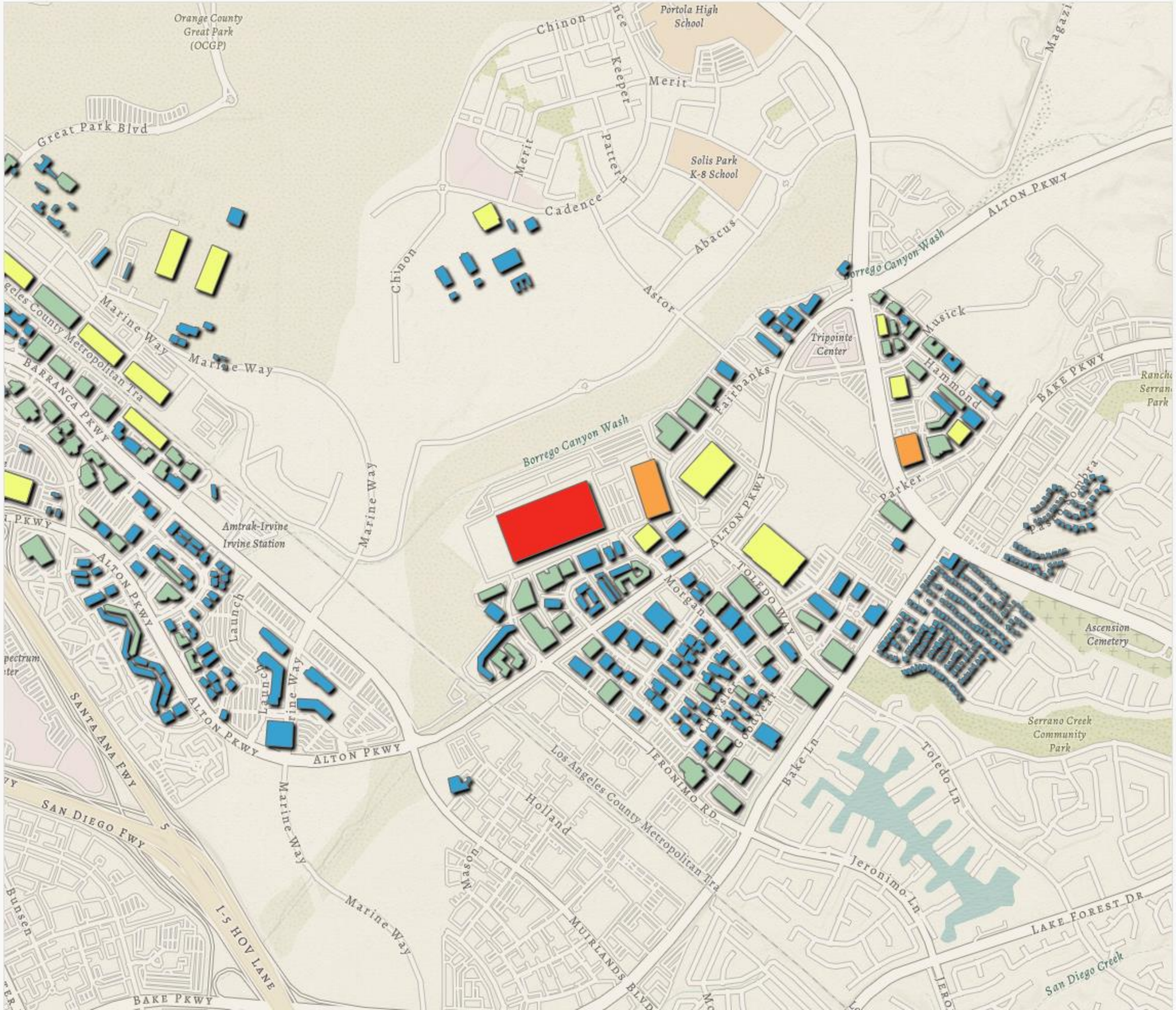
NFAEX003000183 Medical Laboratory
Total Wasted Carbon: 3211833.418959 pounds
Surface Area: 768535.554514 sf
Floor Area: 1266267.395720 sf
Shape Factor: 0.530791
LW ratio: 2.152242
Main Direction: NS

NFAEX003000255 Miscellaneous Operations Support Building
Total Wasted Carbon: 2954859.230104 pounds
Surface Area: 472778.800032 sf
Floor Area: 1192915.471848 sf
Shape Factor: 0.829187
LW ratio: 1.283052
Main Direction: NS

NFAEX003000614 N/A
Total Wasted Carbon: 1721533.018285 pounds
Surface Area: 560845.095015 sf
Floor Area: 884980.342265 sf
Shape Factor: 0.572818
LW ratio: 2.673228
Main Direction: NS

NFAEX003000634 N/A
Total Wasted Carbon: 1554296.944244 pounds
Surface Area: 449697.813070 sf
Floor Area: 586560.843297 sf
Shape Factor: 0.433950
LW ratio: 2.485922
Main Direction: NS

NFAEX003000197 N/A



Additional Propane (gal)

12.9k

Additional Electricity (kWh)

7.5M

Additional Gas (mcf)

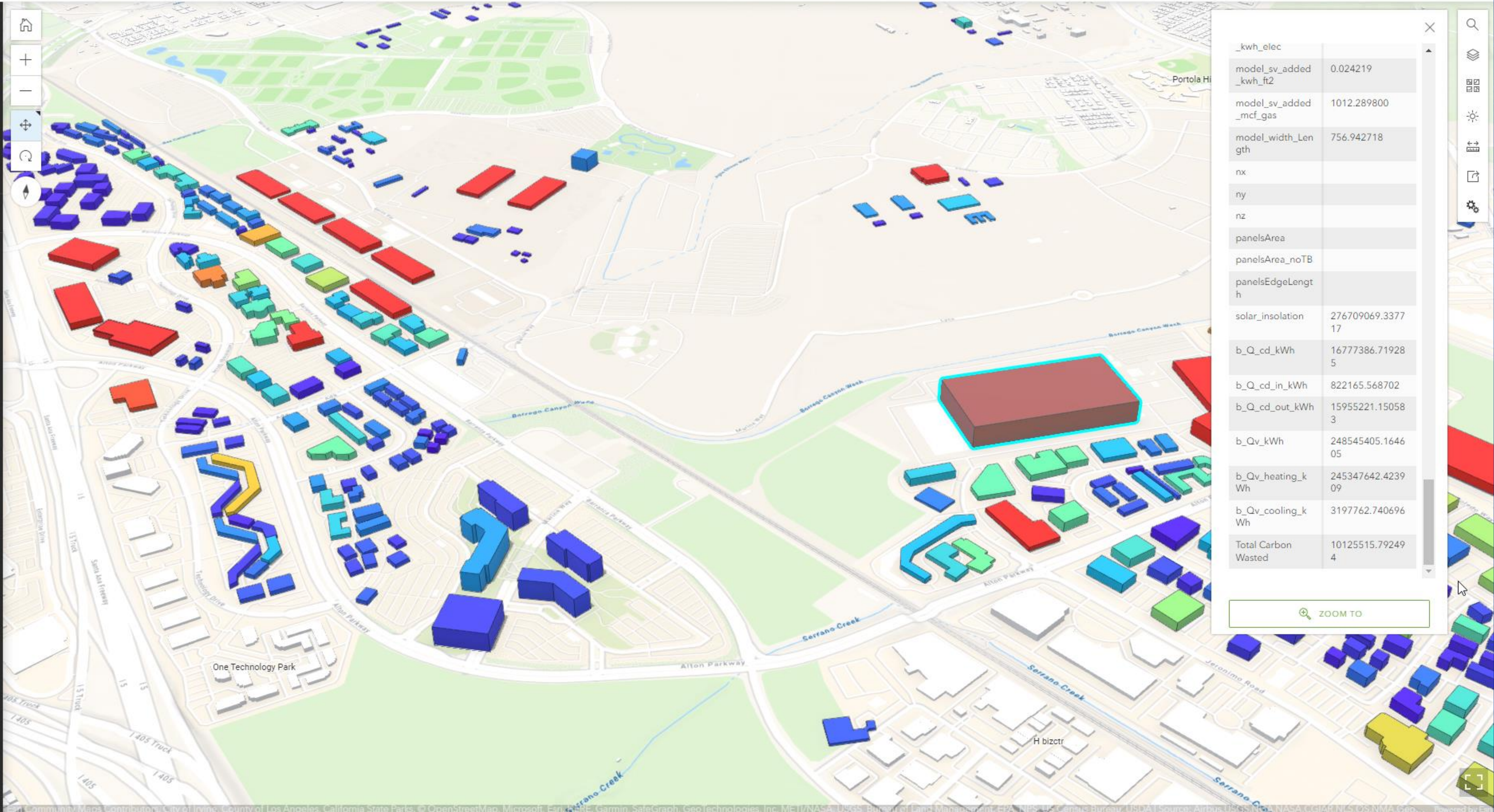
14.5k

Total Additional Carbon

73.6M lbs/year

Home ▾ el Diablo Buildings by Wasted Carbon

New Scene ▾ Patrick ▾



_kwh_elec	
model_sv_added_kwh_ft2	0.024219
model_sv_added_mcf_gas	1012.289800
model_width_Length	756.942718
nx	
ny	
nz	
panelsArea	
panelsArea_noTB	
panelsEdgeLength	
solar_insolation	276709069.337717
b_Q_cd_kWh	16777386.719285
b_Q_cd_in_kWh	822165.568702
b_Q_cd_out_kWh	15955221.150583
b_Qv_kWh	248545405.164605
b_Qv_heating_kWh	245347642.423909
b_Qv_cooling_kWh	3197762.740696
Total Carbon Wasted	10125515.792494

Decarbonizing the Built Environment

User Needs

- Architects / Engineers
  - quickly evaluate building form metrics and energy reductions / carbon savings
  - UI/UX needs. Form CAD or BIM as plugin, or simple web interface to upload model and get results.
- Facility Engineers / RP Asset Managers
  - evaluate building form metrics, potential energy reductions, carbon and cost savings. Metrics for MILCON and facility sustainment, eg. Lifetime OE savings
  - UI/UX Needs. Load models and view dashboard (as-is vs. to-be). See ESG scores
- Facility Planners / Installation Command
  - Tools to score proposed MILCON, existing infrastructure and help develop new installation design policies
  - UI/UX Needs. Data curation and publishing tools, analytics tools to create information products for decision makers, e.g. DD 1391 review, review of proposed maintenance & repair (why repair a poorly designed facility, instead of demo/new build)
- Policy Makers / Executives
  - Evaluate building form metrics for installation / command / service.
  - See potential energy, carbon and cost reductions. Data to craft funding policies for rehabilitation of facilities, annual and lifetime energy, carbon reductions, trajectory to ideal state
  - UI/UX Needs. View dashboard (as-is vs. to-be). See building metrics, energy and climate scores

BUILDING INNOVATION
Conference

Questions?

Thank you