Symposium on Sustainable Urban Design

Case Studies and Design Workflows

umi

Overview

Goal, Context and Workflow

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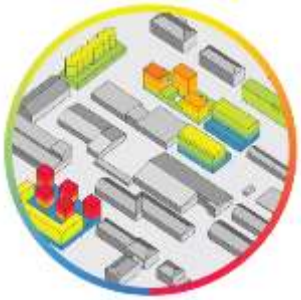
Department of Architecture
Building Technology Program
Sustainable Design Lab



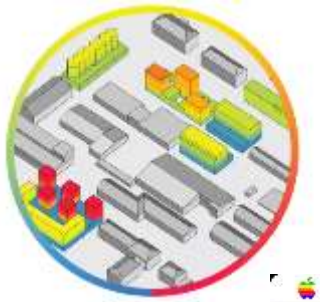
umi

Goal

To develop an urban modeling platform to design and improve new and existing neighborhoods regarding multiple measures of urban sustainability including operational energy use, daylighting, outdoor comfort and sustainable transportation.

This effort is currently supported by

NSF EFRI Grant (with Harvard and Penn State)
US DOE (Pennsylvania HUB)
MIT Energy Initiative
United Technology Corporation
Transsolar Climate Engineering



Context

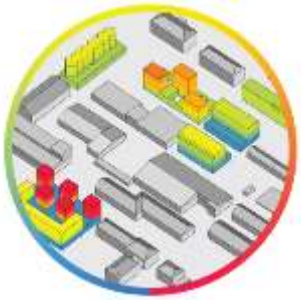
1989 SimCity by W Wright – Computer Game based on System Theory

Context

Build

Destroy

2013 SimCity 5 by Maxis



Context

2013 SimCity 5 by Maxis

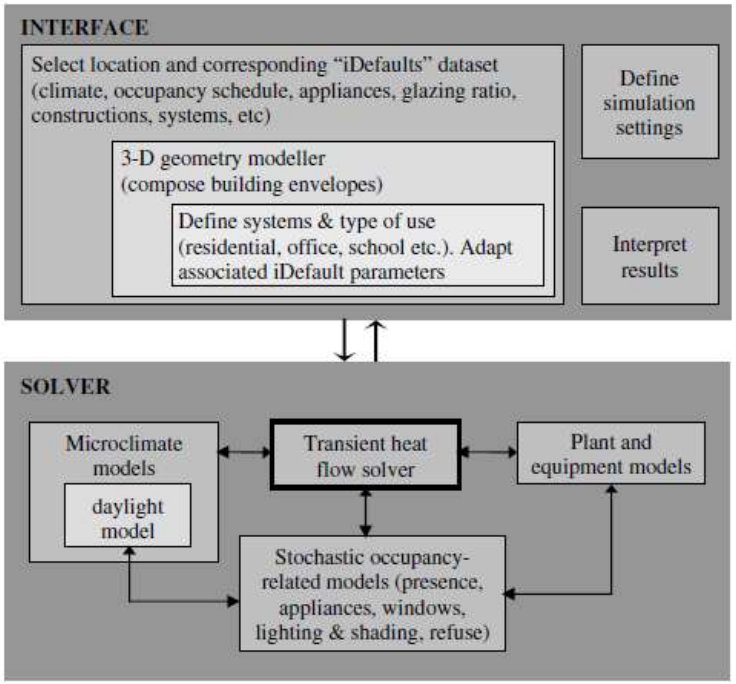
"I don't want to enforce sustainable design principles in the game — I want them to emerge as natural consequences of your interaction with the simulation. [...] If you don't deal with your sewage, with traffic congestion, with walkability and transit, with ground and air pollution — your city will reflect that!"

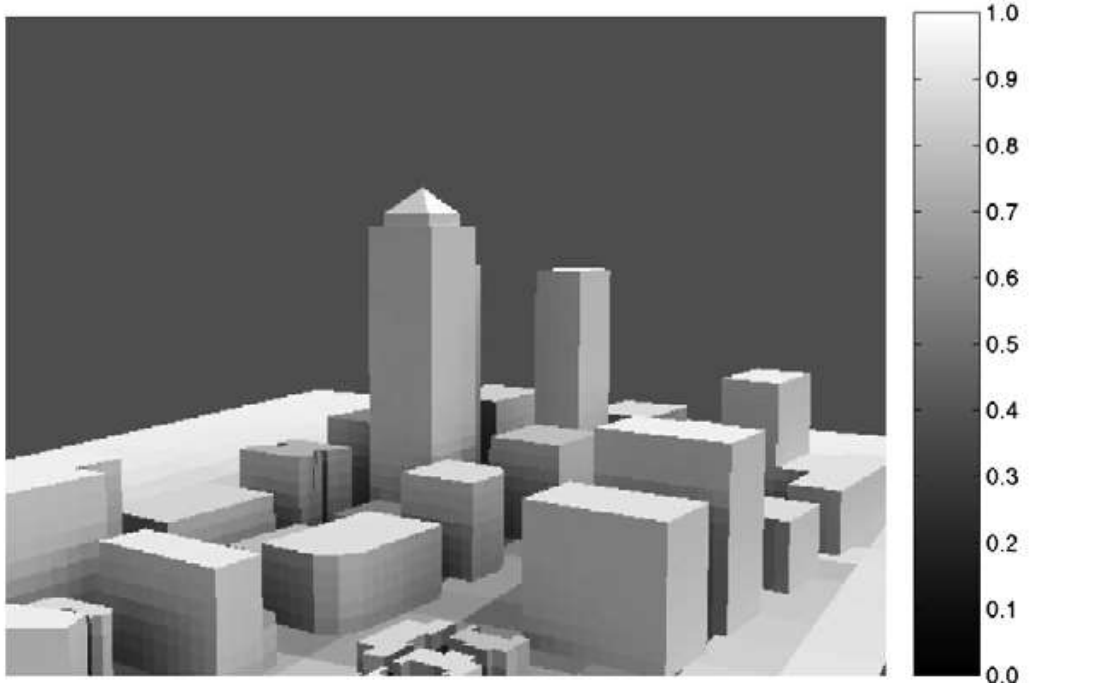
Dan Moskowitz (creative director SimCity 5)

Context

CityEngine by Efri:3D urban scenes based on two dimensional geographic information system (GIS) databases

Context

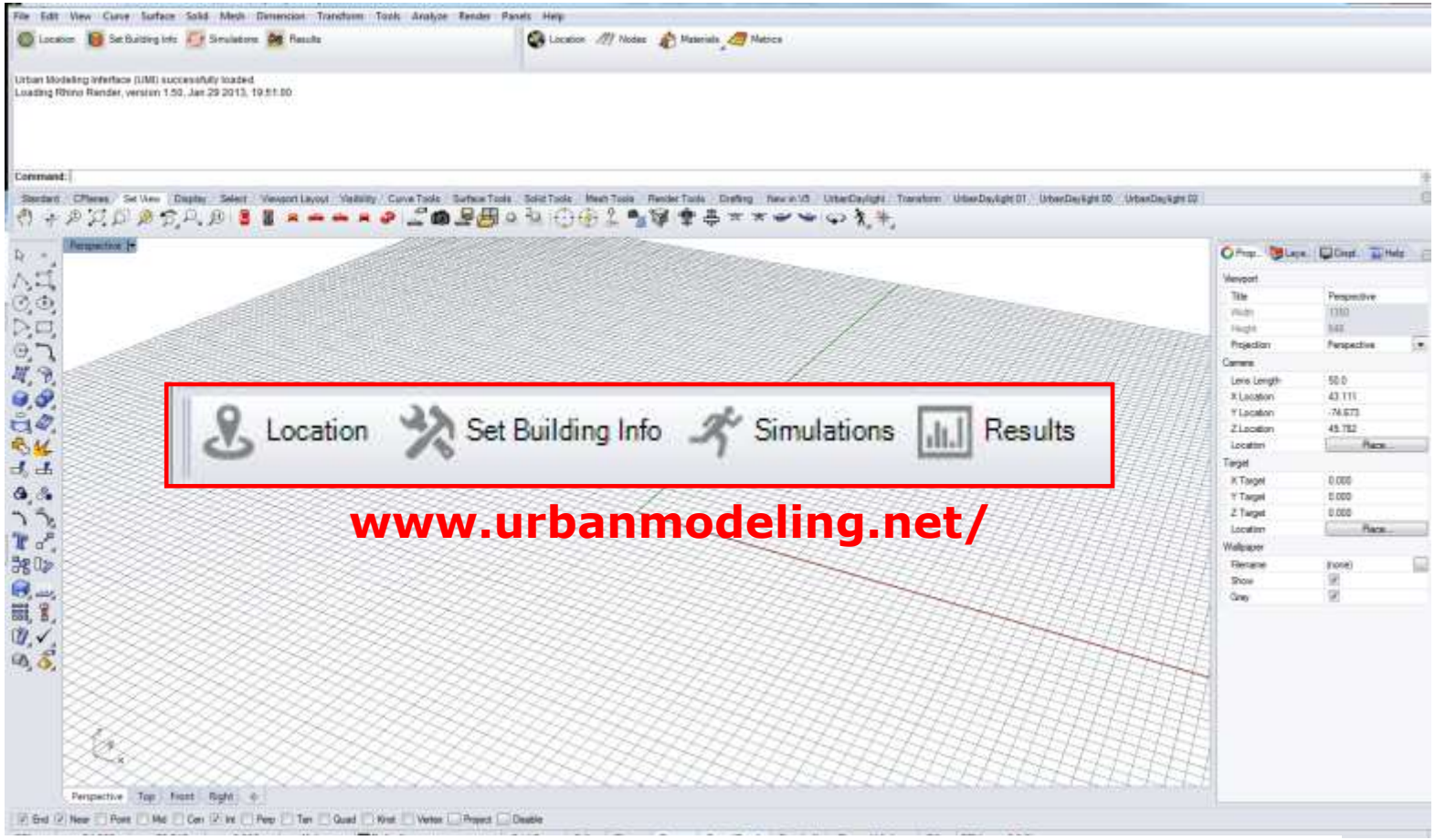




SUNtool (Darren Robinson): Strong Building Physics; no public release

Paper Robinson D, N Campbell, W Gaiser, K Kabel, A Le-Mouel, N Morel, J Page, S Stankovic and A Stone, SUNtool - A new modelling paradigm for simulating and optimising urban sustainability, Solar Energy 81:1196-1211, 2007

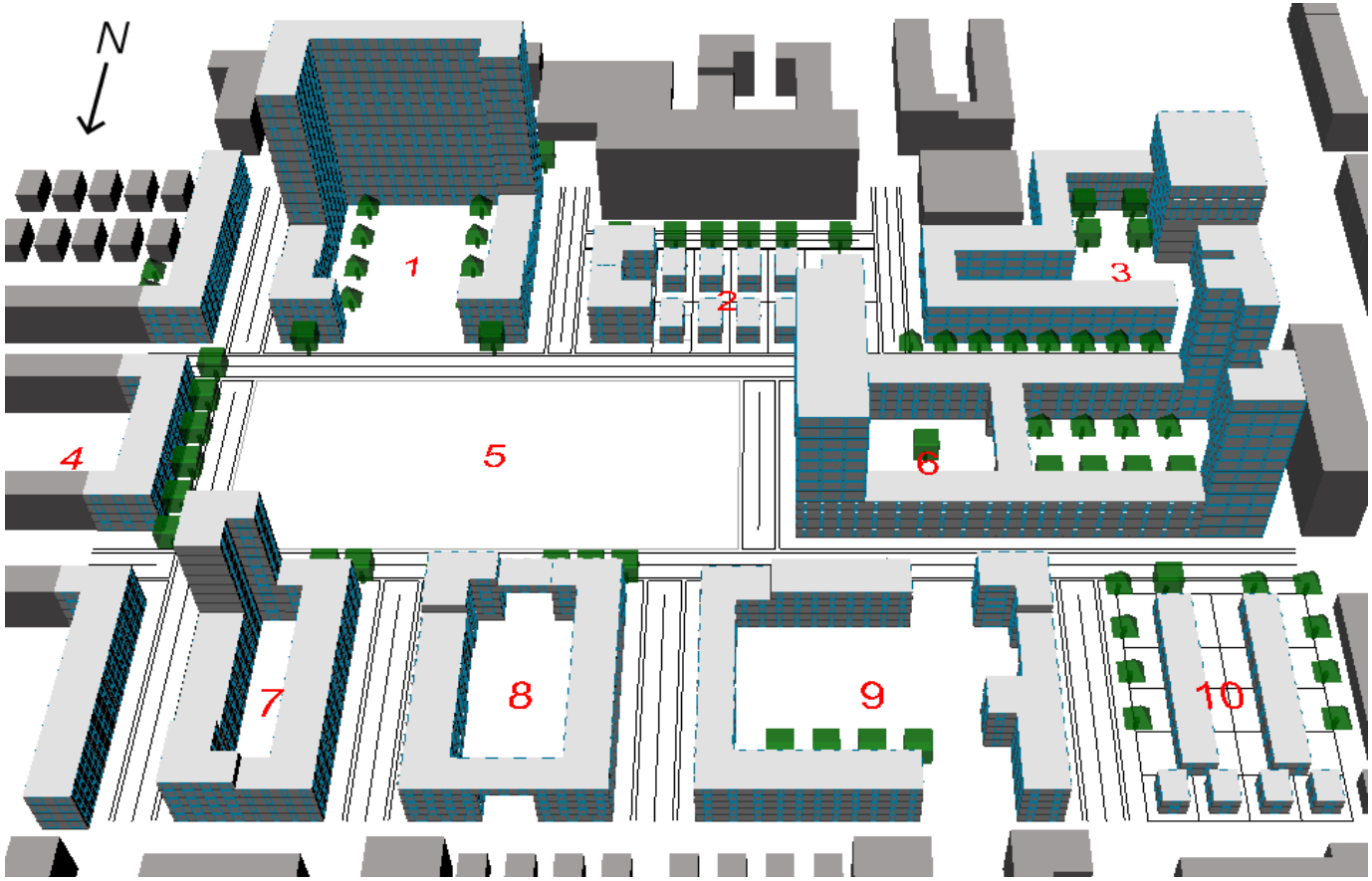
Workflow



Plug-in for NURBS Modeler Rhinoceros 5

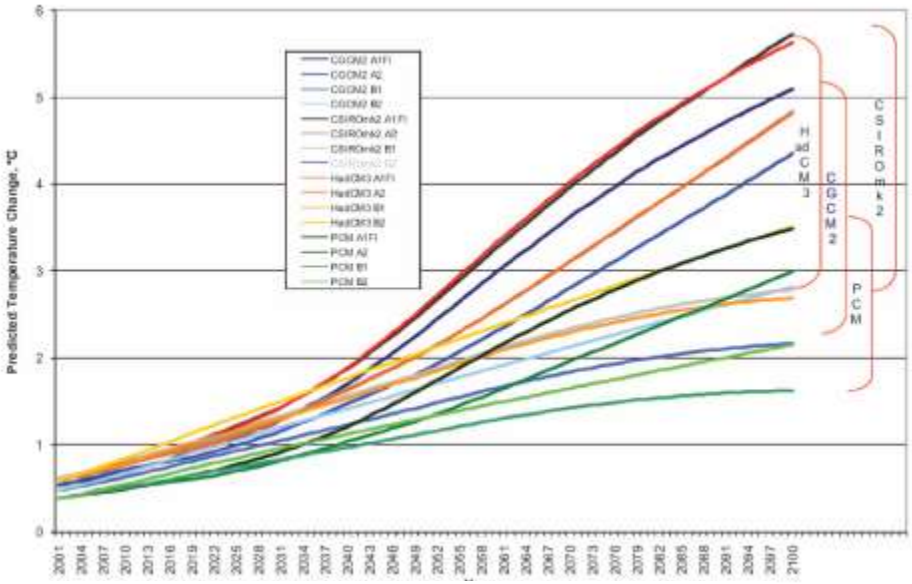
Paper C F Reinhart T Dogan, J A Jakubiec, T Rakha, A and A Sang, "umi – An urban simulation environment for building energy use, daylighting and walkability", Building Simulation 2013, Chambery, France, August 2013.

Massing Model



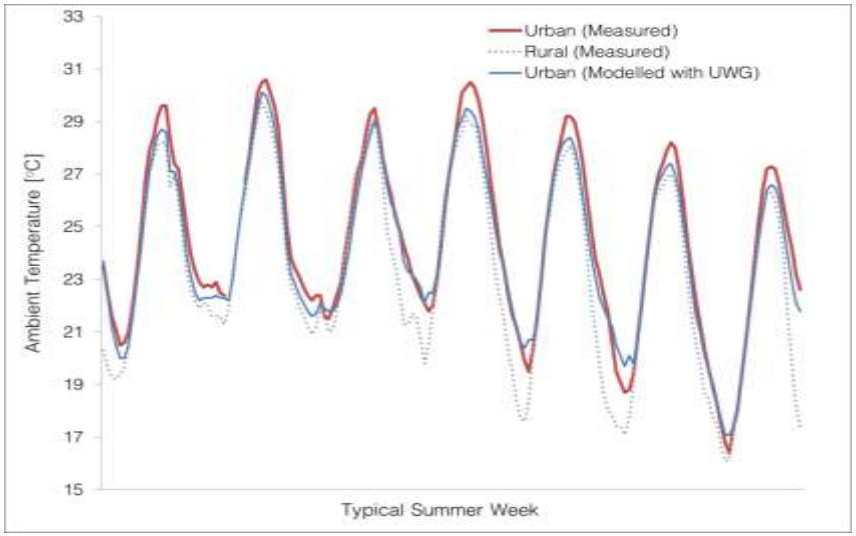
Manipulating Climate Files

Climate Change



CCWorldWeatherGen (Excel)
University of Southampton

Urban Heat Island



Urban Weather Generator (MATLAB)
MIT

Paper Jentsch MF, Bahaj AS, James PAB. Climate change future proofing of buildings - Generation and assessment of building simulation weather files. Energy and Buildings 2008; 40 (12): 2148-2168.
Paper B Bueno, L Norford, J Hidalgo and G Pigeon, "The urban weather generator", Journal of Building Performance Simulation, 2012

Symposium on Sustainable Urban Design

Case Studies and Design Workflows

Operational Energy

An Introduction to Citywide Energy Modeling

J. Alstan Jakubiec alstan@jakubiec.net

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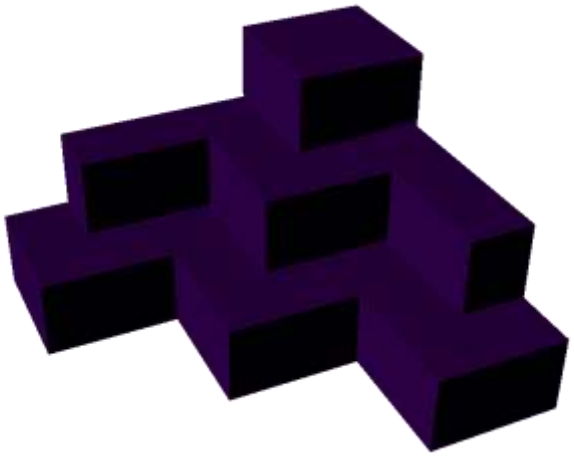
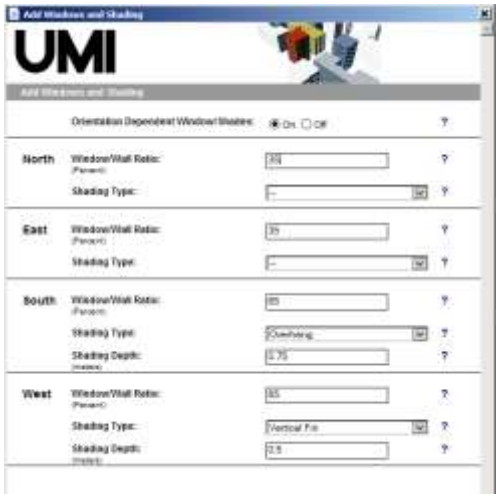
Department of Architecture
Building Technology Program
Sustainable Design Lab

How Does it Work?

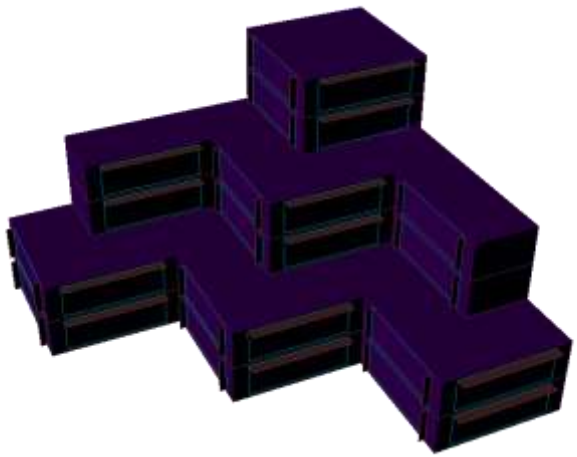
User Perspective



1. Design a building form



2. Assign energy templates and fenestration information



3. Simulation model constructed

Energy Plus

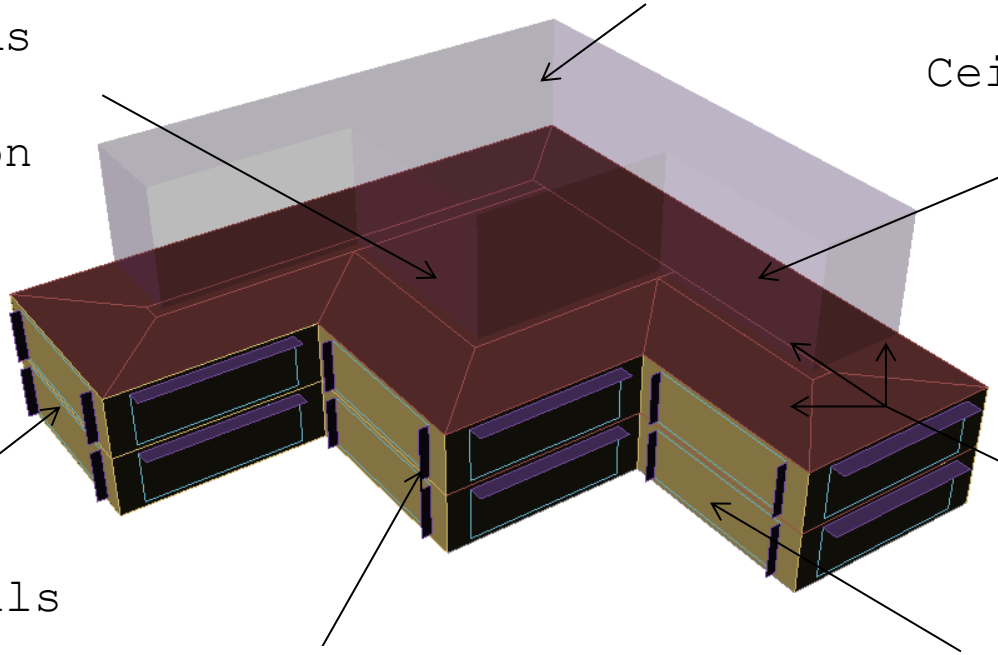
A validated thermal simulation engine

- Building construction information.
- Building use information.
- Building geometry with automatic thermal zoning.
- Surrounding urban context.

- Whole building energy simulation engine.
- Produced by the US Department of Energy.
- Validated by ASHRAE 865, ASHRAE 1052, ANSI 140-2011, and IEA BESTEST.
- One of the tools used modeling energy consumption for LEED compliance.

Automated Model Creation

Automatically Fed to EnergyPlus



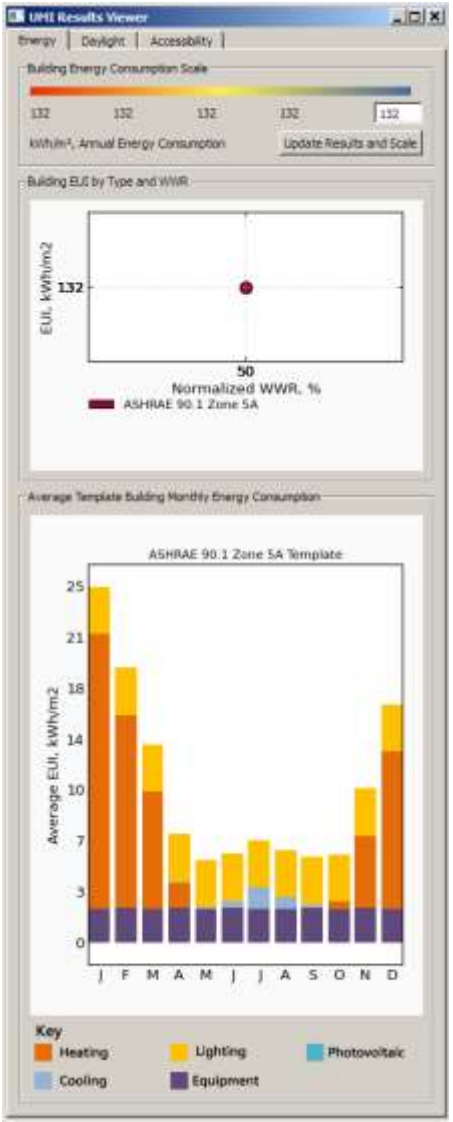
+ : Natural ventilation Photovoltaic panels Daylighting systems and controls

Results Viewer

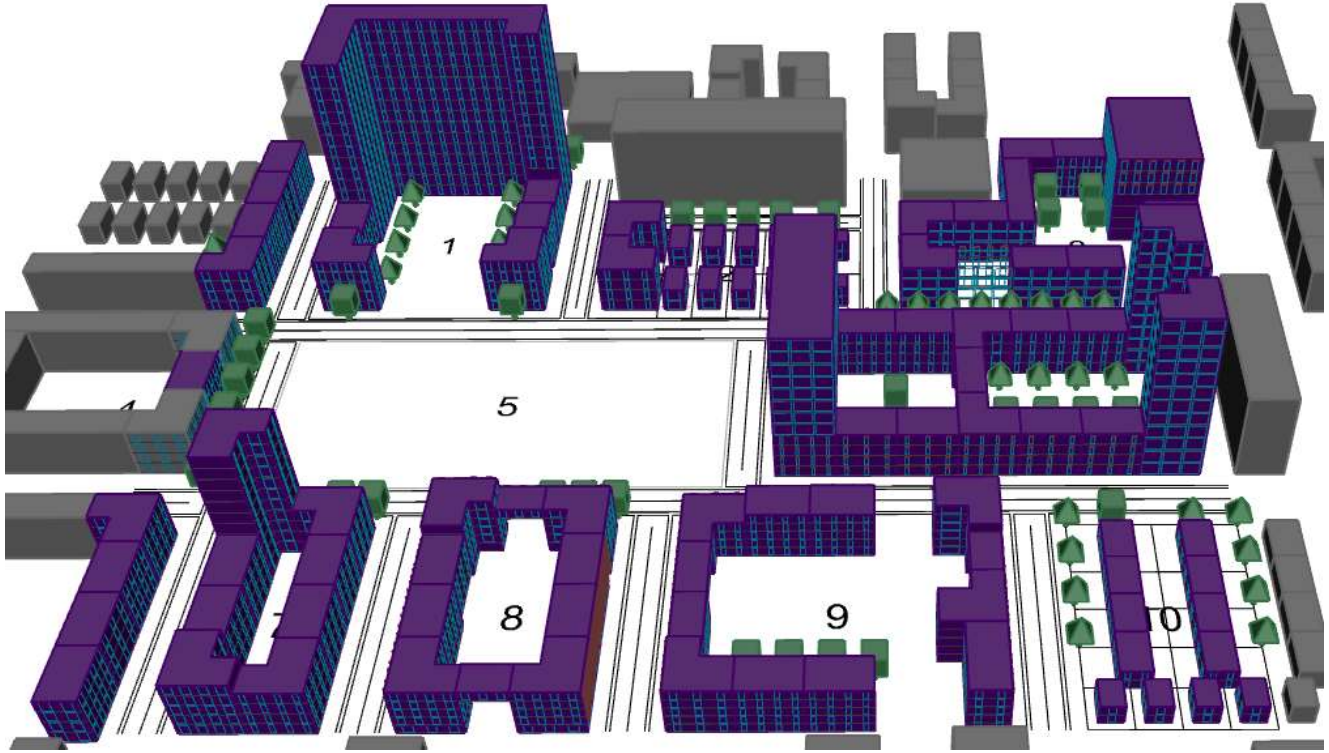
Results Scale

Scatter plot organized by building type

Average monthly loads by building type

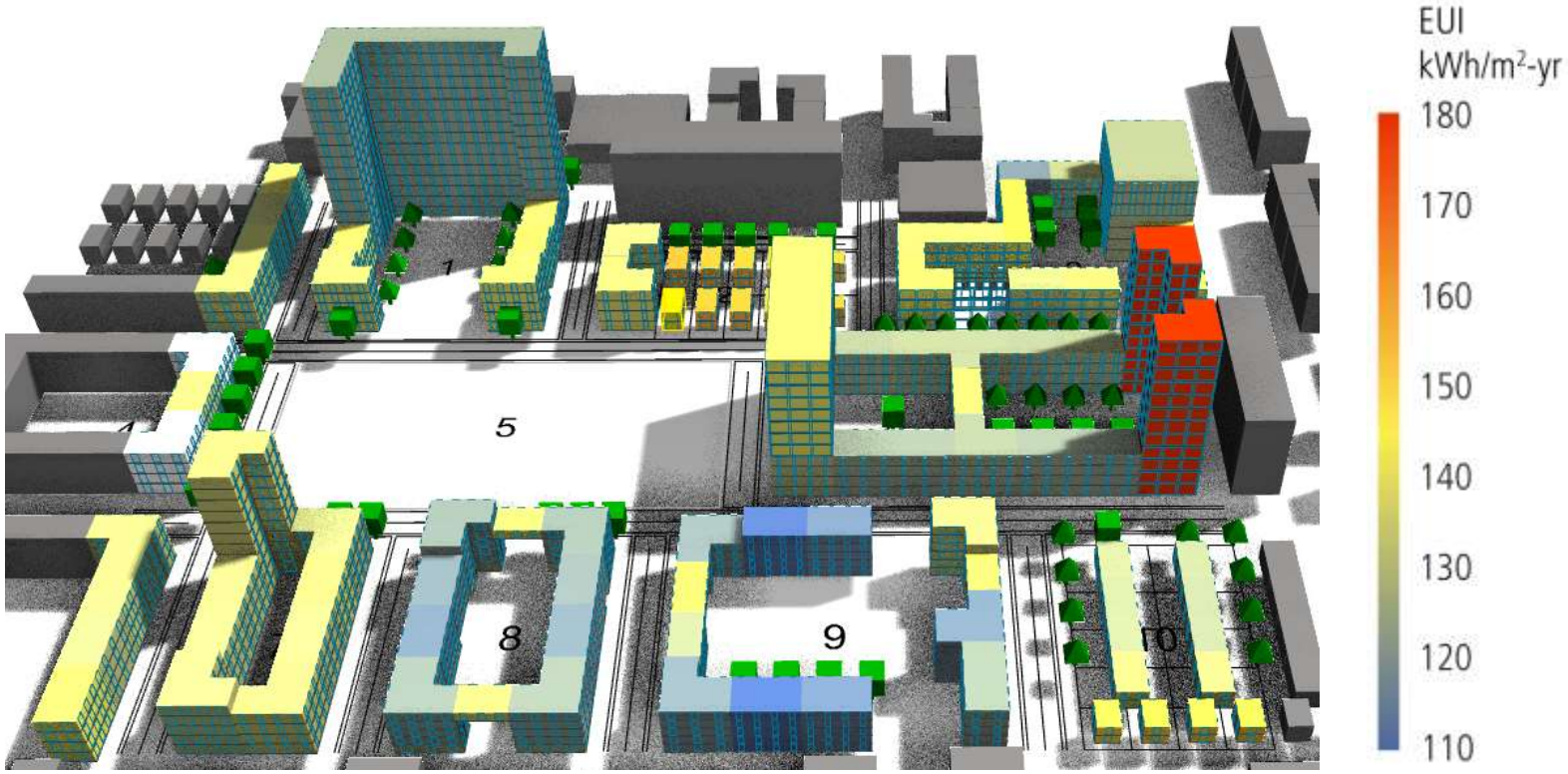


Setting up an Entire City Model



All buildings use ASHRAE-90.1 standard materials and loads, but have different window-to-wall ratios, and urban contexts.

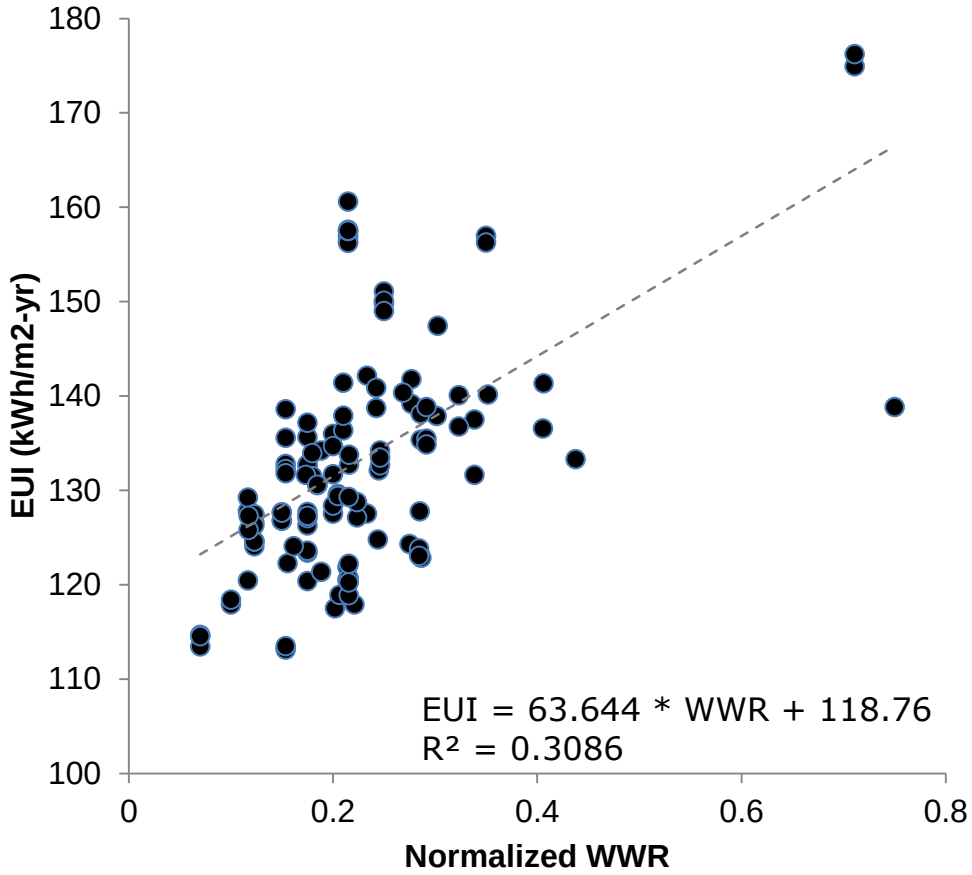
Visualizing umi-Thermal Simulation Results



Export and simulation time: ~20 minutes with parallel processing (8 GHz-hours).

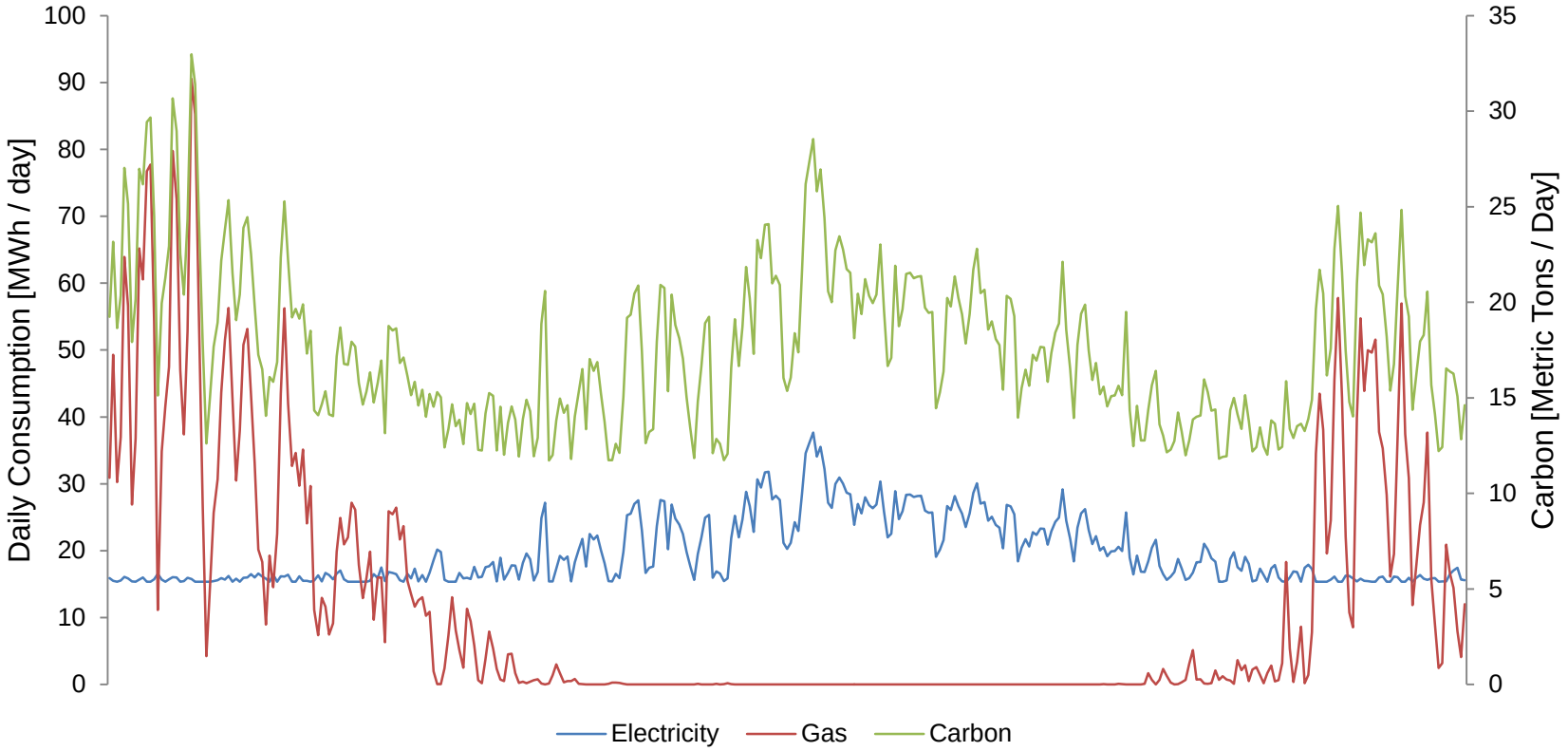
Shading and Adjacency

in the urban context make a difference



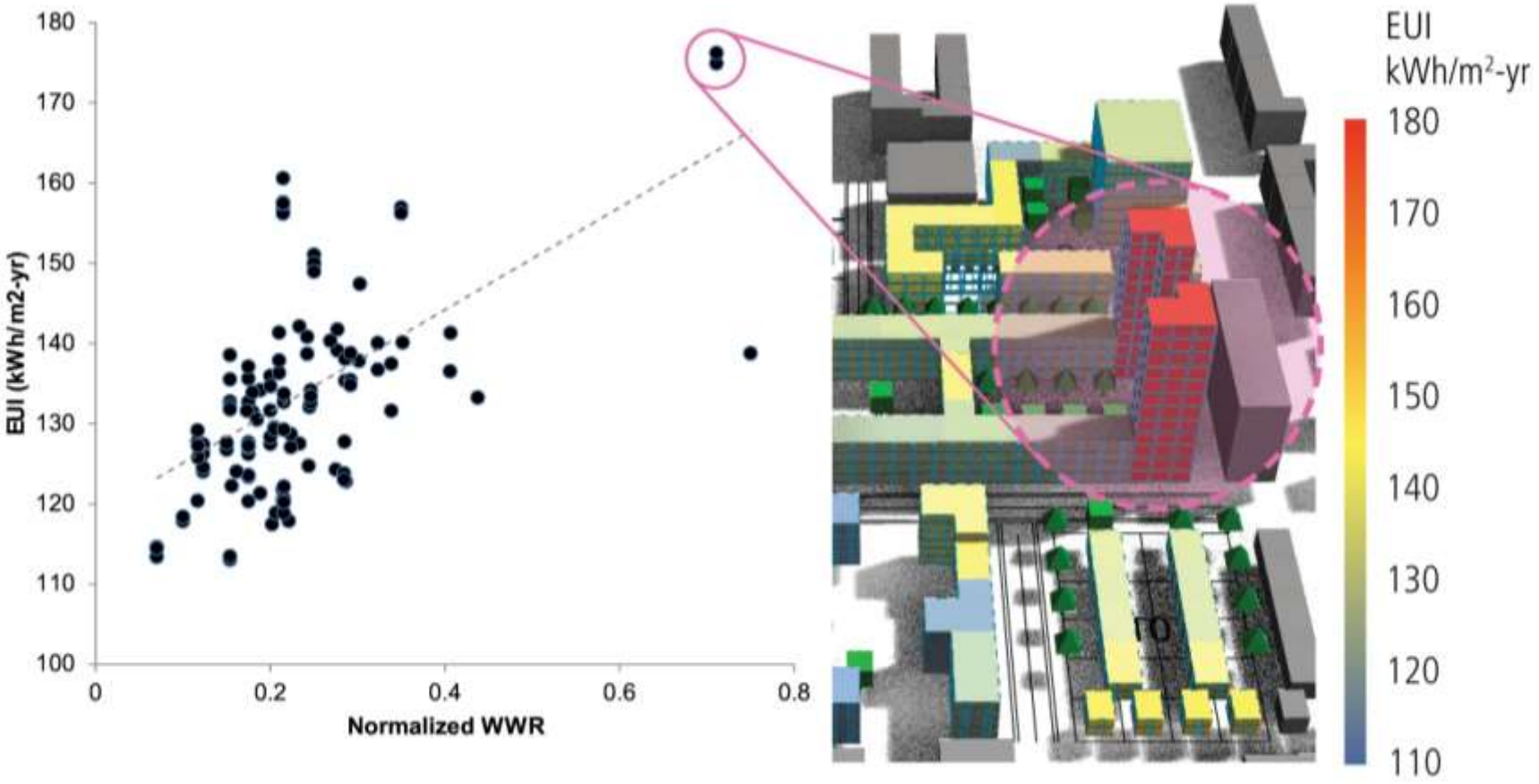
In this model, only 31% of the variation in EUI can be explained by the WWR alone.

Whole city electricity, gas and carbon emissions.



Such results allow utility companies or district heating and cooling providers to investigate ways of predicting and reducing peak loads.

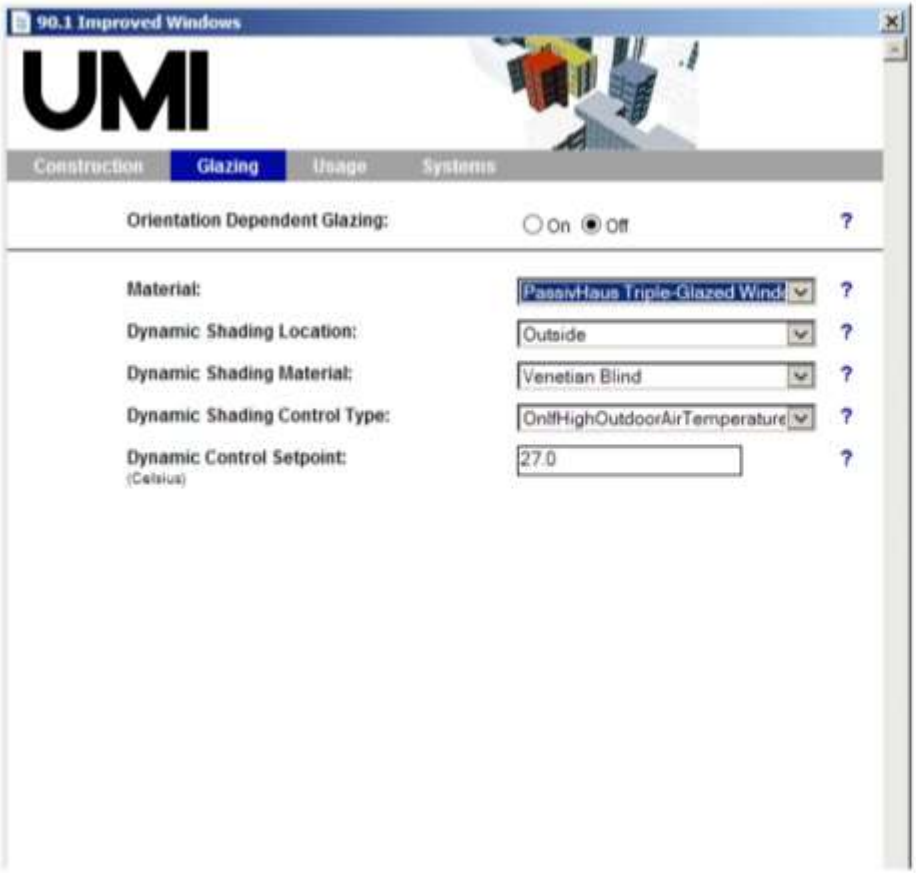
Revisiting the simulation results

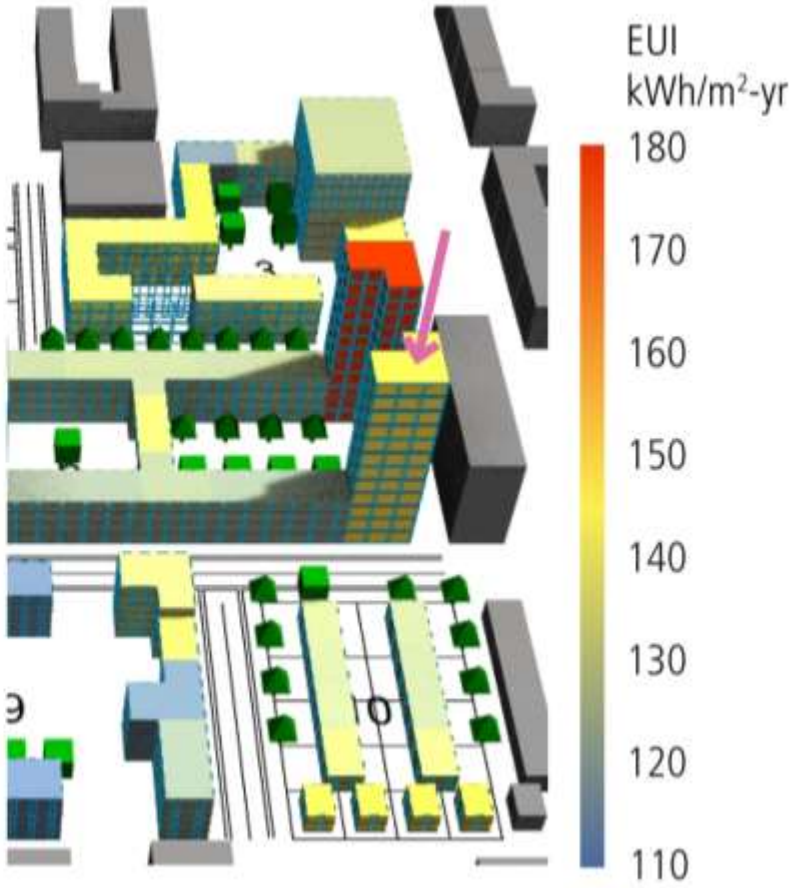


What can be done about the worst performers?
A pair of L-shaped office buildings with 75% glazed area.

Revisiting the simulation results

1. Simply require better glazing materials

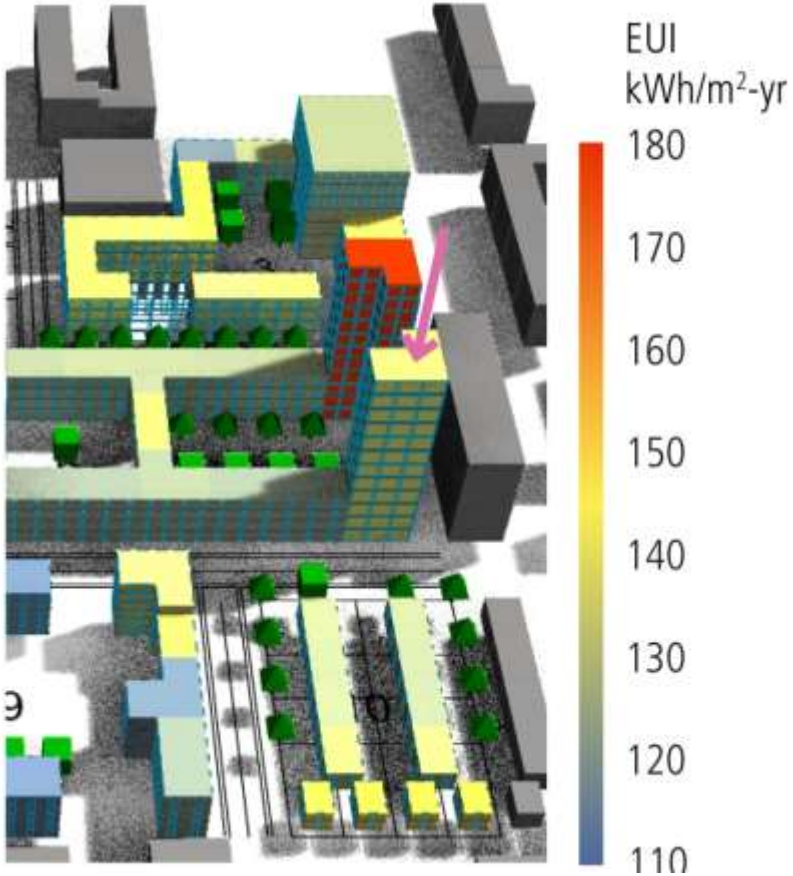




EUI: ~145 kWh/m2-yr

Revisiting the simulation results

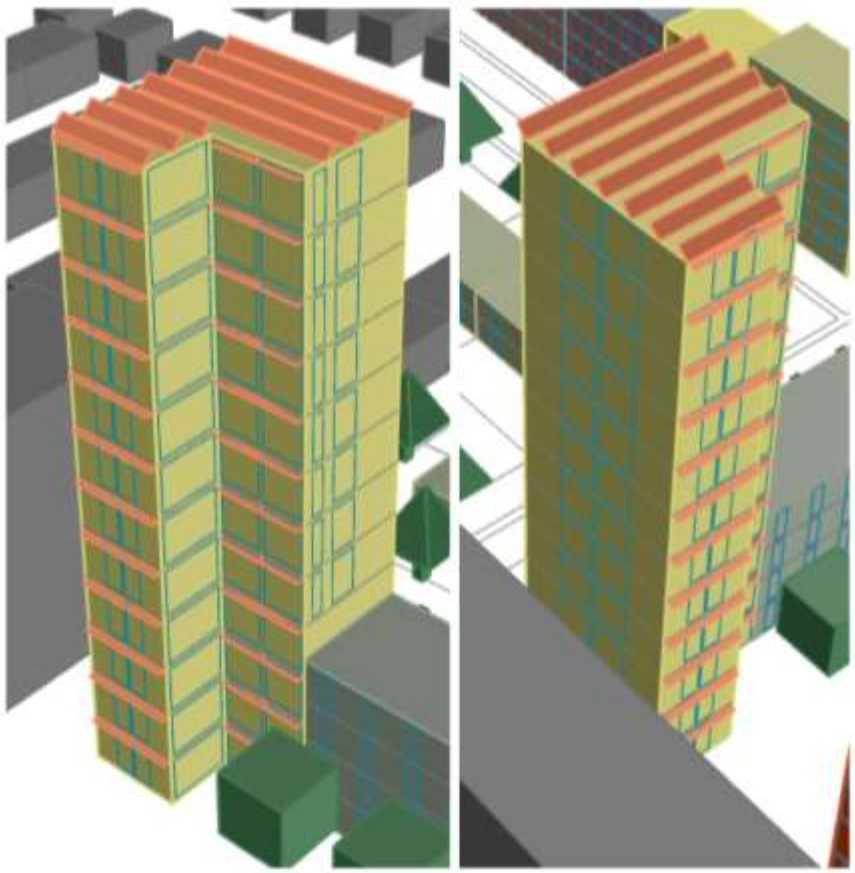
2. Add photovoltaic panels (roof&wall-mounted)

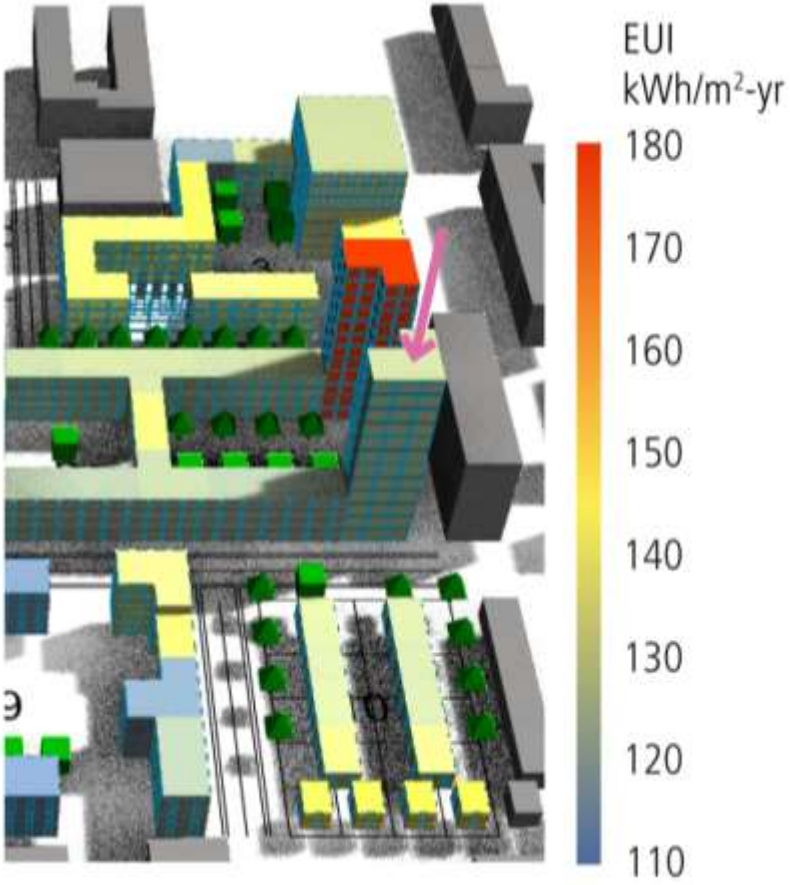


EUI: ~140 kWh/m2-yr

Revisiting the simulation results

3. Reduce WWR in less-desirable orientations.





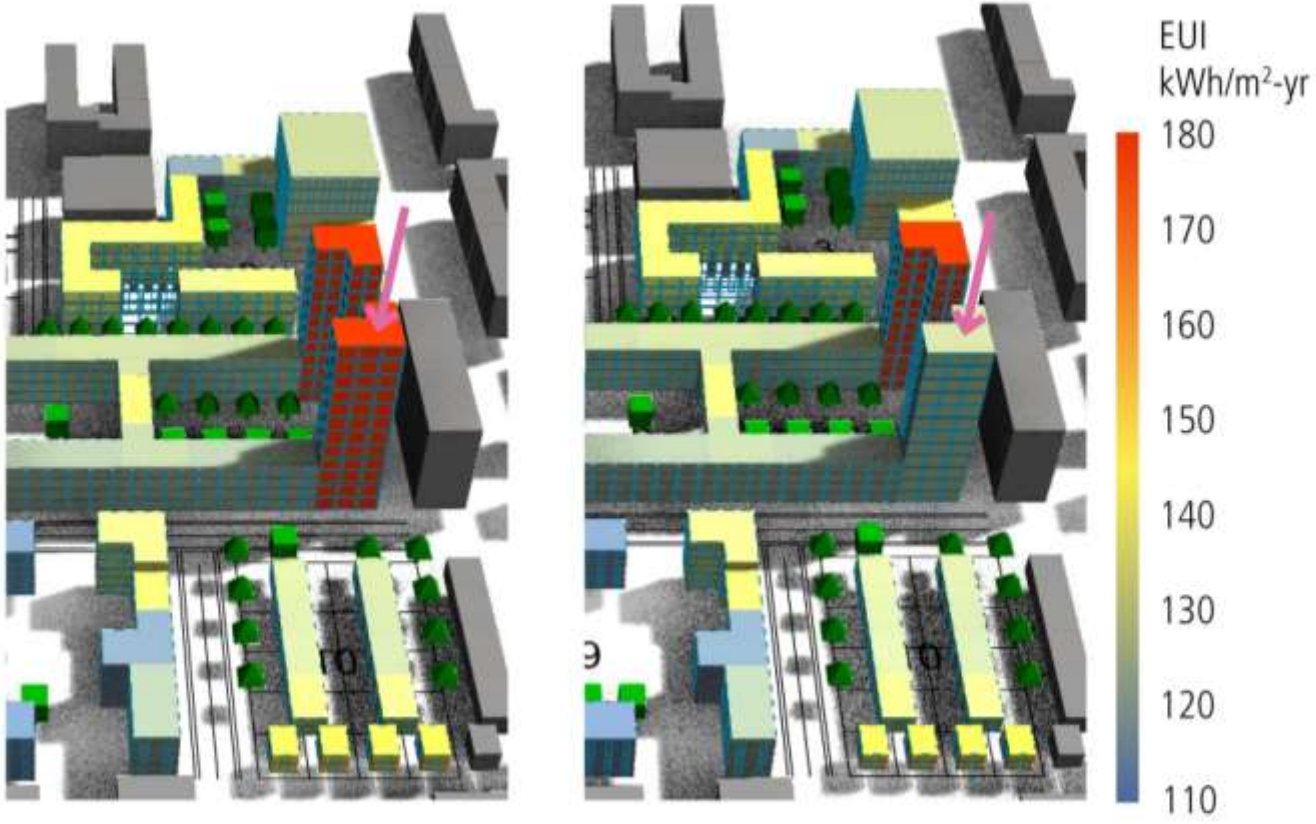
EUI: ~128 kWh/m2-yr

Revisiting the simulation results

Before and after comparison

Before (~180 kWh/m2-yr)

After (~128 kWh/m2-yr)



All of these measures can be implemented as a rule-based system using umi's templates and building setup tools.

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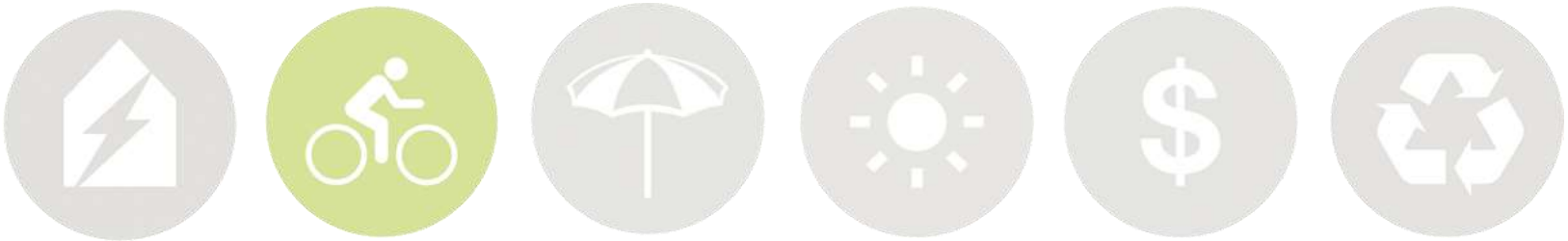
Case Studies and Design Workflows

Accessibility

Evaluating the Walkability of Cities



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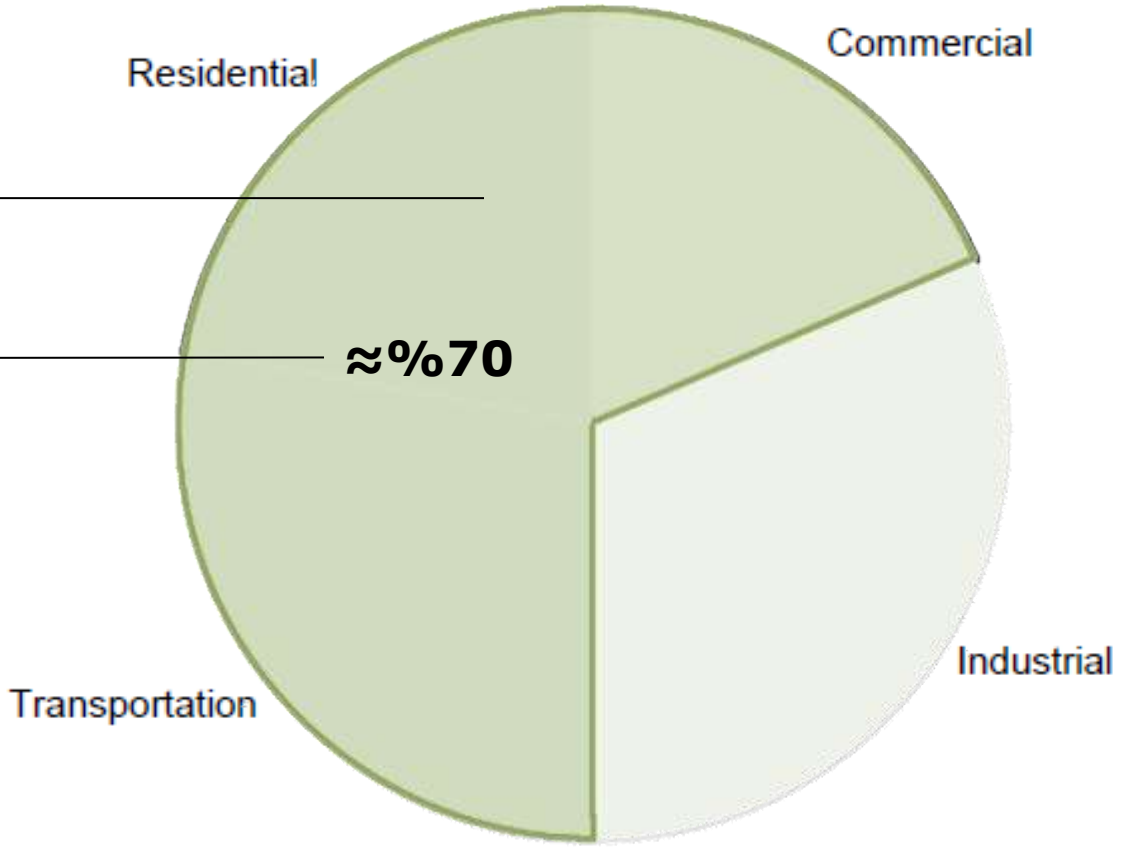
Sustainable Design Lab

Energy

End-Use Sector Shares of Total Consumption, 2011



Modeling on the Building Scale

Modeling on the Urban Scale

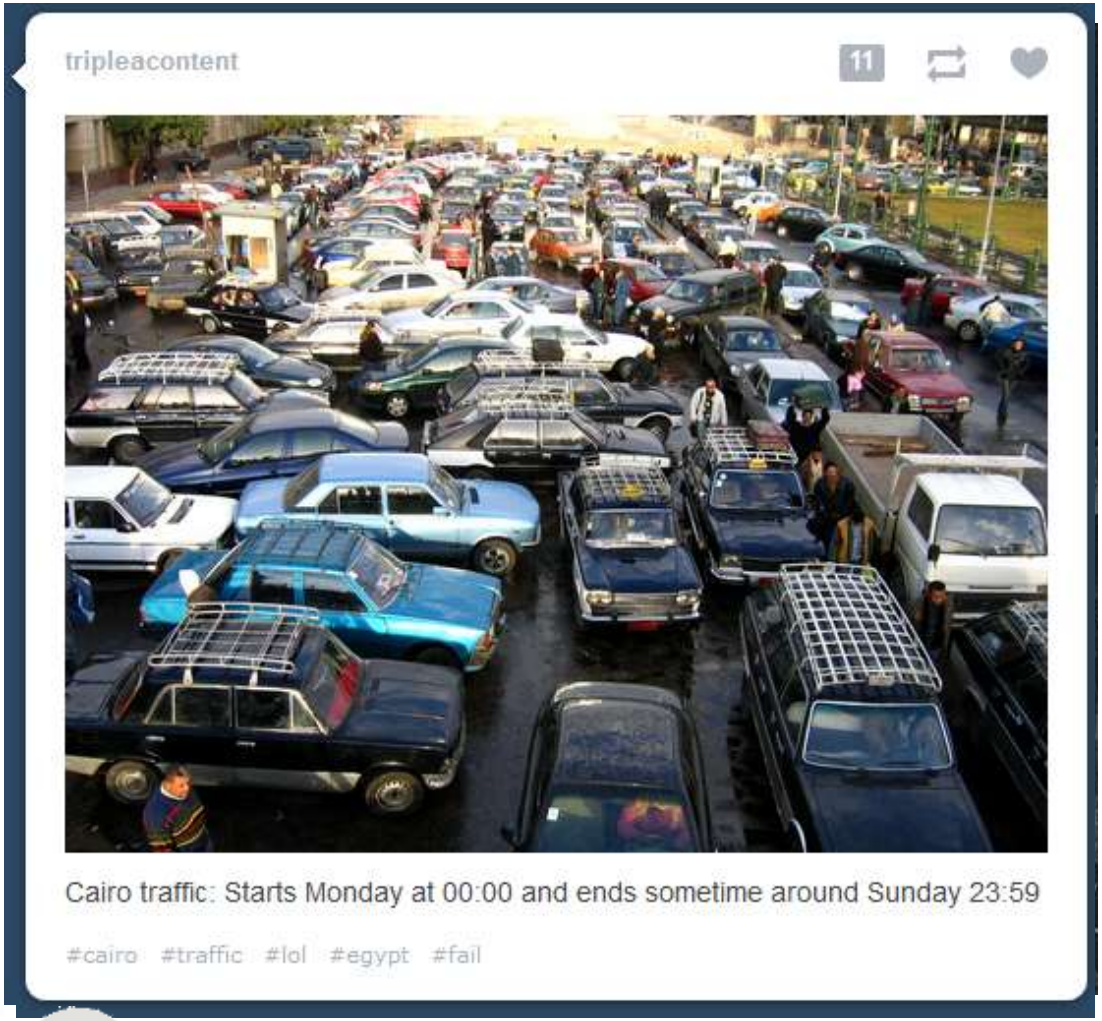
Source: EIA

What is Walkability?

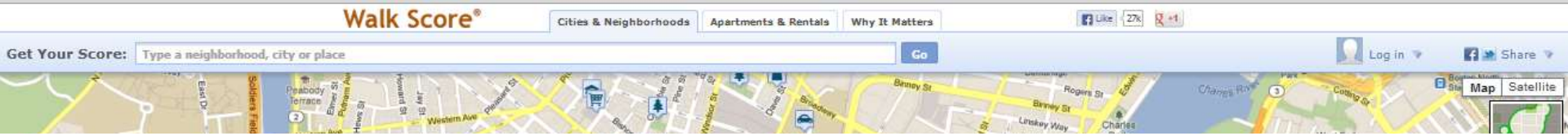
"The design of built environments that welcome and support active (human powered) transportation"

Why Walkable Cities?

- Health
- Energy
- Emissions
- Pollution
- Economics
- Livability
- Social



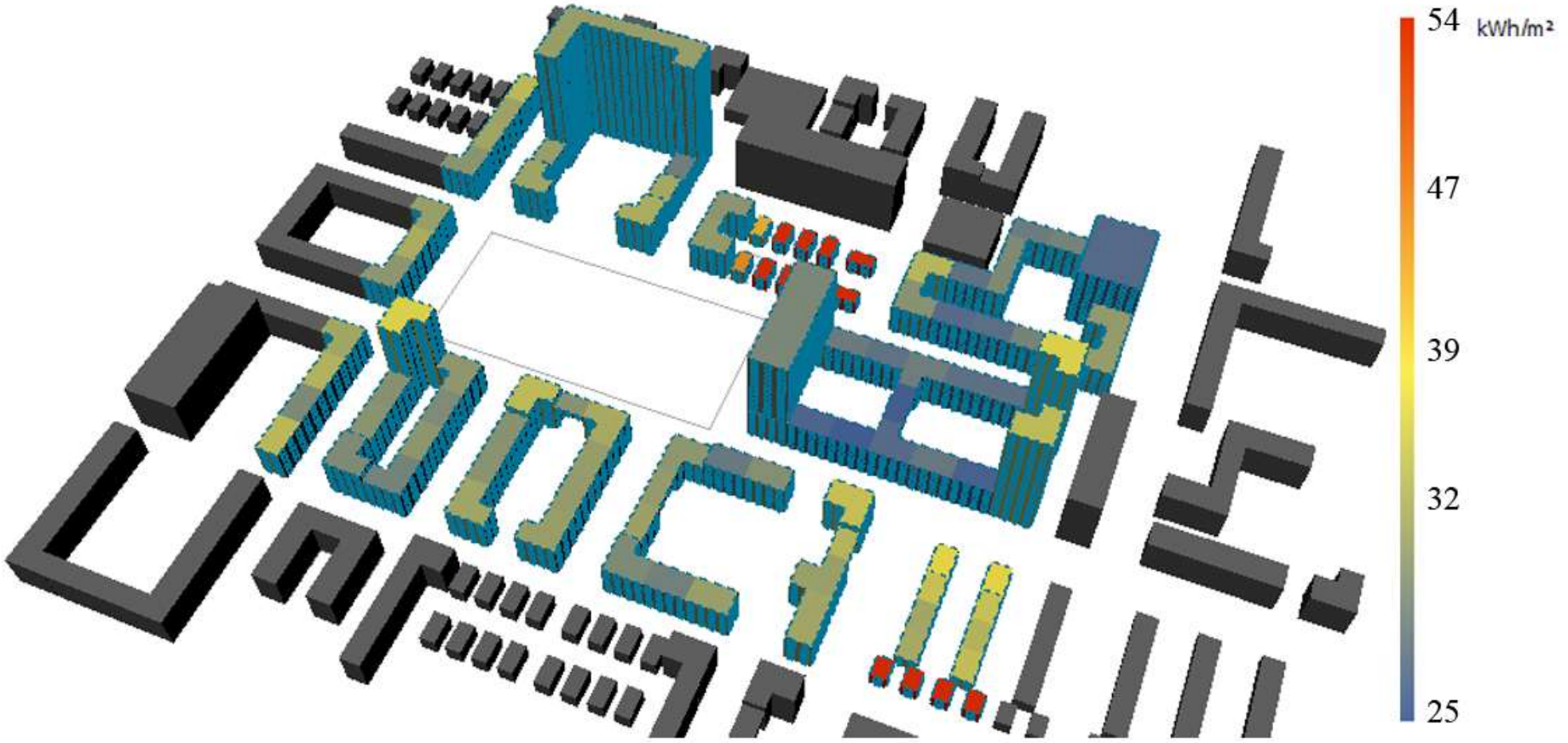
Walkscore



Walkability is linked to the density of amenities, number of intersections and block lengths.

Walkscore in umi

PassivHaus Neighborhood

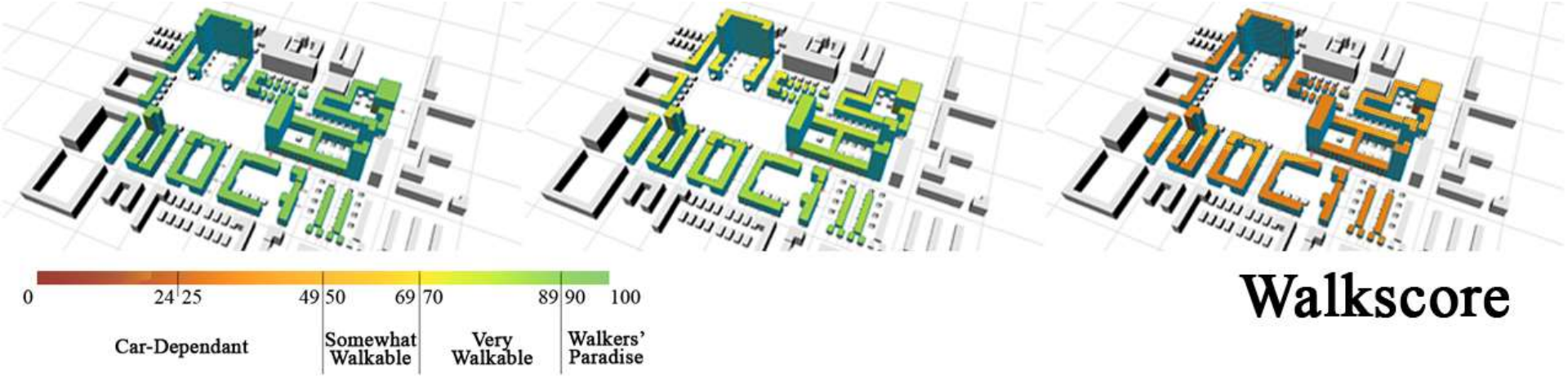


Paper Rakha, T. and Reinhart, C F., 2013. "A carbon impact simulation-based framework for land use planning and non-motorized travel behavior interactions," accepted in Building Simulation 2013, 25 -28 August, Chambery: France.

Walkscore in umi

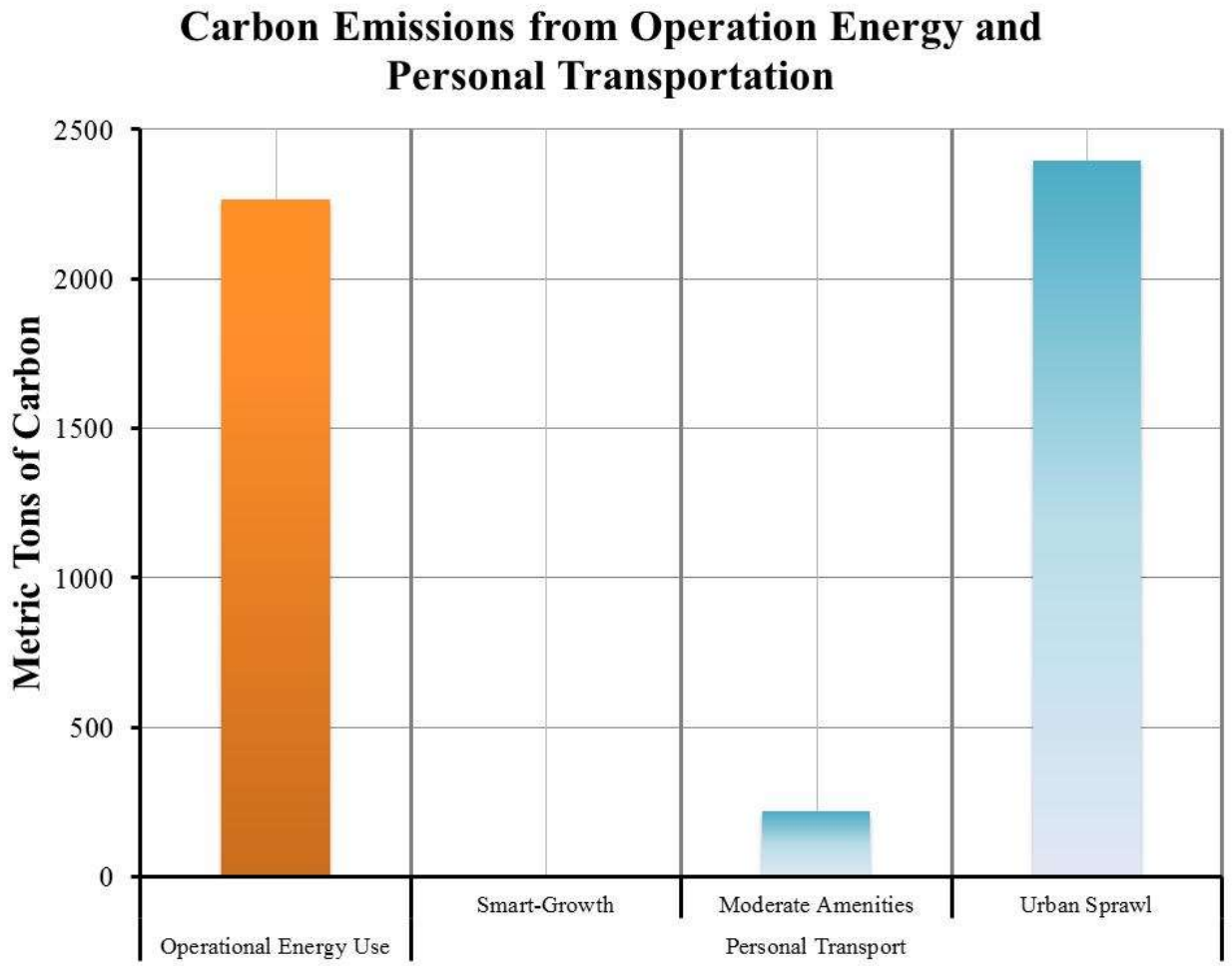
A lot of activities
eg: 4 Cafes within walking distance

No activities
eg: 1 Grocery within 2.5 miles



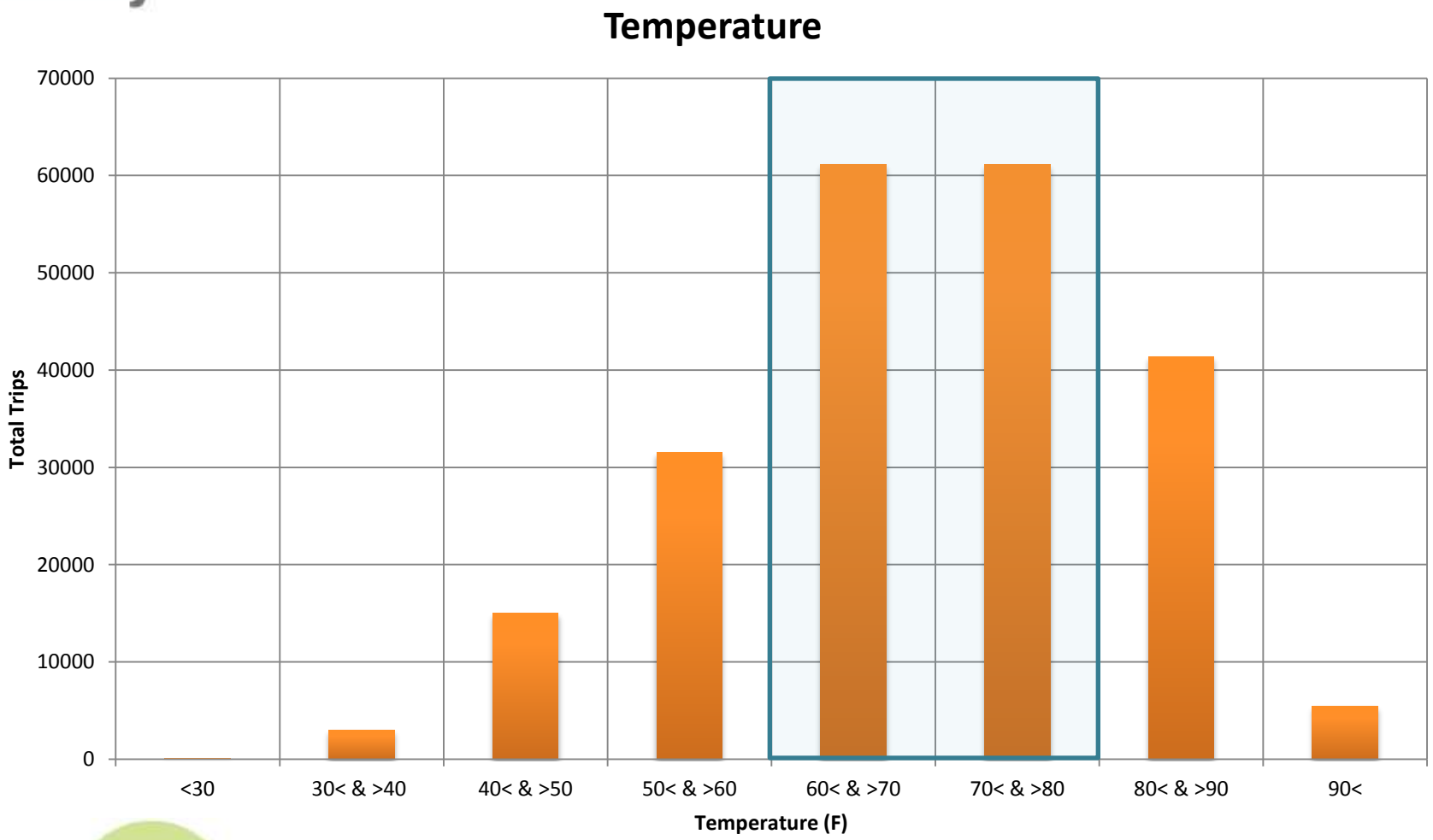
Paper Rakha, T. and Reinhart, C F., 2013. "A carbon impact simulation-based framework for land use planning and non-motorized travel behavior interactions," accepted in Building Simulation 2013, 25 -28 August, Chambery: France.

Walkscore in umi

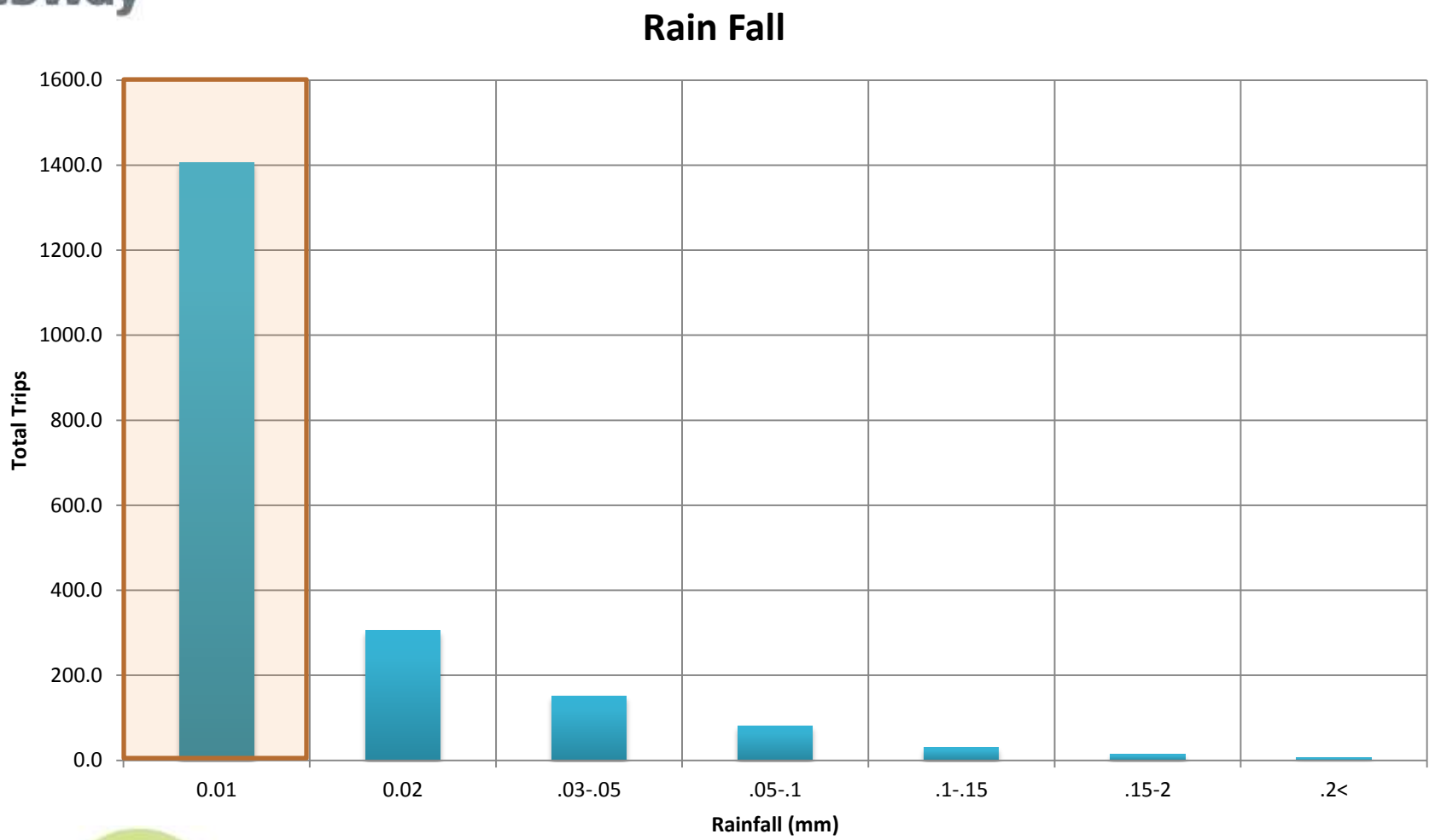


Paper Rakha, T. and Reinhart, C F., 2013. "A carbon impact simulation-based framework for land use planning and non-motorized travel behavior interactions," accepted in Building Simulation 2013, 25 -28 August, Chambery: France.

Moving Forward



Moving Forward



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umi

Outdoor Comfort

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Building Technology Program
Sustainable Design Lab

Outdoor Comfort

Fast & simple spatial mapping of comfort:

-> interesting for alternative modes of transportation

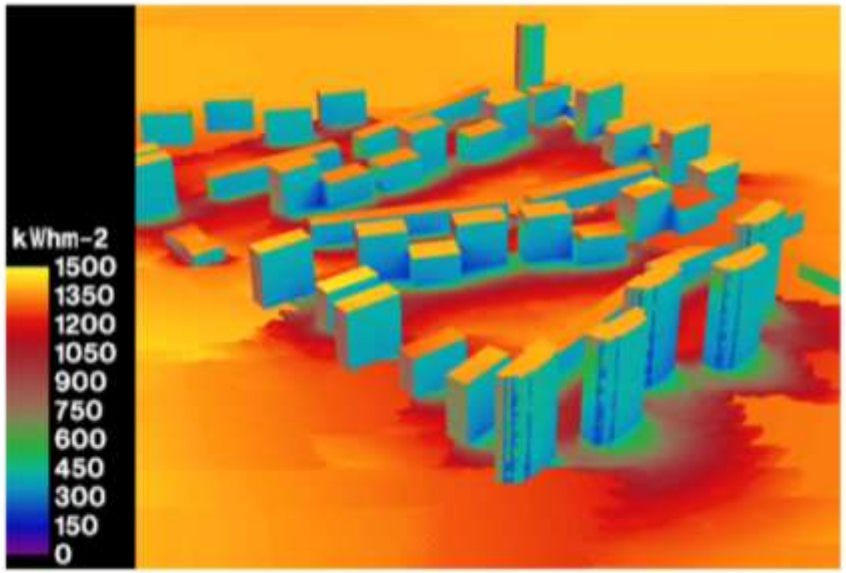
-> allocating/evaluating potentials for urban functions

Central Park NYC

Seagram Building Plaza

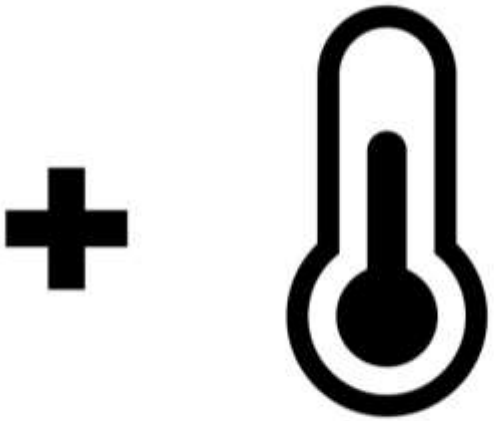
Outdoor Comfort

Hourly Solar Radiation:



-> Daysim/Radiance

Hourly Outdoor Air Temperature

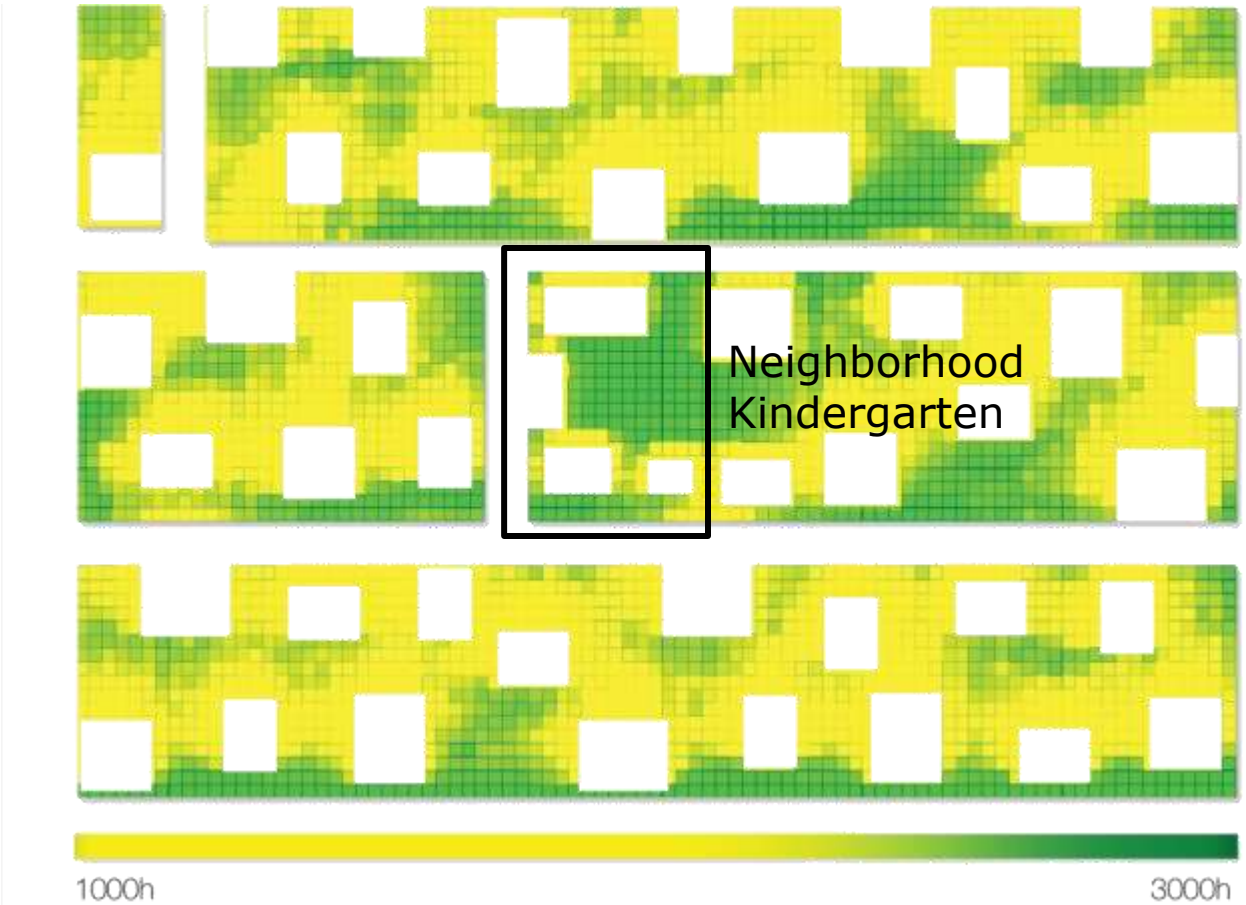


-> E+ Weather File

Huang, Jianxiang, Microclimate, Thermal Comfort, and Urban Form: Towards a Simulation Method for Design

Temperature dependent sunny hours

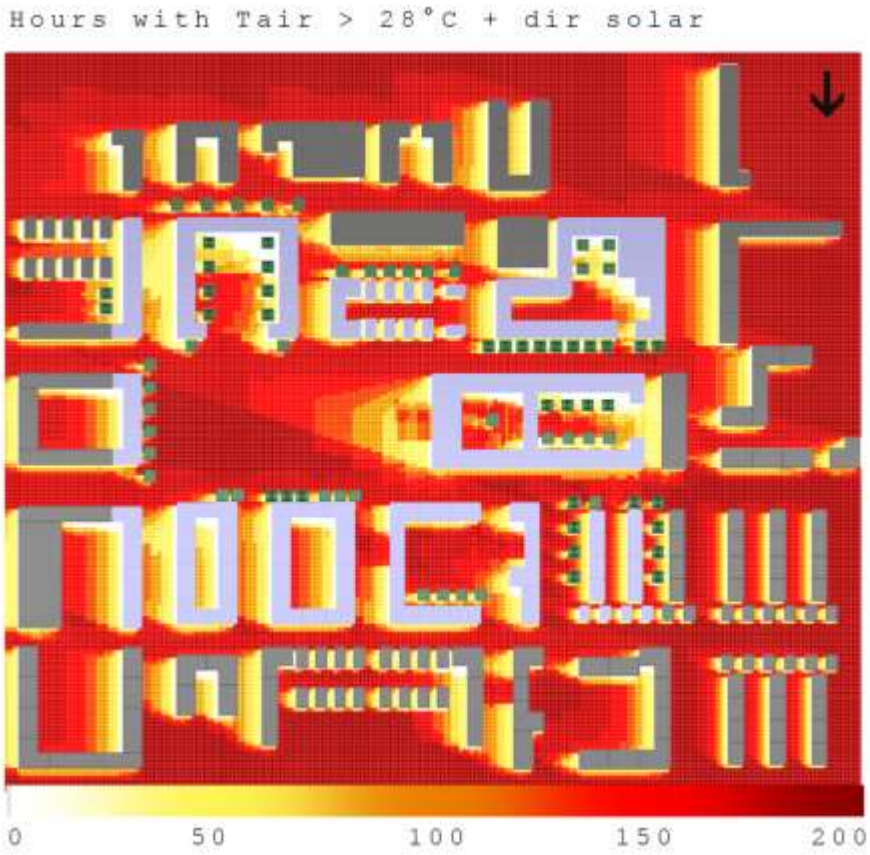
Tmin = 18C Tmax = 25C *



* Assumptions based on "The Social Life of Small Urban Spaces" by William Whyte
** Design by Sakamoto Architects

Outdoor Comfort

Tair > 28 °C & dir solar



hours / yr

Tair < 5 °C & without dir solar

hours / yr

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umi

Daylight

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Sustainable Design Lab

Motivation

Energy

Office lighting - Zumtobel, CH

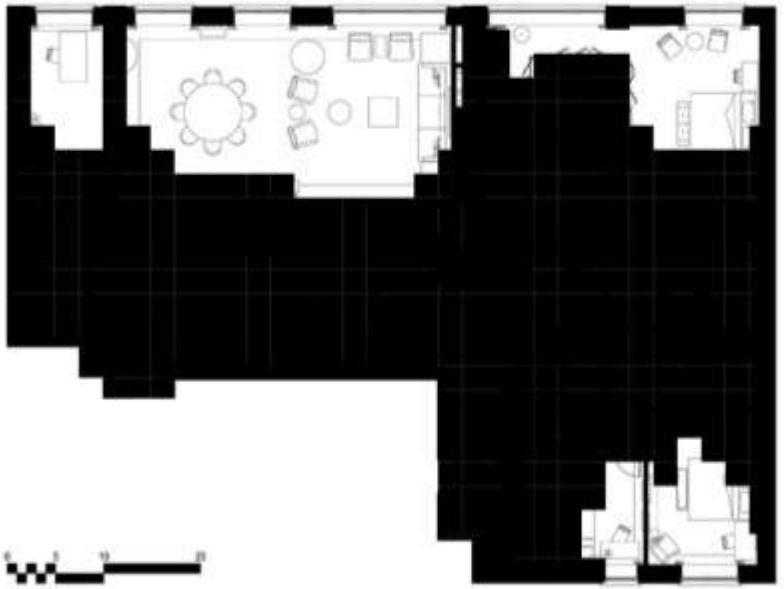
Quality of Space

Southwest facing balconies - Paris 2009

Motivation

Quality Example -> spaces with daylight access

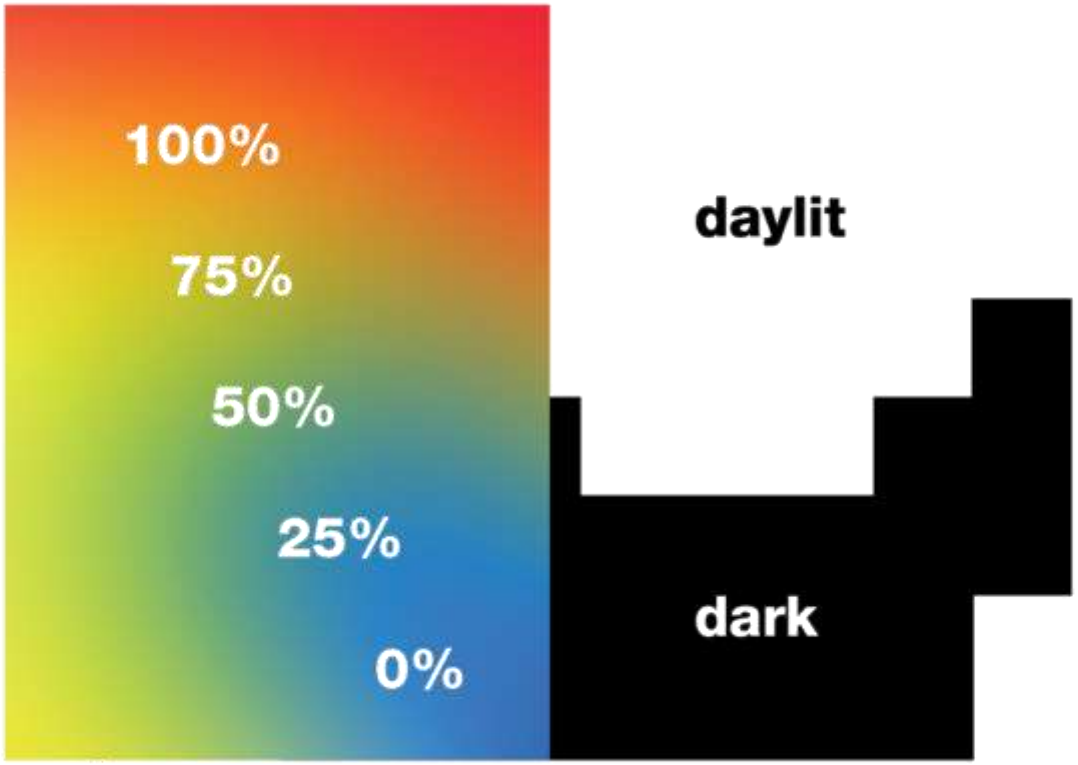
New York City apartment



spaces with daylight access

uses IES standard metrics

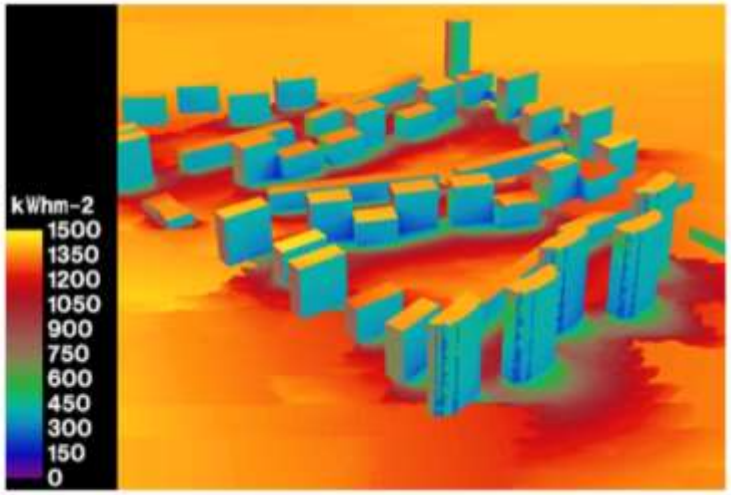
Continuous Daylight Autonomy = cDA* Spatial Daylight Autonomy = sDA**



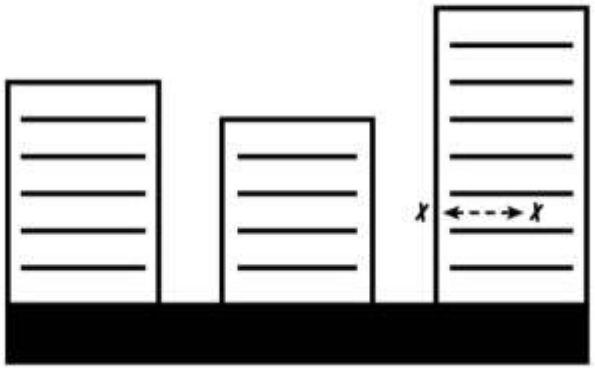
* Reinhart, Mardaljevic, Rogers, Dynamic Daylight Performance Metrics for Sustainable Building Design, Leukos Vol3 #1, July 2006, pages 7 – 3 1: www.iesna.org
** Approved Method: IES Spatial Daylight Autonomy (sDA), ISBN: 978-0-87995-272-3

For the urban scale

we need an accelerated approach



Hourly Exterior Solar Radiation*



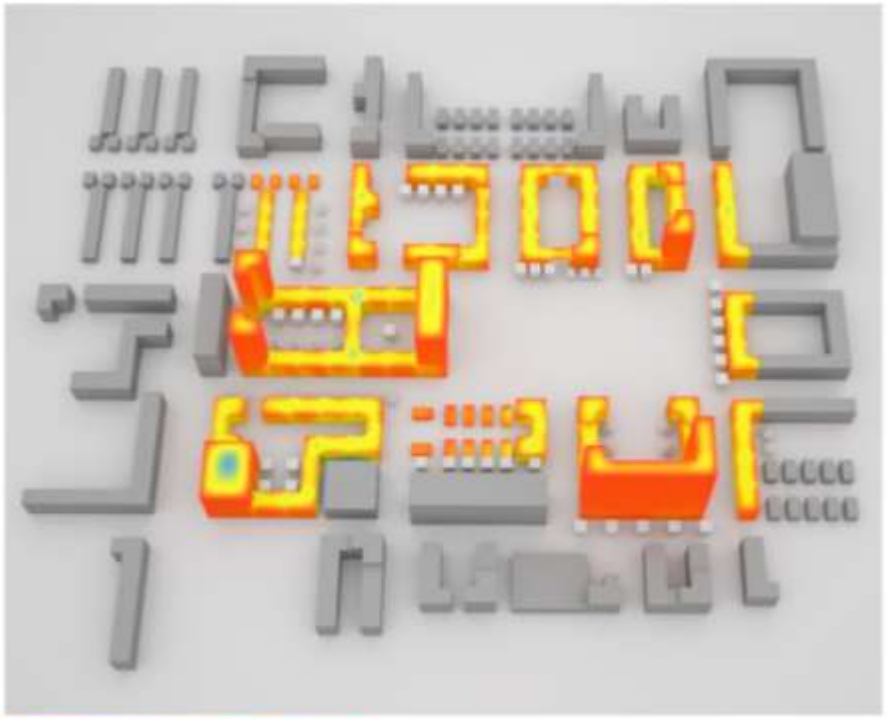
Interior light solver **

* Using Daysim/Radiance

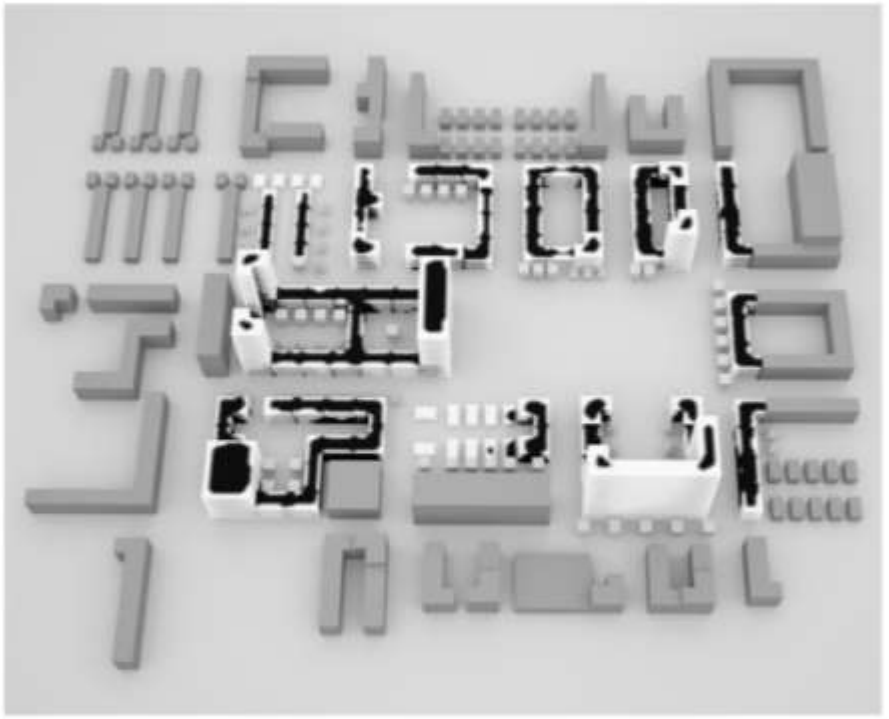
** Dogan, Reinhart, Michalatos, URBAN DAYLIGHT SIMULATION CALCULATING THE DAYLIT AREA OF URBAN DESIGNS, SimBuild 2012

umi Example / Maximum Daylight Potential

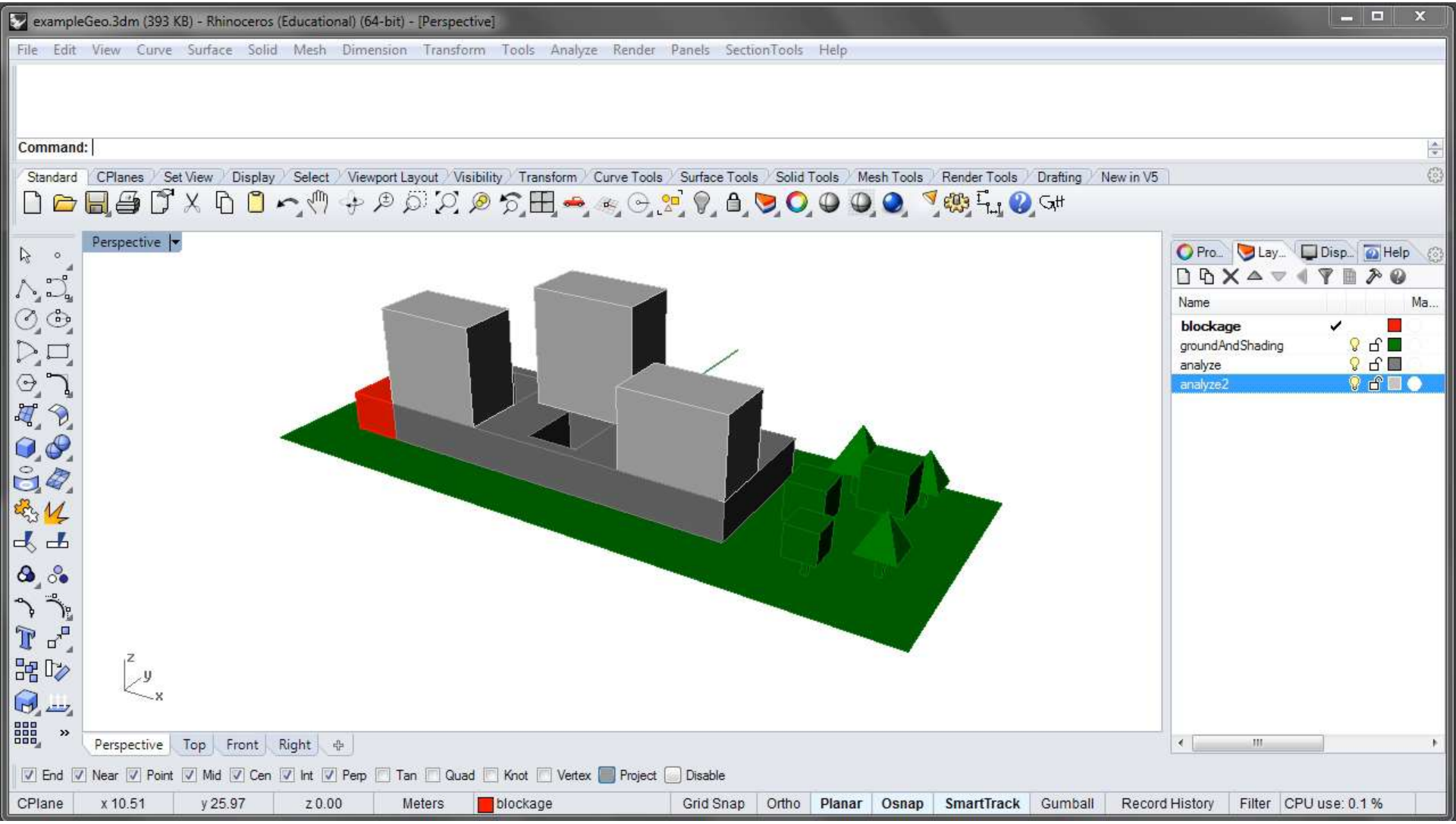
computed in less than 30 min (including model setup)



0% 100% mean cDA 58%



dark daylit Daylit Area 39%

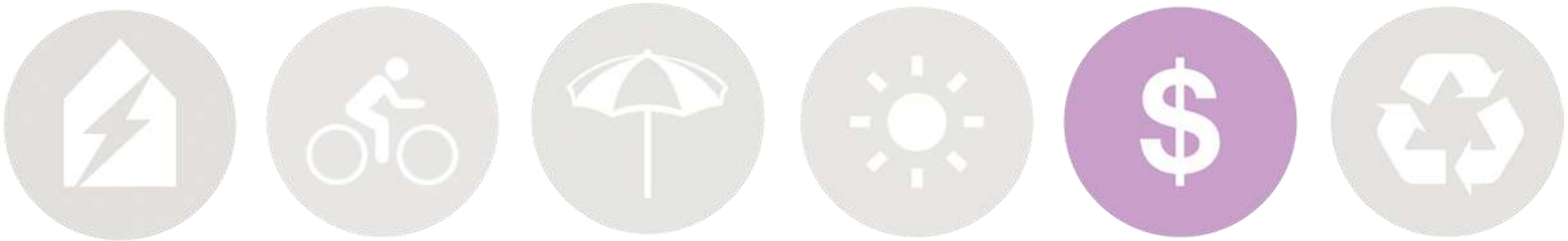

exampleGeo.3dm (393 KB) - Rhinoceros (Educational) (64-bit) - [Perspective]
File Edit View Curve Surface Solid Mesh Dimension Transform Tools Analyze Render Panels SectionTools Help
Command:
Standard CPlanes Set View Display Select Viewport Layout Visibility Transform Curve Tools Surface Tools Solid Tools Mesh Tools Render Tools Drafting New in V5
Perspective
Pro... Lay... Disp... Help
Name Ma...
blockage
groundAndShading
analyze
analyze2
Perspective Top Front Right
End Near Point Mid Cen Int Perp Tan Quad Knot Vertex Project Disable
CPlane x 10.51 y 25.97 z 0.00 Meters blockage Grid Snap Ortho Planar Osnap SmartTrack Gumball Record History Filter CPU use: 0.1 %

Symposium on Sustainable Urban Design

Case Studies and Design Workflows

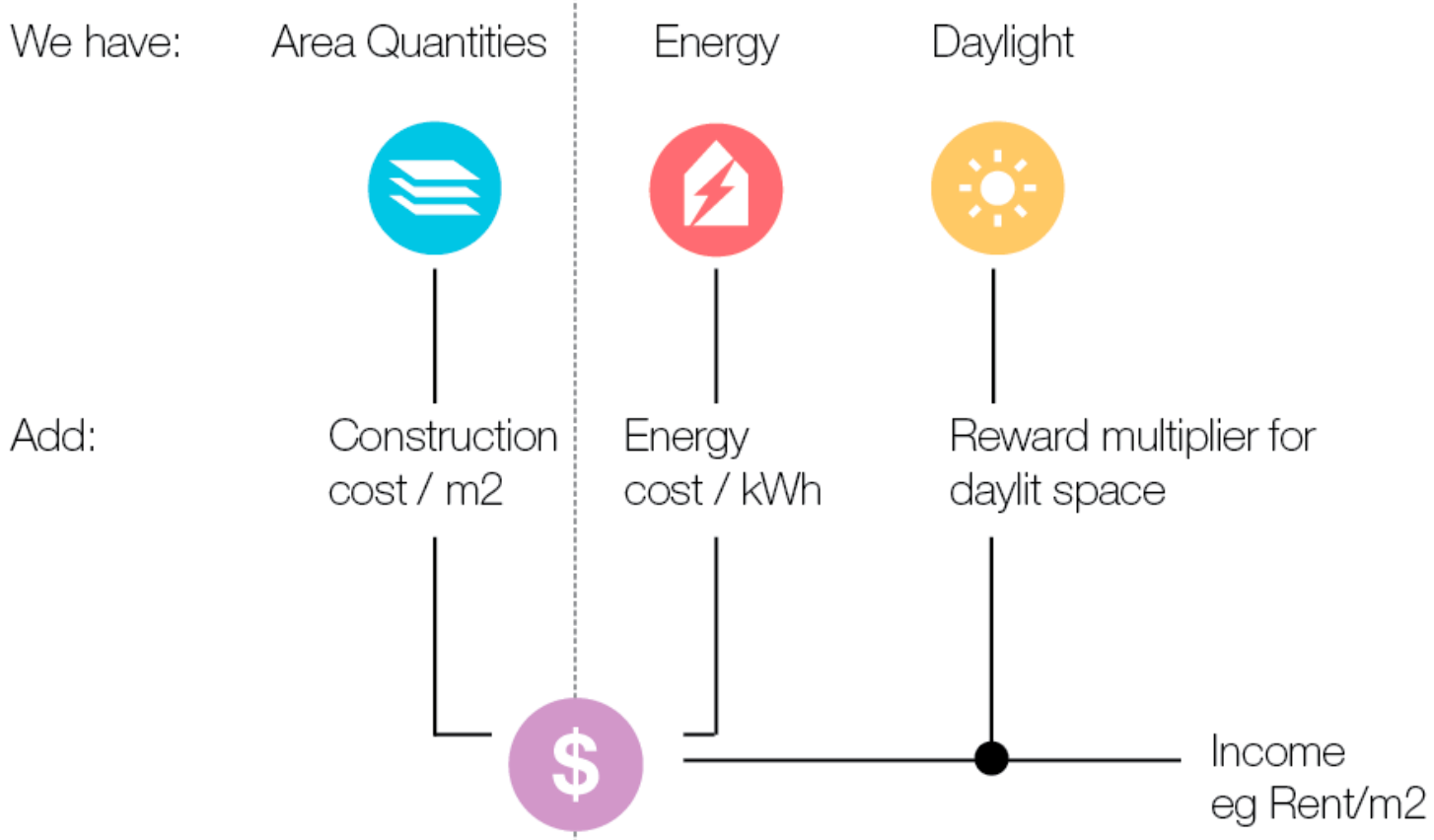
umi

Finance



Timur Dogan tkdogan@mit.edu

Massachusetts Institute of Technology
Department of Architecture
Building Technology Program
Sustainable Design Lab

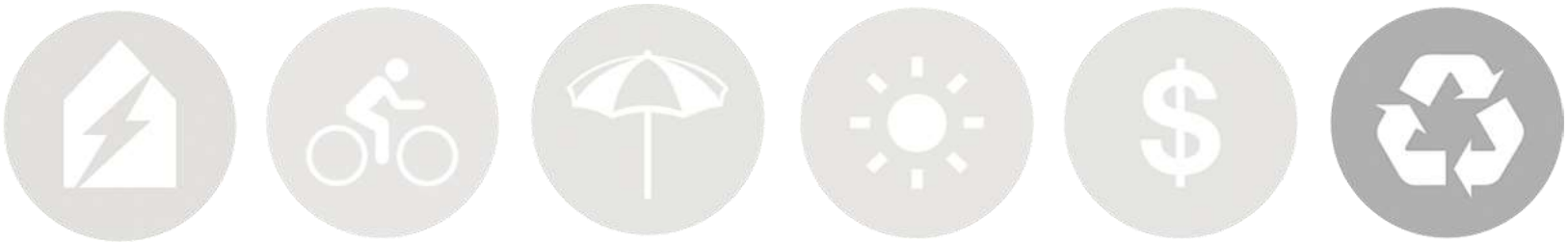


Work in progress, together with John Macomber at HBS

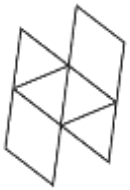
Symposium on Sustainable Urban Design

Case Studies and Design Workflows

Embodied Energy

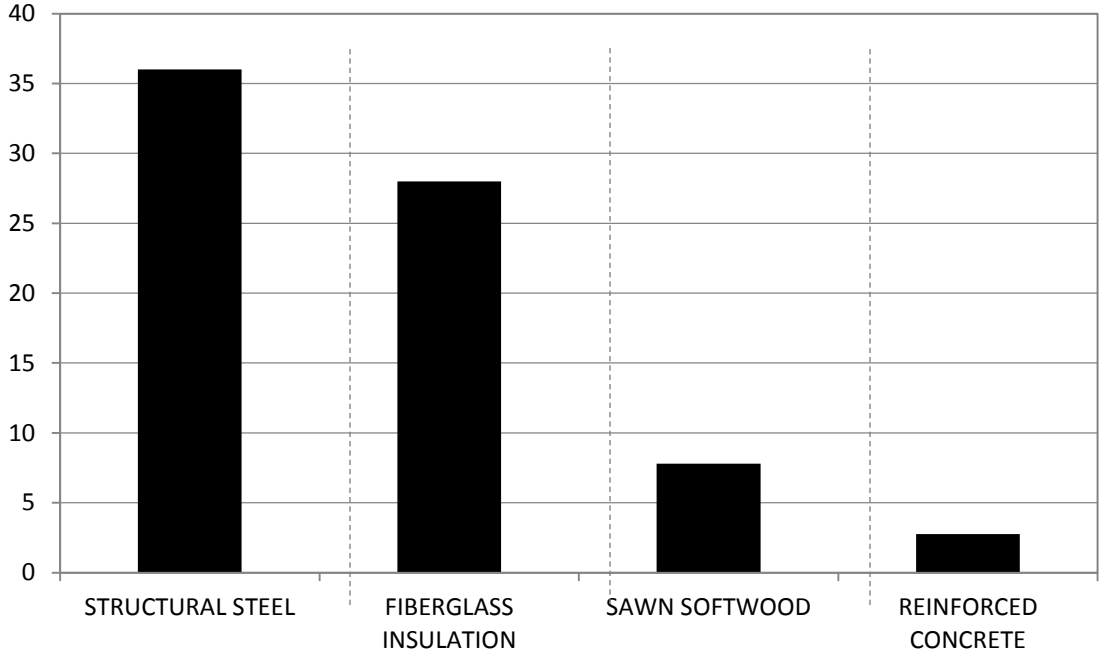


Carlos Cerezo carlos.cerezo.davila@gmail.com

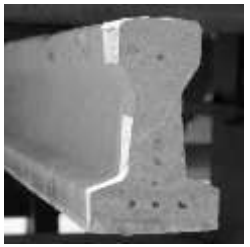


Harvard University
Graduate School of Design
Energy and Environments

Embodied Energy of Construction Materials

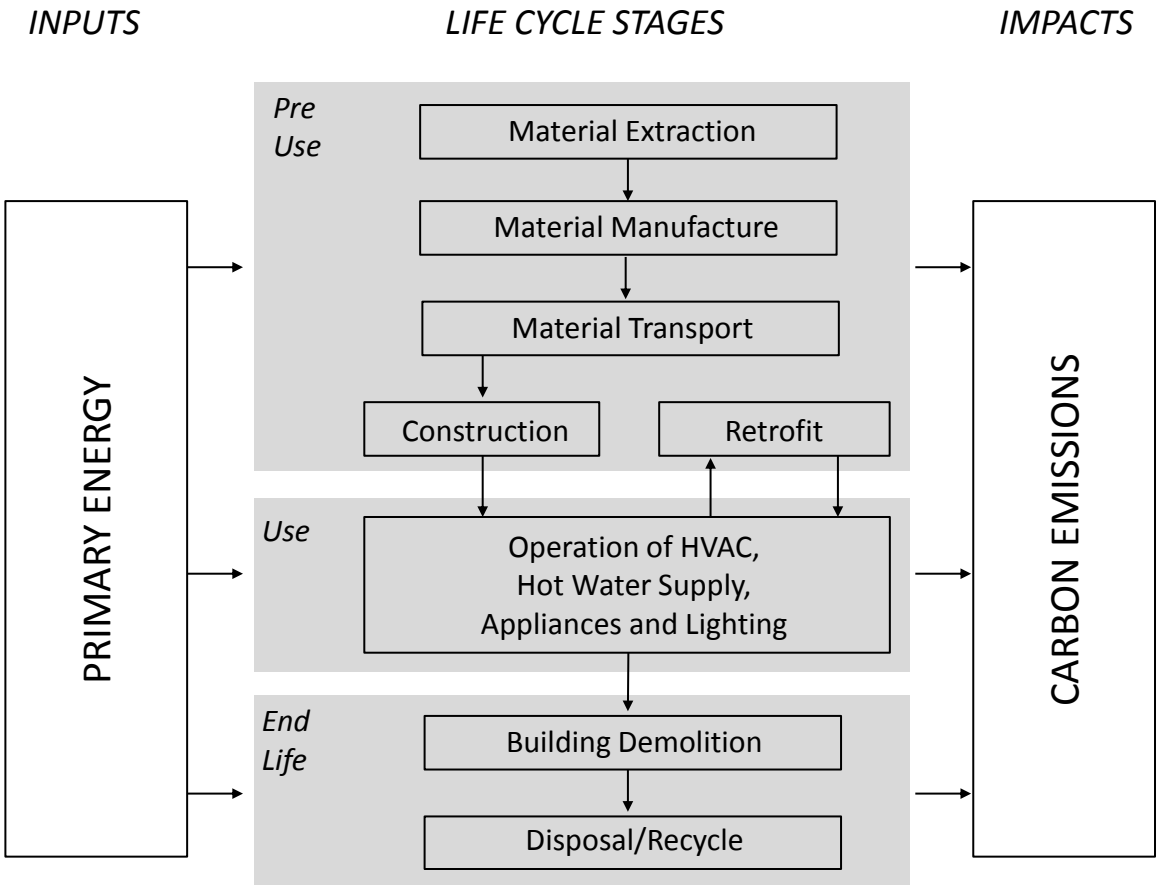




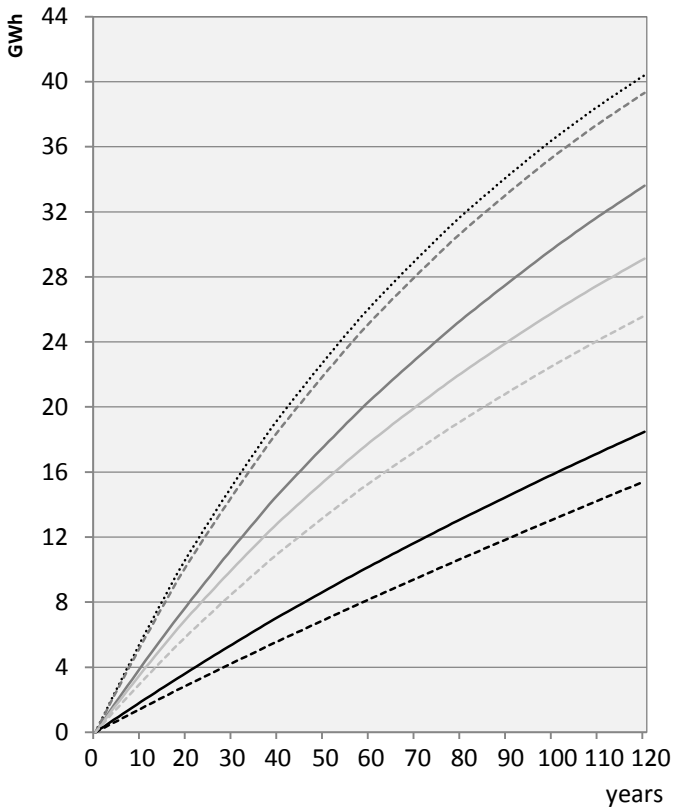
Source: G Hammond, C Jones, 2008. "Inventory of Carbon and energy (ICE)" v1.6a, University of Bath, UK

LCA Techniques for Long Term Energy Goals

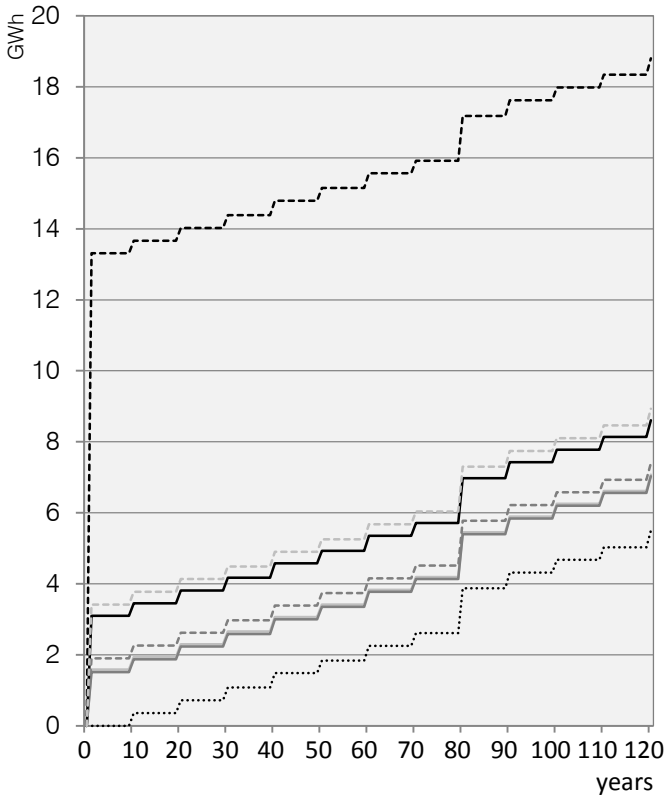


Operation Energy VS Embodied Energy

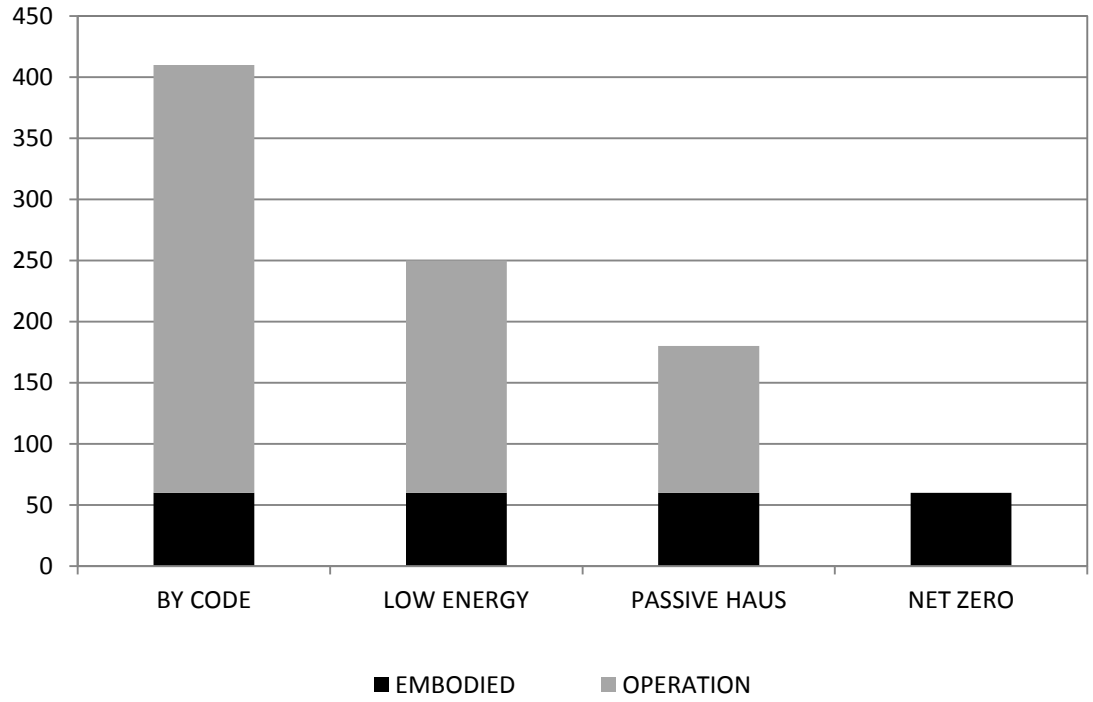
CUMULATIVE OPERATION ENERGY
Continuous input through time



CUMULATIVE EMBODIED ENERGY
Discontinuous input through time



Operation Energy VS Embodied Energy



The Embodied Energy component in a 50 years lifecycle represents 5 to 45% of the Total Primary Energy consumption of a building, depending on its performance efficiency.

Paper I Sartori, A. Hestnes, "Energy use in the life cycle of conventional and low-energy buildings: A review article", Energy and Buildings 39 (2007) 249–257

Current LCA Limitations for Urban Modeling

1. MATERIAL DATABASES UNCERTAINTY

- Lack or reliable project specific data
- Limited customization and connectivity

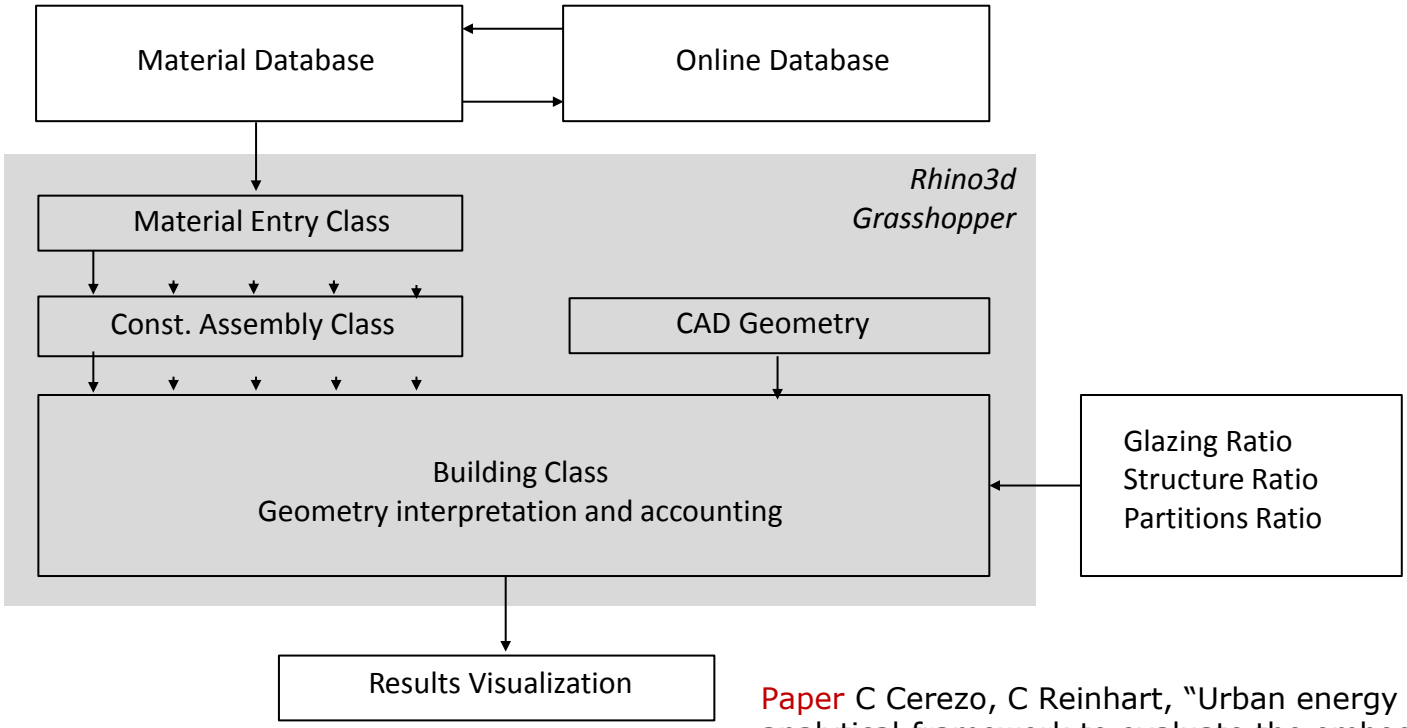
2. SOFTWARE WORKFLOW LIMITATIONS

- No connection to CAD or parametric tools
- No multiple building analysis
- No scenario modeling capabilities

SOLVED

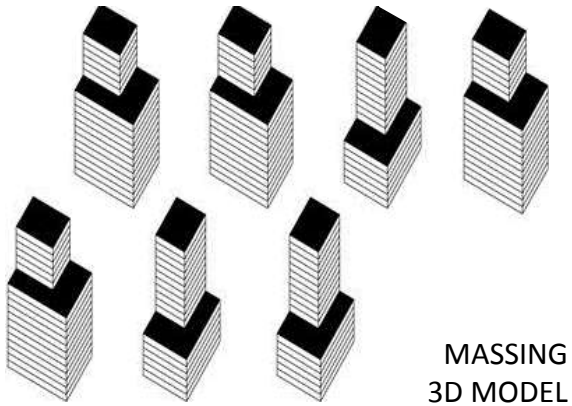
Embodied Energy CAD Workflow Proposal

umi incorporates a simplified BIM structure at the urban level to connect CAD geometry with Embodied Energy databases



Paper C Cerezo, C Reinhart, "Urban energy lifecycle: An analytical framework to evaluate the embodied energy use of urban developments", Building Simulation 2013, Chambery, France, August 2013

Embodied Energy CAD Accounting Model

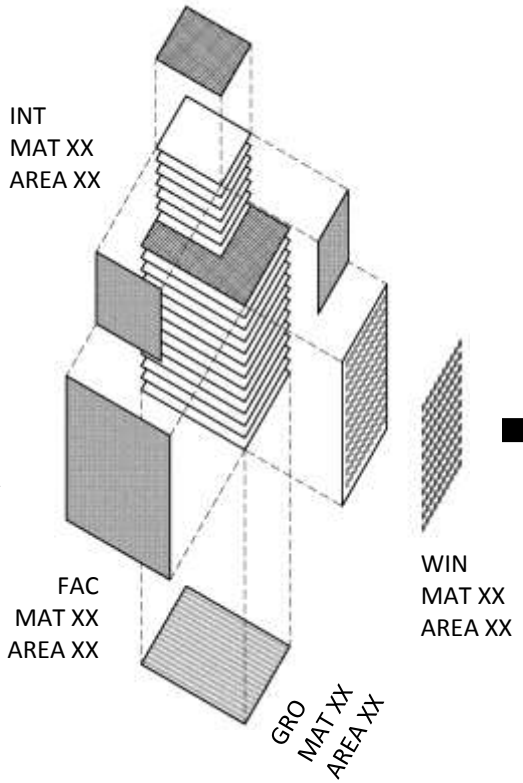


MASSING
3D MODEL

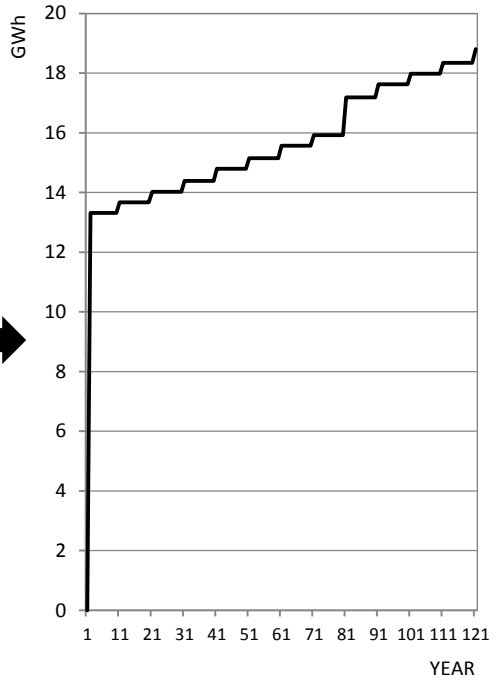
MATERIALS
DATABASE

MATERIAL ref

MAT NAME	DENSITY	EENERGY	ECARBON
"XXXXXXXX"	XXX kg/m3	XXX MJ	XXX Ton
"XXXXXXXX"	XXX kg/m3	XXX MJ	XXX Ton
"XXXXXXXX"	XXX kg/m3	XXX MJ	XXX Ton
[...]			
"XXXXXXXX"	XXX kg/m3	XXX MJ	XXX Ton

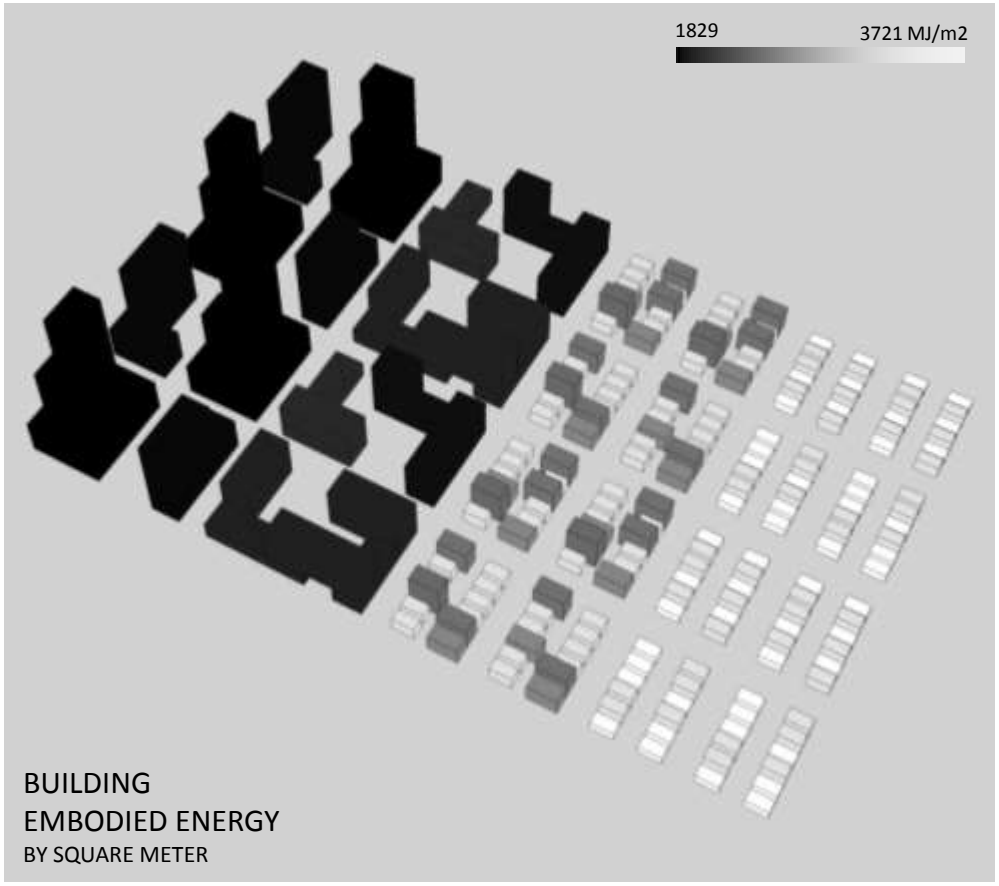


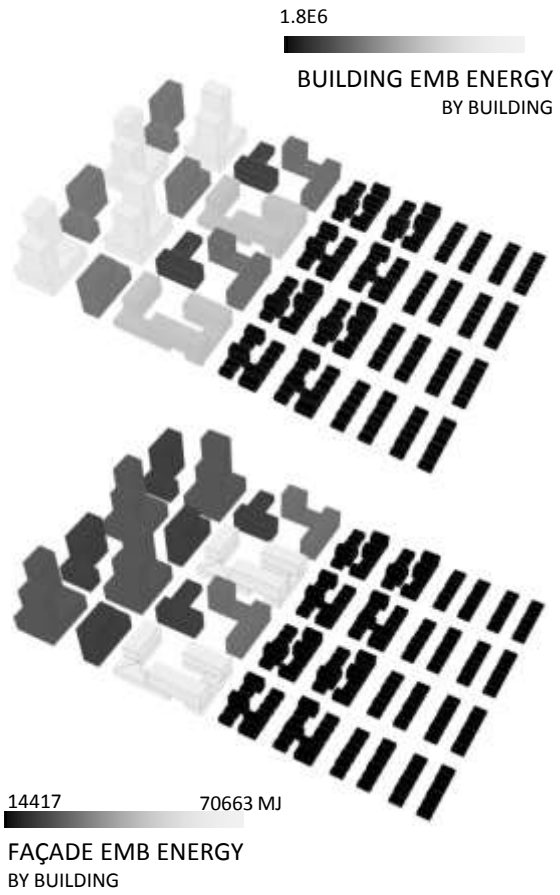
ACCOUNTING MODEL



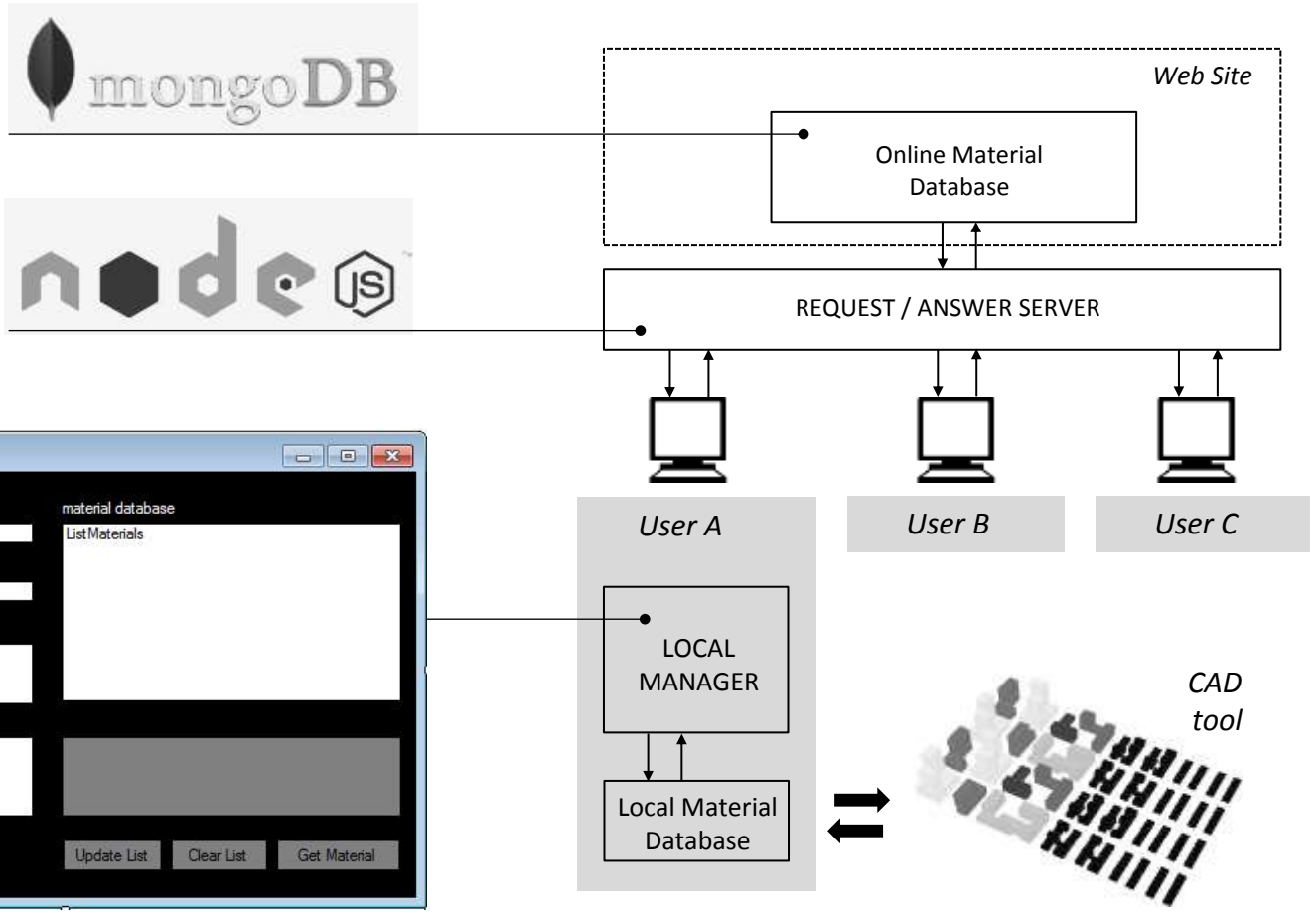
EENERGY LCA VISUALIZATION

Embodied Energy Visualization Component





Online Material Database Infrastructure



Scorecard

1.3	7.1	133	39	70	100
Density[FAR]	Cash Flow/ Construction {%}	Energy[kWh/m2 a]	Daylit Area[%]	Accessibility[%]	Comfort[%]

umi City

Mixed use neighborhood in Boston, MA