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Energy Modeling

- and implementation of -

Complex Building Systems

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Thesis Prep Fall 2014
Advisor: Bess Krietemeyer

Abstract

Complex/dynamic systems and technologies are gaining traction in architecture, but accurate analysis and simulation of conflicting dynamic systems within a building model has yet to be achieved. Most ideas of analysis and simulation revolve around a set process: model one instance of a building (i.e. without changing parameters) and analyze in a separate program. The use of a parametric base for analysis/simulation plugins, as well as an easily manipulatable and responsive model would not only further the accuracy of testing the effects of multiple dynamic systems, but become a new tool that merges model, behavior, analysis and simulation to strive for efficient implementation of these technologies and act as a platform for testing systems' compensation for introduced variables (bio-responsiveness, enviro-responsiveness, manipulability, system-responsiveness). My method for testing this system utilizes Grasshopper, which excels at: providing a base for parametric plugins linking 'static' software, using data trees for complex behavioral modeling, and easing the manipulability of a parametric model. This method for analysis and optimization would facilitate the efficient implementation of dynamic/advanced/sustainable technologies in any number of building typologies.

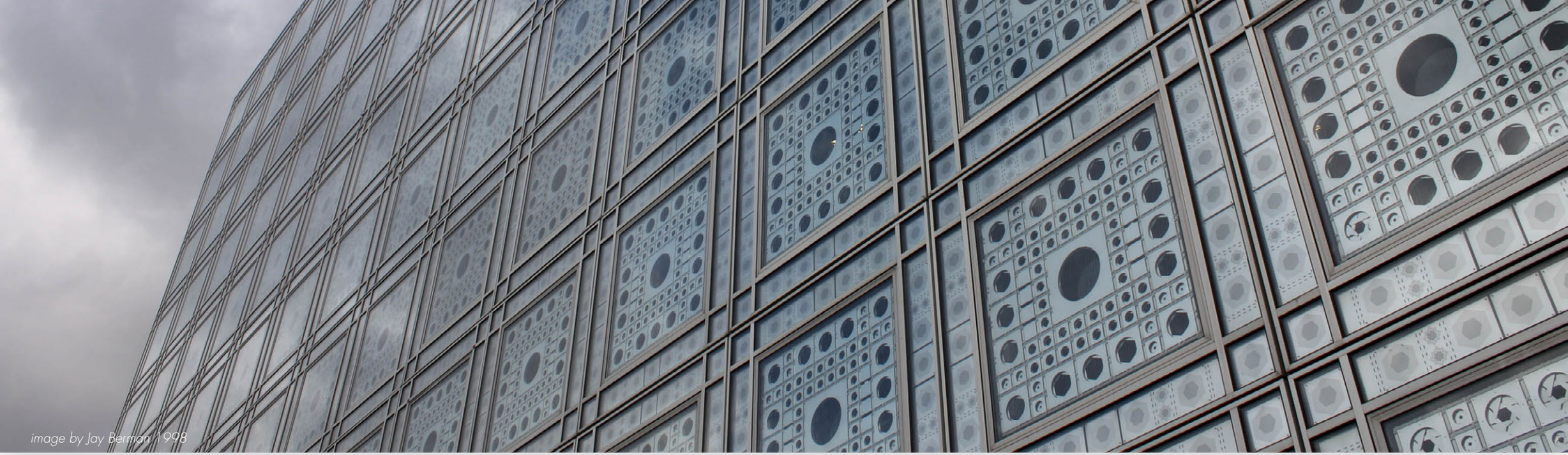


image by Jay Berman 1998

Issue of Interest

Accurate digital modeling and analysis of complex systems in architecture (across four dimensions: 1. A dynamic system affecting architectural conditions. 2. Multiple dynamic+static systems affecting architectural conditions. 3. The behavior of each system as it affects, and the resulting behavior of, architectural conditions. 4. The behavior of the dynamic systems as they respond to said architectural conditions) is, at the moment, mostly unachievable.

Simulation of complex systems and their performance holds merit within the design phase for many reasons:

Attributes of complex systems occur on a case-by-case basis. It is difficult to speculate the performance of a system before implementing it unless there is reference of a similar building type utilizing the same technology in the same way in an equivalent climate zone.

Taking this into account, an accurate simulation engine analyzing complex systems will foster more implementation: If a developer can see the system in action, he/she may be more likely to invest.

There are standards set for sustainable building design which require the analysis of complex systems pre-construction. LEED standards dictate: A whole-building energy simulation to find the minimum energy performance required & a simulation of spatial daylighting autonomy and annual sunlight exposure.

Arab World Institute - by Jean Nouvel 1987

A south-facing facade responds to lighting conditions by opening and closing motorized apertures.

Other Dynamic Systems Examples

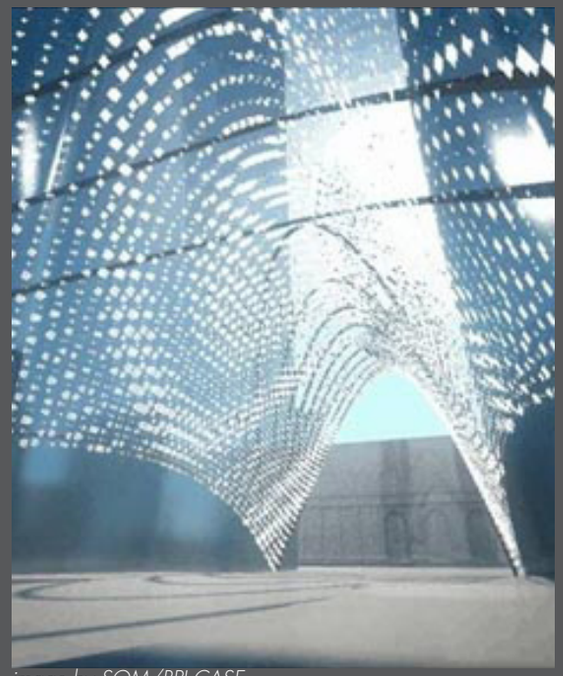


image by SOM/RPI CASE

image by David Benjamin

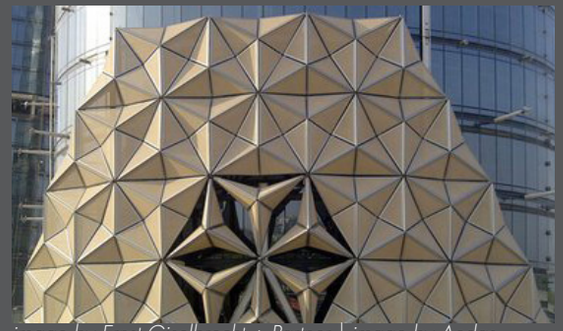


image by Ernst Giselbrecht + Partner | image by Aedas

Current question on dynamic systems:

1. How do we simulate the impact of these systems pre-construction?

2. How do we simulate theses systems' reactions to results from [1]?

3. How do we analyze data from simulation [2] to impact the use of the system?

Electroactive Dynamic Display Systems (EDDS)

With the potential to be bioresponsive, enviroresponsive, manually operated, dynamic or static, EDDS can be generalized to a manipulatable/ controlled facade of 'pixels' which can be turned transparent or opaque. On a building scale, this would affect interior air quality/temperature, and daylighting levels, and the system has potential as interior partitions, providing an atmospheric effect.

The Living: Breathing Facade

Flexible wall that 'breathes' according to shifting conditions outside. It could also be used as a system for interior airflow control. It is enviroresponsive.

Kiefer Technic Showroom & Al Bahr Towers

Both buildings utilize manipulative facades which can emulate a design strategy or simply be a performative aspect for the building.

Current Strategies

Daylighting/thermal/air quality/etc analysis and simulation software tools currently exist to accurately map out any number of pre-construction conditions. Two main software examples include EnergyPlus and OpenStudio, both developed/funded by the US Department of Energy, which import .idf digital models with .epw weather models for site to accurately analyze specified zones of a building. Within these programs are thousands of preset implementable building standards, from programmatic-based usage schedules, to HVAC systems.

Typical methods of achieving whole [or partial] building simulations rely on completed digital models which are exported to the aforementioned software tools for analysis. The resulting simulation only provides faults, and not recommendations for improvements.

More recent attempts, such as those by Christoph Reinhart, combat this model-then-analyze ideology. Plugins developed for 3D modeling programs facilitate the link between model and analysis/results in a way that allows the designer to keep manipulating parameters on the model until a desired analysis result is achieved.

EnergyPlus

EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model energy and water use in buildings. Modeling the performance of a building with EnergyPlus enables building professionals to optimize the building design to use less energy and water.

EnergyPlus models heating, cooling, lighting, ventilation, other energy flows, and water use. EnergyPlus includes many innovative simulation capabilities: time-steps less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, water use, natural ventilation, and photovoltaic systems.

-energy.gov

OpenStudio

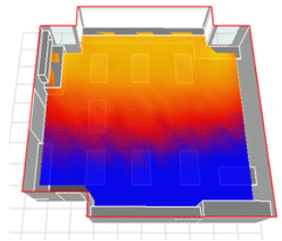
OpenStudio is a cross-platform collection of software tools to support whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance.

-openstudio.nrel.gov

Radiance

Radiance is a suite of programs for the analysis and visualization of lighting in design. There are no limitations on the geometry or the materials that may be simulated. Radiance is used by architects and engineers to predict illumination, visual quality and appearance of innovative design spaces, and by researchers to evaluate new lighting and daylighting technologies.

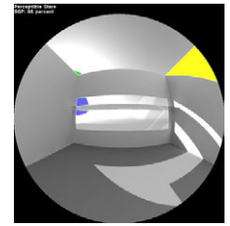
-radsite.lbl.gov/radiance/



DaySim

DAYSIM is a Radiance-based daylighting analysis software that models the annual amount of daylight in and around buildings. DAYSIM allows users to model dynamic facades systems ranging from standard venetian blinds to state-of-the-art light redirecting elements, switchable glazings and combinations thereof. Users may further specify complex electric lighting systems and controls including manual light switches, occupancy sensors and photocell controlled dimming.

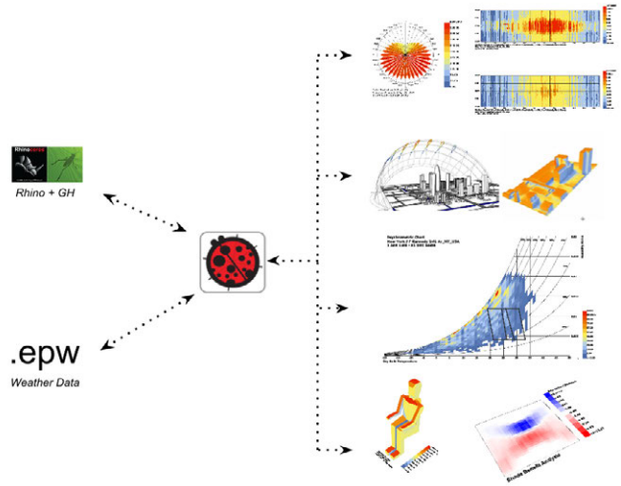
-daysim.ning.com



EvalGlare

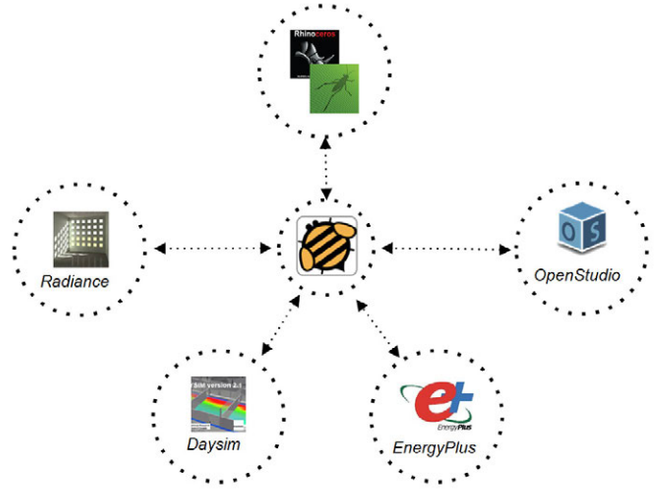
A Radiance-based tool to evaluate daylight glare in office spaces.

Grasshopper Plugins:



Ladybug

Ladybug is an open source environmental plugin for Grasshopper3D that helps architects and engineers create an environmentally-conscious architectural design. Ladybug imports standard EnergyPlus Weather files (.EPW) into Grasshopper and provides a variety of 3D interactive graphics to support the decision-making process during the initial stages of design.



Honeybee

Honeybee connects Grasshopper3D to EnergyPlus, Radiance, Daysim and OpenStudio for building energy and daylighting simulation. The Honeybee project intends to make many of the features of these simulation tools available in a parametric way.

ArchSim Energy Modeling for GH

Similar to Honeybee, Archsim Energy Modeling is a plugin that brings fully featured EnergyPlus simulations to Rhino/Grasshopper and thus links the EnergyPlus simulation engine with a powerful parametric design and CAD modeling environment. Archsim allows you to effortlessly create complex multi-zone energy models, simulate them and visualize results without ever switching between tools.

-archsim.com

UrbanDaylighting

Uses Radiance & daysim to simulate daylighting of large urban designs.

-archsim.com

DIVA for Rhino: GH Plugin

DIVA-for-Rhino is a highly optimized daylighting and energy modeling plug-in for Rhino and Grasshopper. DIVA-for-Rhino allows users to carry out a series of environmental performance evaluations of individual buildings and urban landscapes.

-diva4rhino.com

Reinhart Method for Daylighting Simulation

MIT Lecture: Daylighting Course

Goal: Assess the luminous environment in daylit spaces via simulation.

The scene consists of a three-dimensional geometric model of the investigated daylit object(s) including optical material descriptions for all surfaces in the scene.

Areas of interest in the scene can be selected viewpoints and/or discrete sensors such as a grid of upward facing illuminance sensors.

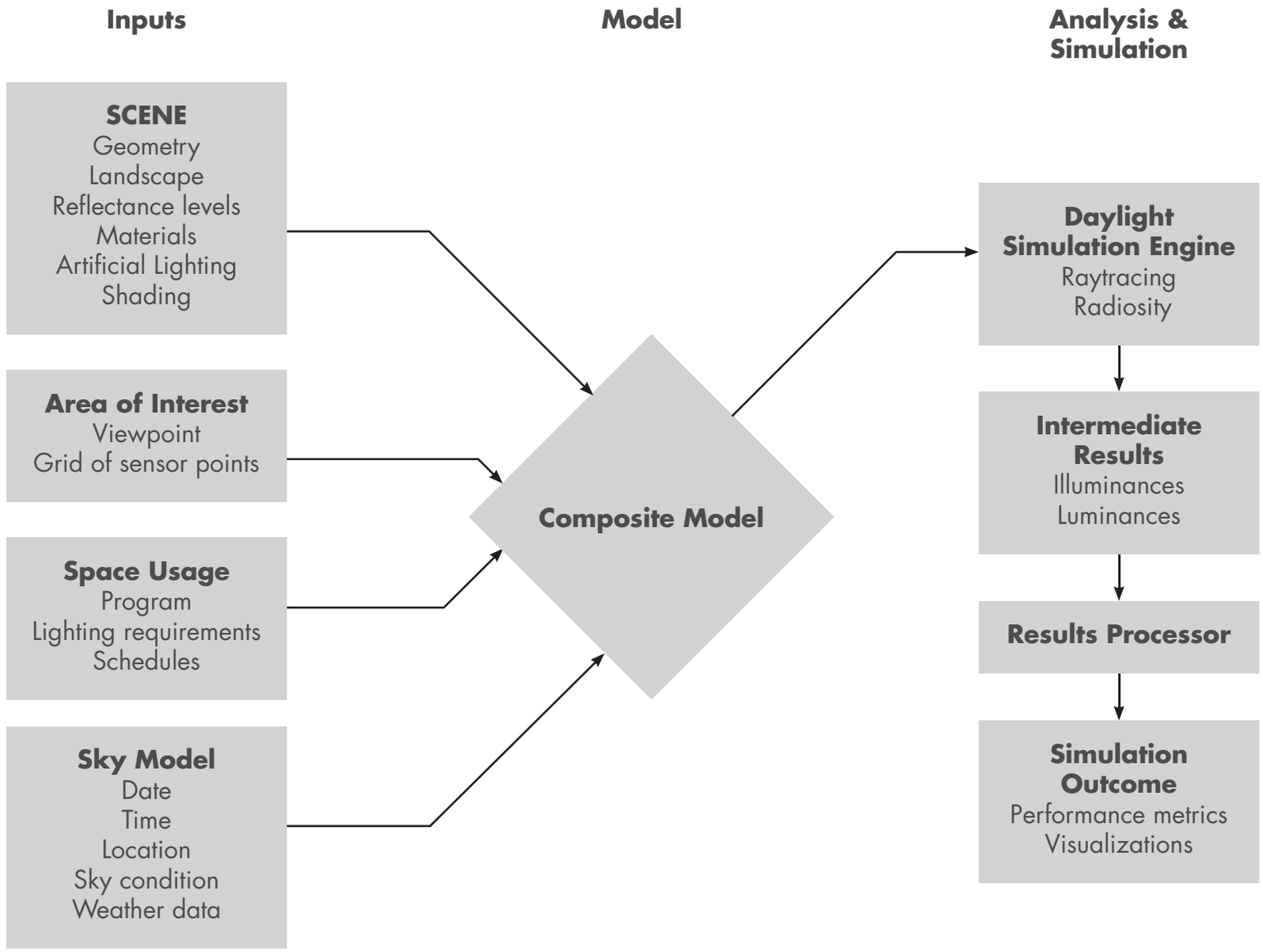
Space usage information describe the type of space investigated (office, classroom,...), required lighting levels and occupancy schedules.

The sky model quantifies the amount of direct sunlight and diffuse daylight coming from the different parts of the celestial hemisphere.

The composite model brings all information together into one defined set of data for export to the analysis/simulation engines.

The daylight simulation engine combines the sky model with the scene and calculates illuminances and/or luminances within the scene.

The results processor translates the raw simulation results into a format that can directly inform design decisions. Example formats are scene visualizations and false color maps of the daylight factor and/or other performance metrics including daylight autonomy and useful daylight illuminance



Reinhart Method Inputs

MIT Lecture: Daylighting Course

Goal: Assess the luminous environment in daylit spaces via simulation.

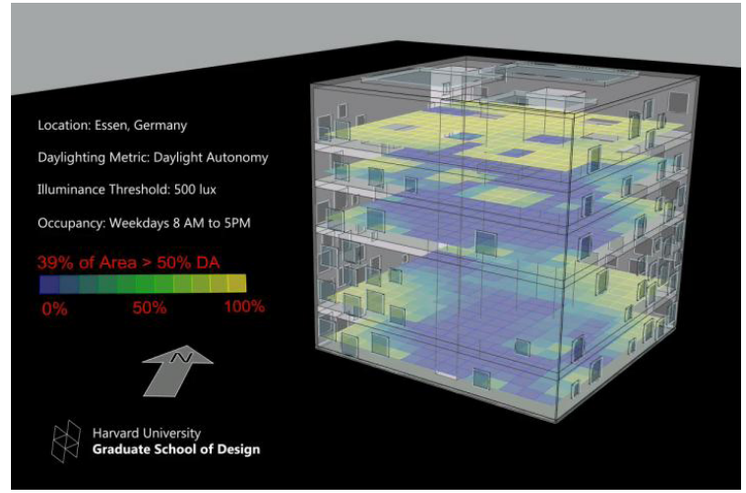
Inputs

SCENE
Geometry
Landscape
Reflectance levels
Materials
Artificial Lighting
Shading

Area of Interest
Viewpoint
Grid of sensor points

Space Usage
Program
Lighting requirements
Schedules

Sky Model
Date
Time
Location
Sky condition
Weather data



Reinhart Example (above):

Scene:
Skylights: Parametric controls
Windows: Parametric controls (cannot be changed when skylights are being changed).
Defined building form (unchangeable).

Area of Interest:
14X14 grid per floor = 980 total analysis nodes

Space Usage:
Weekdays 8am-5pm

Sky Model:
Indoor daylighting levels under overcast skies (info provided)

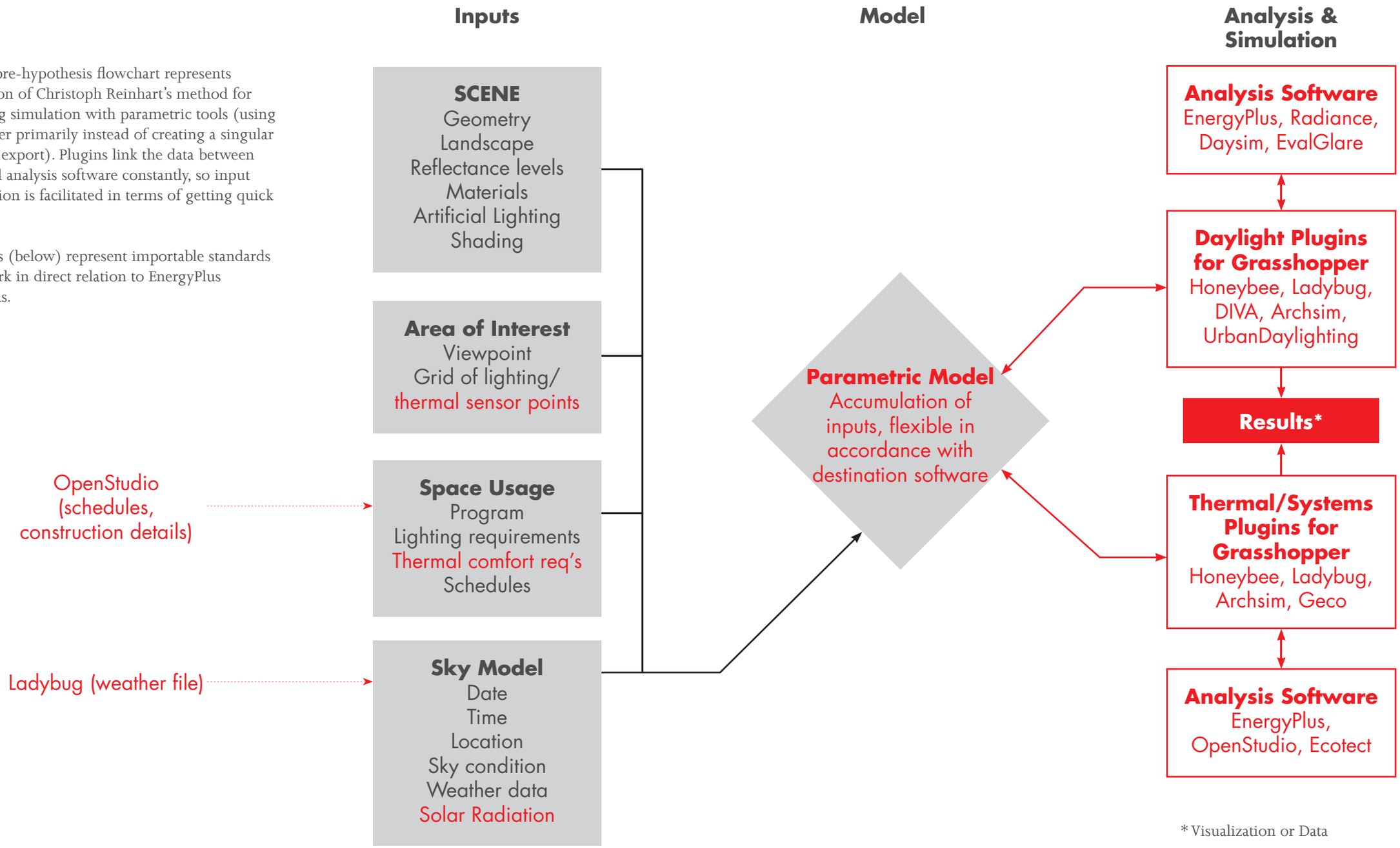
Hypothesis

The use of a parametric base for analysis/ simulation plugins, as well as a new component which facilitates behavioral modeling, would not only further the accuracy of testing the effects of multiple dynamic systems, but become a new tool that merges model, behavior, analysis and simulation to strive for efficient implementation of these technologies and a platform for testing systems' compensation for introduced variables (bio-responsiveness, enviro-responsiveness, manipulability etc).

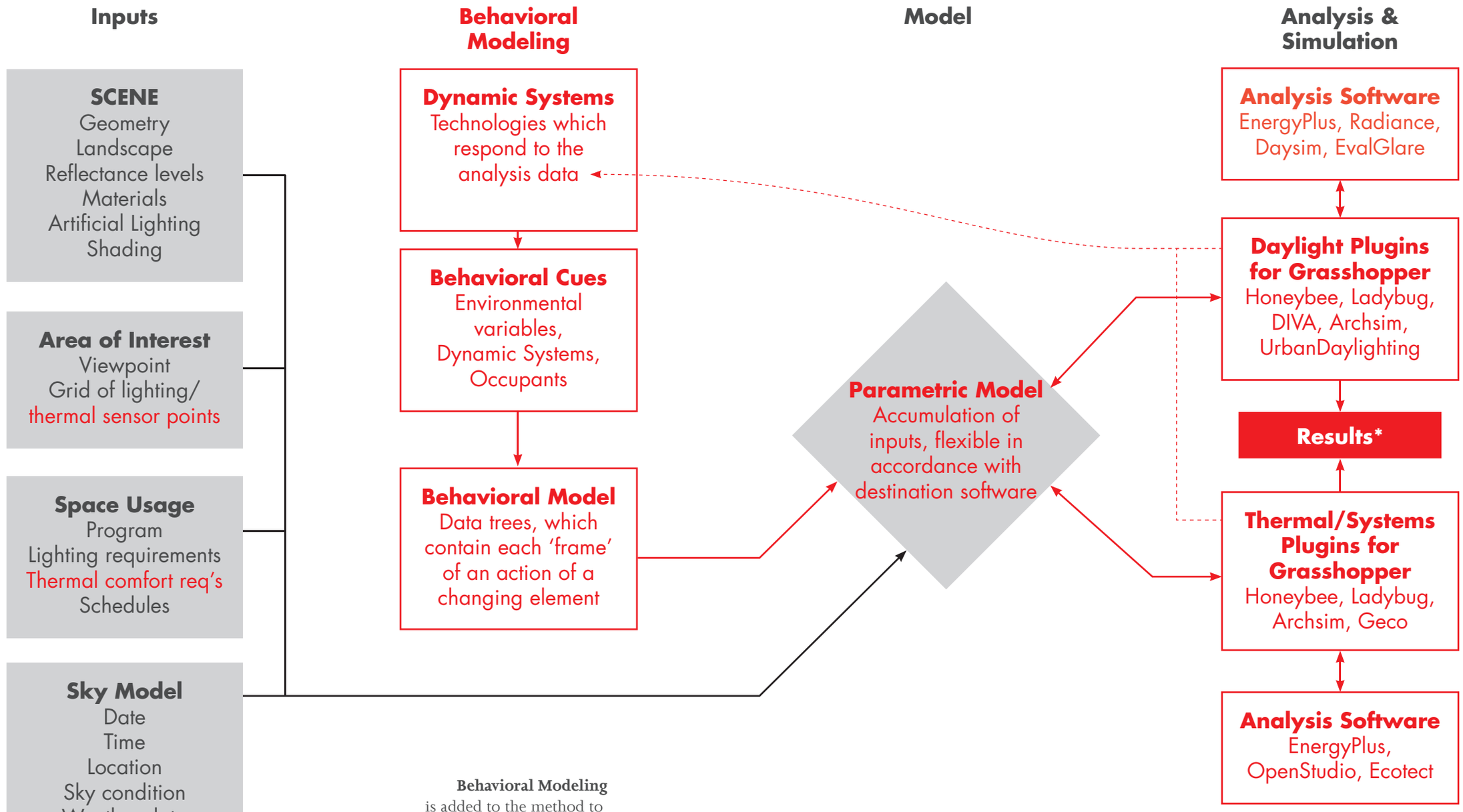
Reinhart + Grasshopper

This pre-hypothesis flowchart represents the adaption of Christoph Reinhart's method for daylighting simulation with parametric tools (using grasshopper primarily instead of creating a singular model for export). Plugins link the data between model and analysis software constantly, so input manipulation is facilitated in terms of getting quick results.

Inputs (below) represent importable standards which work in direct relation to EnergyPlus simulations.

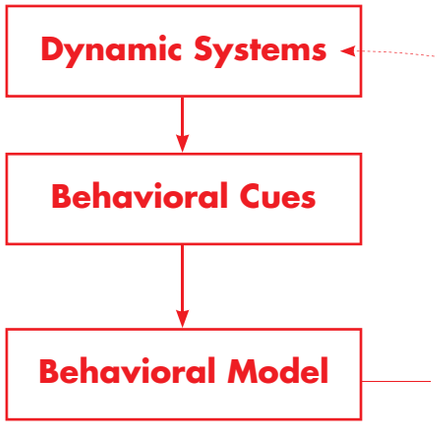


* Visualization or Data



Behavioral Modeling is added to the method to accommodate complex system(s) analysis and simulation.

* Visualization or Data

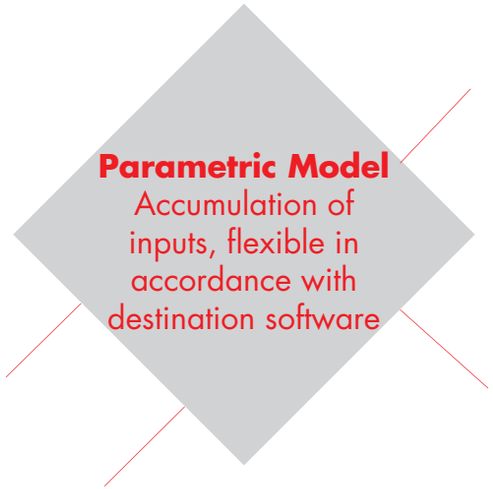


Dynamic systems examples: EDDS (my main focus), automated windows, manipulable lighting/heating/cooling fixtures...

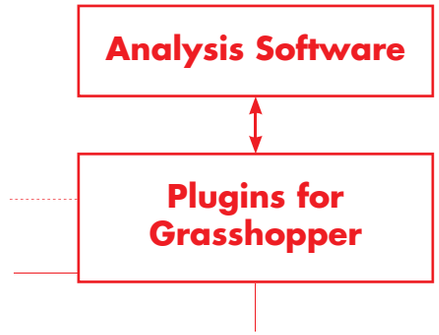
Behavioral cues come from many different possible variables:

1. Environmental variables, in relation to other behavioral cues, come into play when measuring a changing system over a period of time.
2. Other dynamic systems might impact the way another system might function. For example, an EDDS facade might have to overcompensate for thermal loads when an automated window system opens up to ventilate the space.
3. Occupant use, for example, might impact the way an EDDS facade changes when people interact with it.

The behavioral model quantifies sets of data from the behavioral cues and the behaviors of the dynamic systems in relation to those cues.



The parametric model replaces the composite model, as data flows received back from plug-ins become parameters which influence a change in either this parametric model, or the behavioral model.



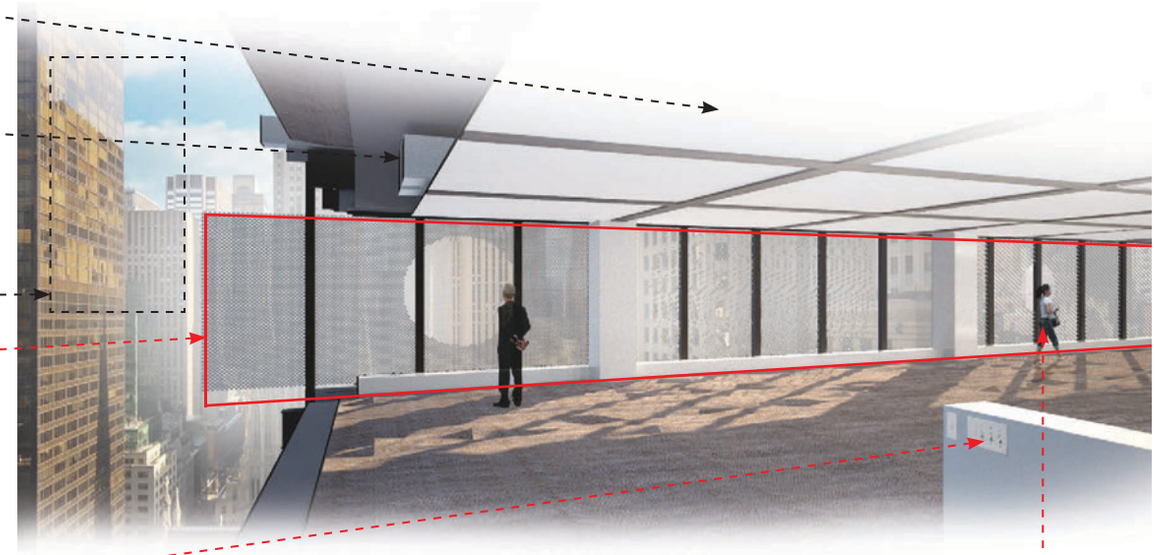
Plugins for Grasshopper allow the linkage between the parametric model and analysis softwares. In general, they seem to only be an export engine for the model as if one were to export the model manually and open it in these softwares. However, the benefit of the plugins is the ability to reload the model and simulation back into Grasshopper, along with comprehensive organized sets of resultant data from the analysis. This data can then inform dynamic systems layouts, optimization goals, or formal qualities of the model itself.

Analysis Software is pretty self explanatory: these are the traditional methods of daylighting/thermal/energy analysis and simulation, which, if functioning on their own, are limited to static (composite) model analyses.

Results are loaded back into Grasshopper as data sets from the plugins (which read the data from Analyses Software). These data sets are usually neatly organized and readable and easily visualized.

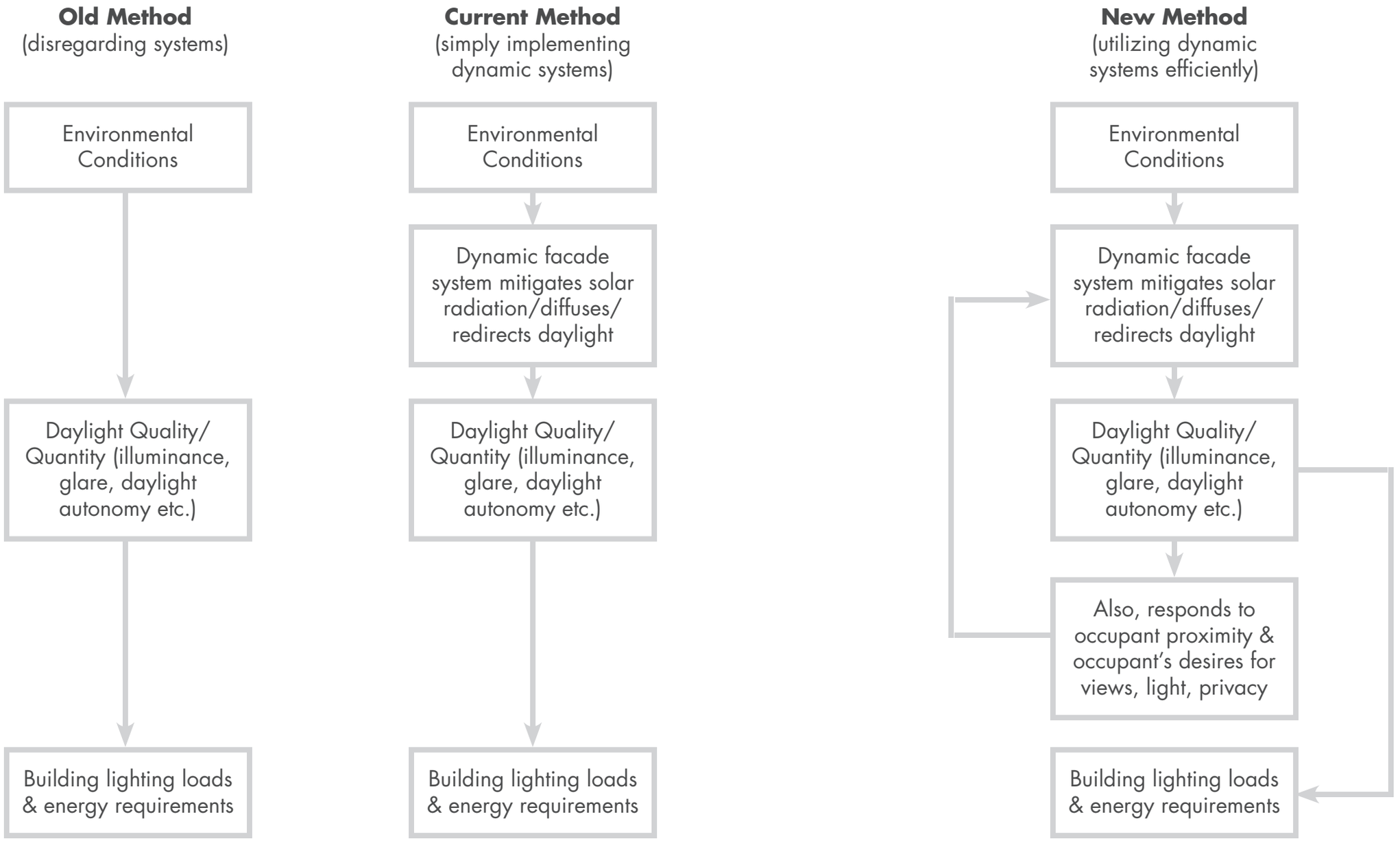
Appended Diagram of Inputs

- **Scene**
  - -Model
    - Building/Zones for implementation/analysis
    - Circulation paths for occupant use
    - Egress/Building Codes
  - -Landscape
    - Degree of slope
    - Ground cover
    - Vegetation/Trees
    - Water
  - -Materials and Reflectance levels
    - Glazing areas
    - Floor/Wall reflectance for diffuse light analysis/glare
    - Construction libraries imported from E+
  - -Artificial Lighting
    - User controllability levels
    - Amount/intensity of lighting systems
  - -Building Systems
    - HVAC
    - Natural ventilation opportunities
- **Area of Interest**
  - -Viewpoint of the area of interest
    - Analysis on a contextual level
    - Whole-building-analysis scope
    - Zoomed in section of building
  - -Grid of lighting & thermal sensor points
    - For whole building/or specified zone
- **Space Usage**
  - -Program
    - Use of the spaces
  - -Lighting requirements:
    - Lighting levels required by occupying program
  - -Thermal Comfort Requirements:
    - Thermal comfort levels required by occupying program
  - -Schedules:
    - Analysis period for simulation
    - Usage schedule, dependent on program typically
- **Sky Model**
  - -Date & Time
    - Day activity hours
    - Night activity hours
  - -Location
  - -Sky Condition
    - e.g. Clouds vs. Direct sunlight
  - -Weather Date:
    - .epw file. Location based
- **Dynamic Systems**
  - -Façade Systems
    - EDDS
      - 'pixel' size
      - Non-responsive pattern (optional)
      - Coverage
    - Coverage
    - Manipulability
    - Other automated systems
  - -Interior Systems
    - Partitions
    - Manipulatable lighting/thermal/comfort controls
    - Other automated systems
- **Behavioral Cues**
  - -Environmental variables
    - Climate variability
    - Wind loads
    - Cloudy-to-sunny transitions
    - Precipitation effects
  - -Dynamic Systems
    - Responsive EDDS
    - Façade/Interior Systems
  - -Occupants
    - Actions
    - Occupant load
    - Movement



Flowchart of Systems' Effects

With Proposed Behavioral Modeling:



Proposed Method

For the aforementioned parametric base, I propose Grasshopper, as it succeeds in combining cross-software plugins, 3D modeling capabilities, custom scripting (Python) if needed, with organized data trees (sets of data which become essential in behavioral modeling). Simulation brings together data from the analysis, 3rd-party programs and the parametric model in Grasshopper, and this data can be used to inform a response among any parametric aspect of the model (one system informing another system, or one system overcompensating for an introduced variable).

To focus my efforts, I will be looking at the analysis/optimization/simulation of technologies implemented in an office tower program in New York City. The dynamic system I will be modeling is an Electroactive Dynamic Display System (EDDS), developed by RPI's CASE with SOM. For the sake of ease, clarity and recognizability, I will be analyzing the implementation of EDDS on the Seagram Building (following page).

EDDS

Electroactive Dynamic Display System:
Technology to be analyzed

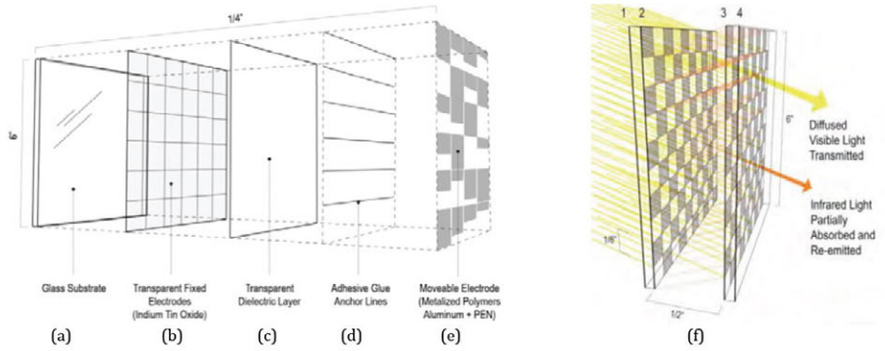
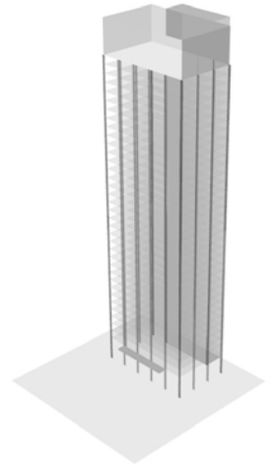
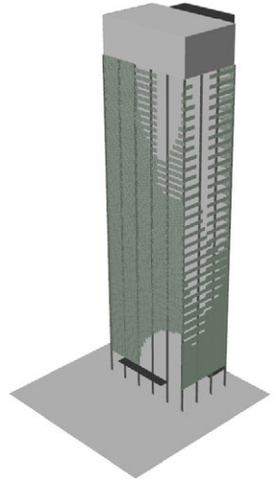


diagram by SOM/RPI CASE

Seagram Building

Testbed for analysis and simulation





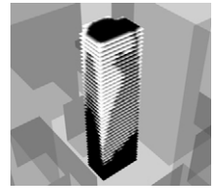
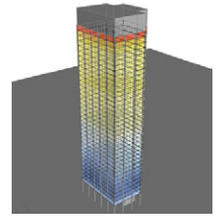
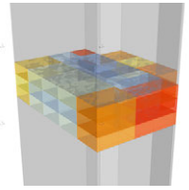
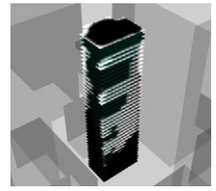
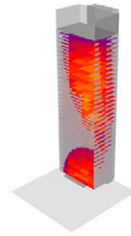
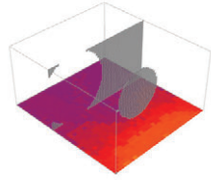
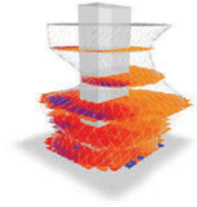
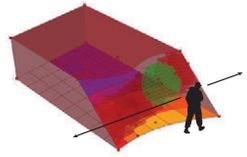
Scale and Depth of Analysis

Overview of the following analyses.

Scale

Systems Analysis	Urban Scale	Building Scale	Zoomed-in Scale
	No EDDS	No EDDS	No EDDS
	Static EDDS	Static EDDS	Static EDDS
	Dynamic EDDS	Dynamic EDDS	Dynamic EDDS

Scale

Systems Analysis			
			
			
	Not yet		

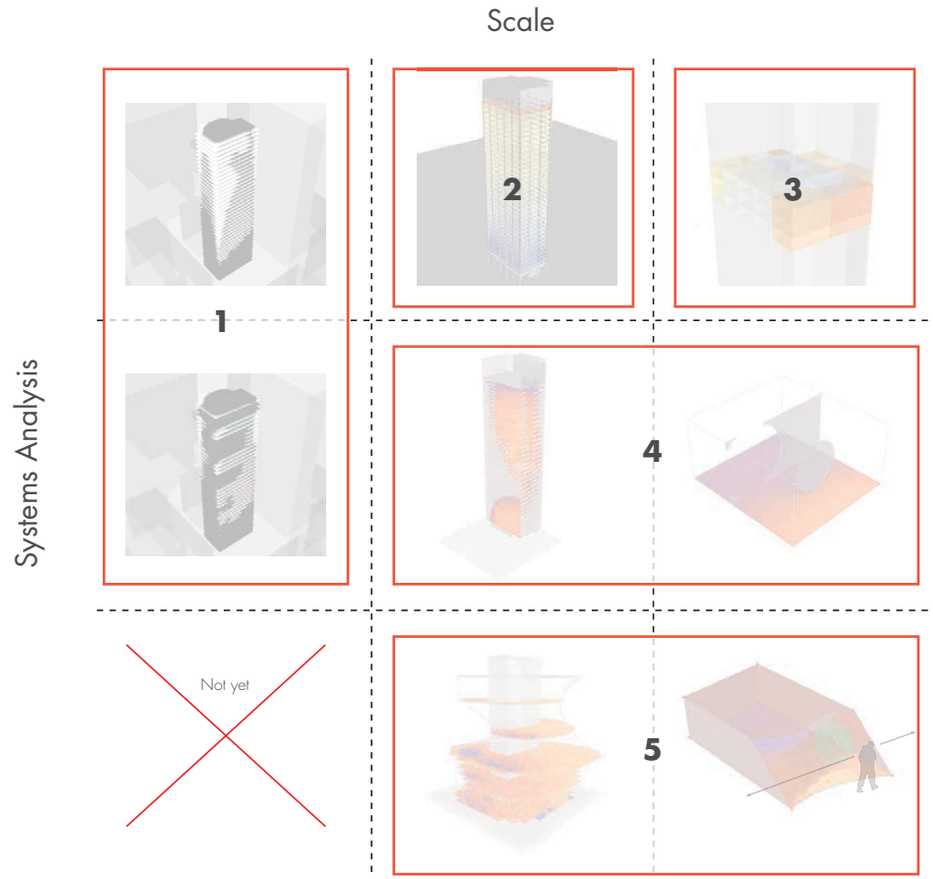
Scale and Depth of Analysis

Order of the following analyses.

First, the two Urban Scale analyses are shown together to compare results of adding an EDDS-like facade to an entire building.

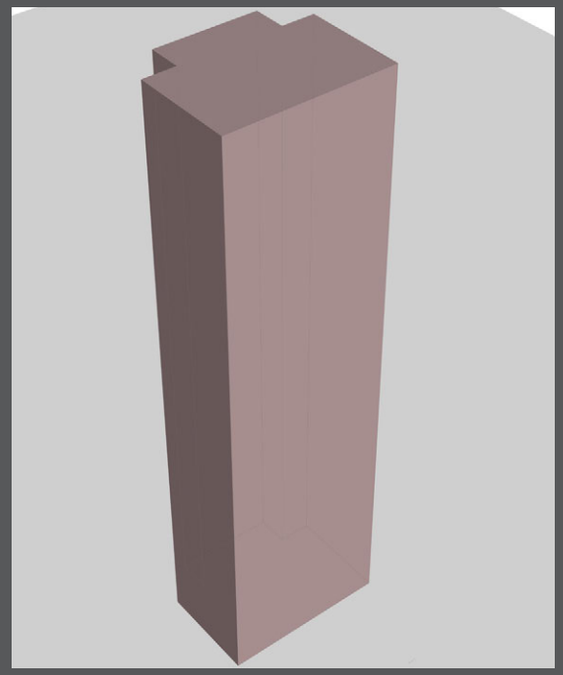
Second, the building and, third, zoomed-in scale are analyzed without EDDS. Both were analyzed and simulated mainly through the EnergyPlus Software.

Fourth and Fifth are Ecotect-analyzed models, which provides a very limiting amount of information data-wise, but shows the possibilities of behavioral modeling, however simple the analysis may be.

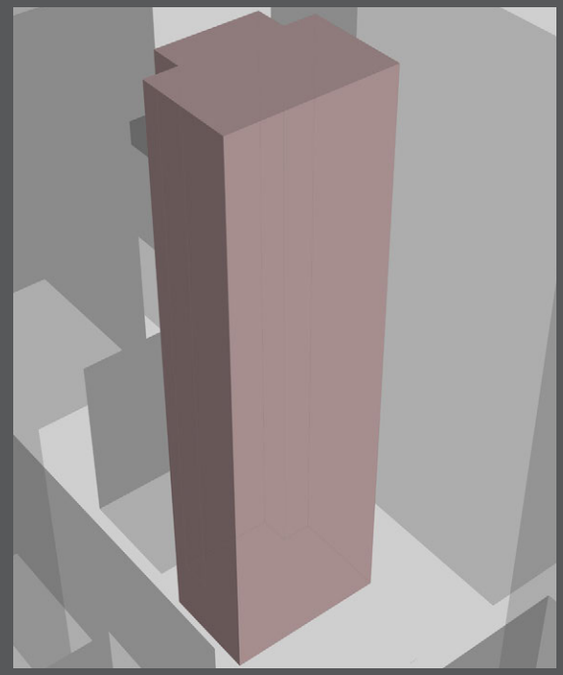


1. Urban Scale, No EDDS

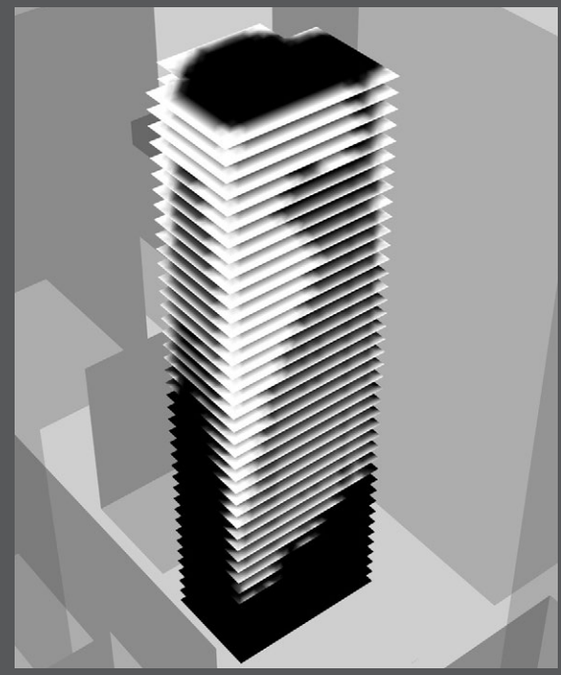
Building+Context Daylighting Analysis



1. Create simplified building mass. At this scale, it would take a long time for the computer to analyze every aspect of a detailed model. Fortunately, the UrbanDaylighting component for grasshopper, which links to DaySim, allows the user to split a mass roughly by floor height/number of floors.



2. Add context/shaders to the model.

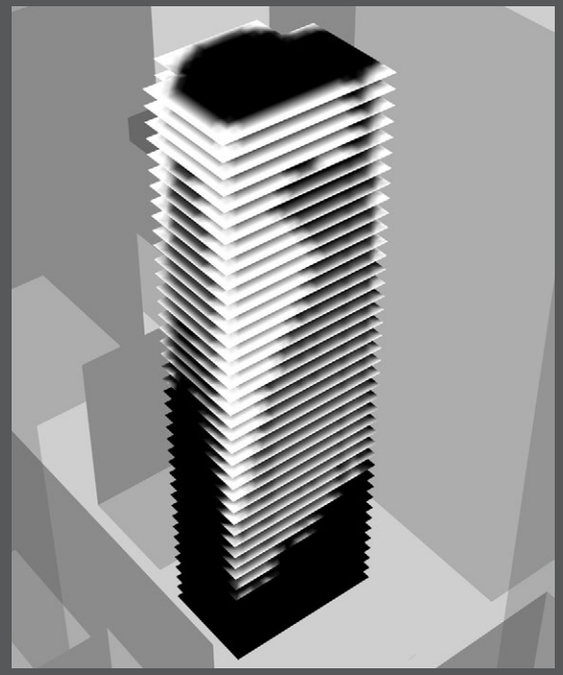


3. Run the simulation. This simulation measures the directly daylit area of the Seagram Building without any shading system implemented.

Results: Of the 54990 m2 floor area,
7142 m2 day-lit
Average 13.0% of floor is directly lit by sun

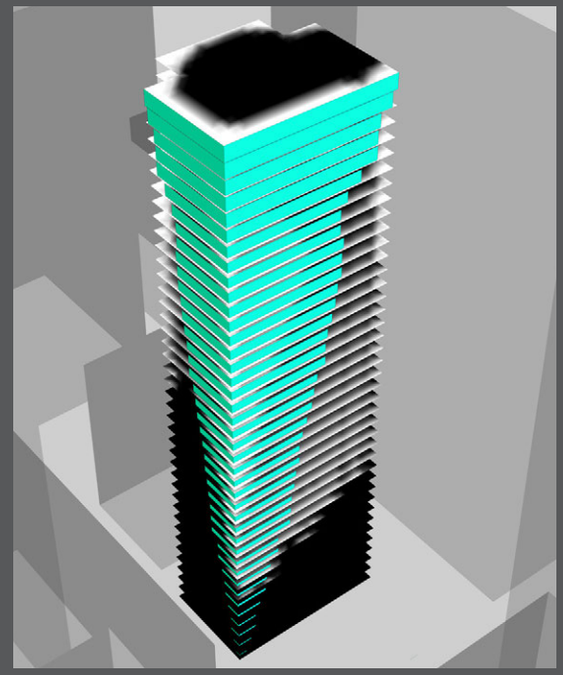
1. Urban Scale, Staic EDDS

Building+Context Daylighting Analysis with EDDS-like shaders added to the facade.

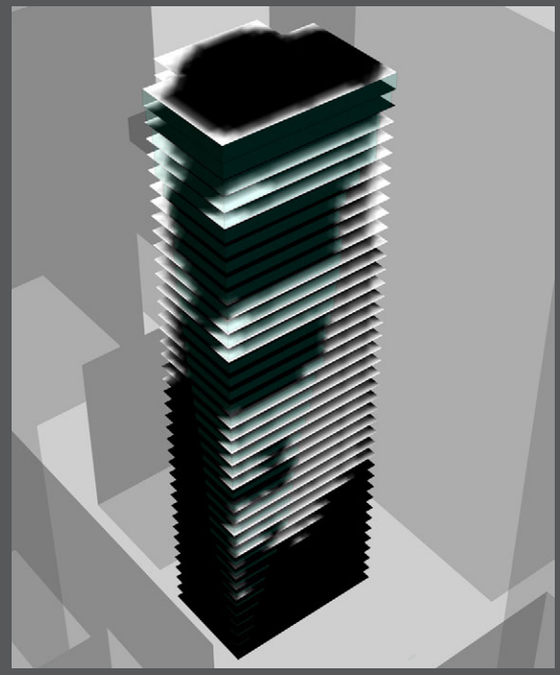


3. Previously-ran no EDDS simulation

Results: Of the 54990 m2 floor area,
7142 m2 day-lit
Average 13.0% of floor is directly lit by sun



4. Import results from simulation as a set of data, rearrange data on a per-floor basis, model the shading system with the size of each panel (shown in blue) customized relative to the amount of light penetrating the building.

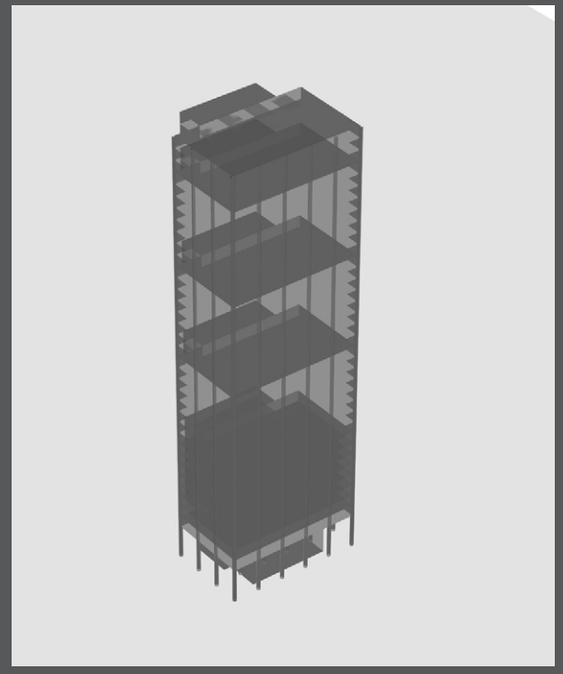


5. Run the simulation a second time.

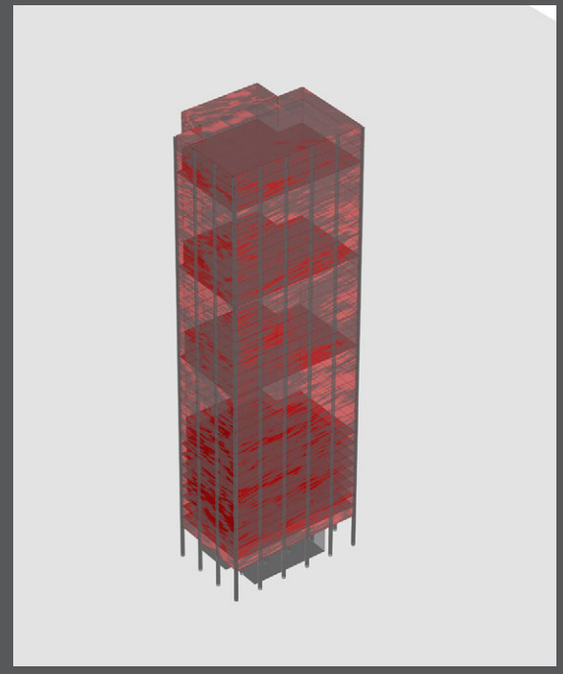
Results: Of the 54990 m2 floor area,
4351 m2 day-lit area
Average 7.9% of floor is directly lit by sun
2792m/60% direct daylighting decrease from non-EDDS analysis

2. Building Scale Setup

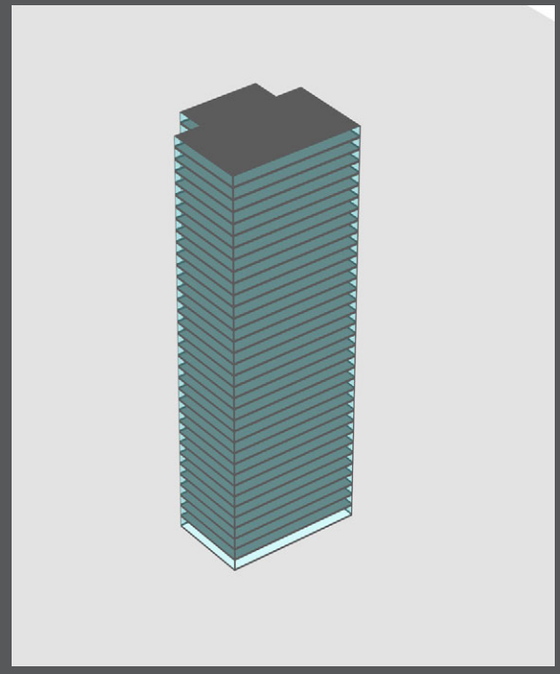
Seagram Building without context or EDDS.



1. Construct model building mass.



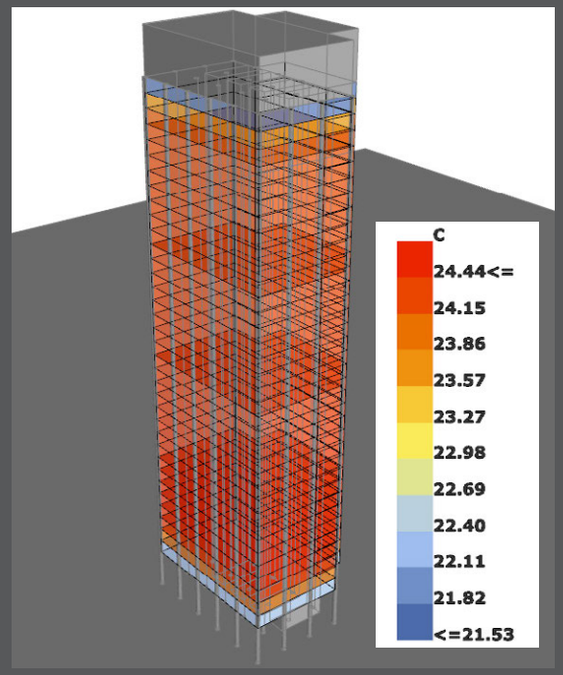
2. Set up EnergyPlus Zones based on the scale of the work. In this example, each floor is a zone, which should average out any values of implied zones on a per floor basis.

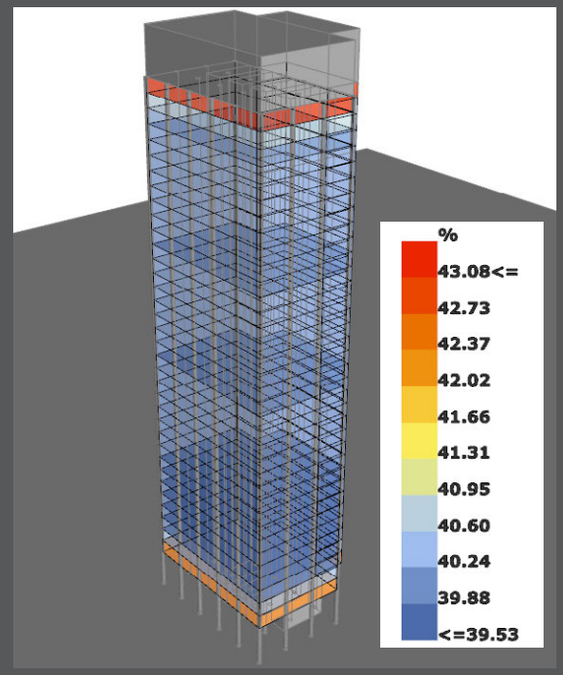


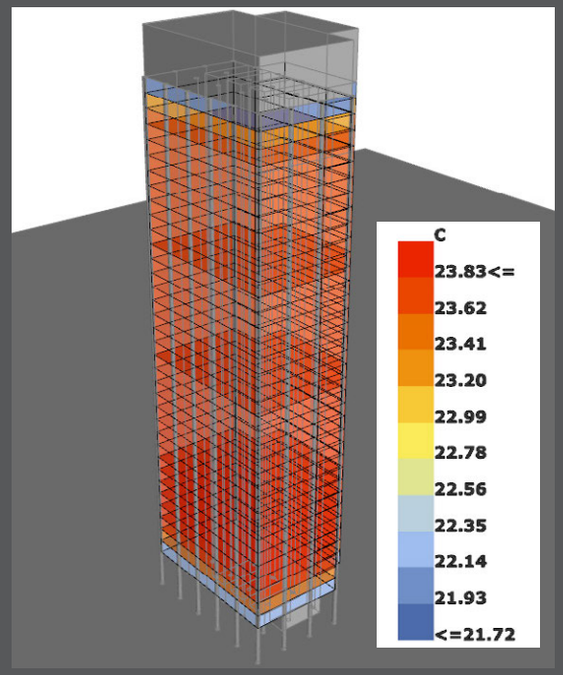
3. Create inputs for the zones, in this case a generalized glazing ratio representing the actual amount of fenestration on the facade.

2. Building Scale: Analyzed with E+

Seagram Building without context or EDDS.







Analyzing Temperature and Humidity:

Mean Radiant Temperature

The mean radiant temperature of each zone (degrees Celsius).

Relative Humidity

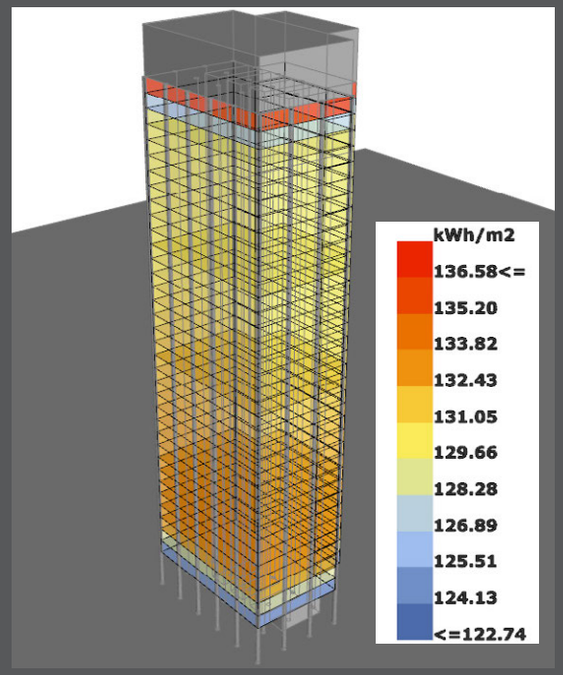
The relative humidity of each zone (%).

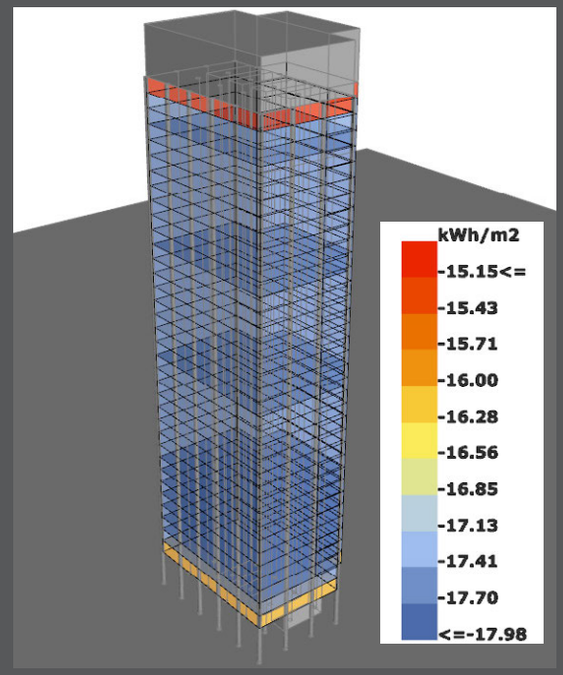
Operative Temperature

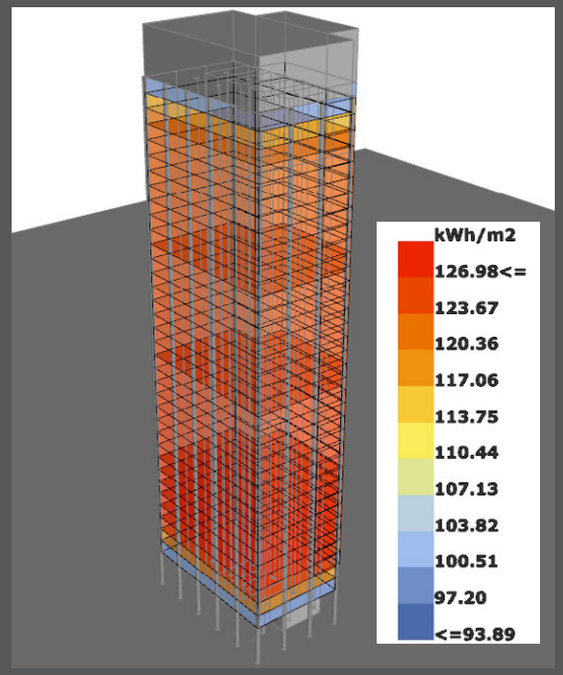
The mean operative temperature of each zone (degrees Celcius).

2. Building Scale: Analyzed with E+

Seagram Building without context or EDDS.







Analyzing Thermal Energy Loads:

Total Thermal Energy Loads

The total thermal energy used by each zone in kWh. This includes cooling and heating.

Heating Loads

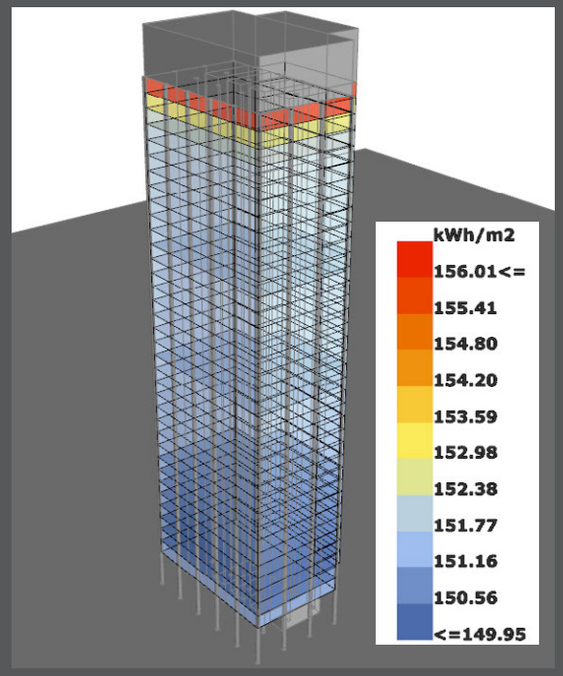
The heating energy needed in kWh. For Ideal Air loads, this is the sum of sensible heat that must be added to each zone. For distributed OpenStudio Systems like Packaged Terminal Heat Pumps (PTHP), this will be electric energy for each zone. For central OpenStudio systems, this output will be a single list for the whole building.

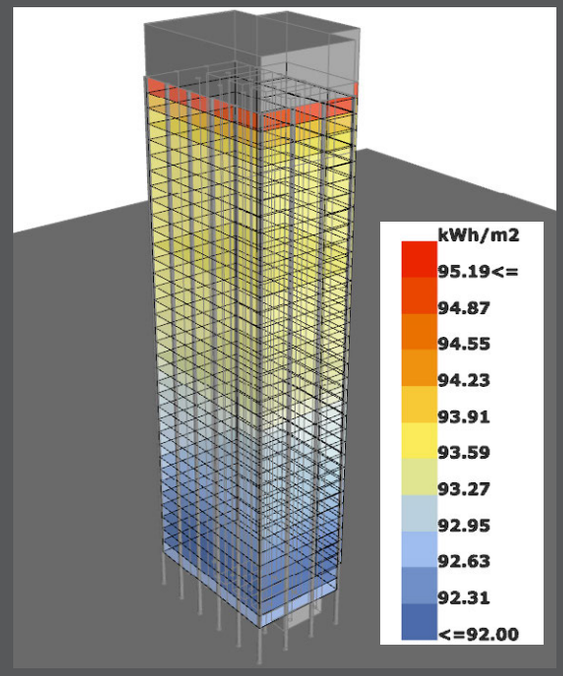
Cooling Loads

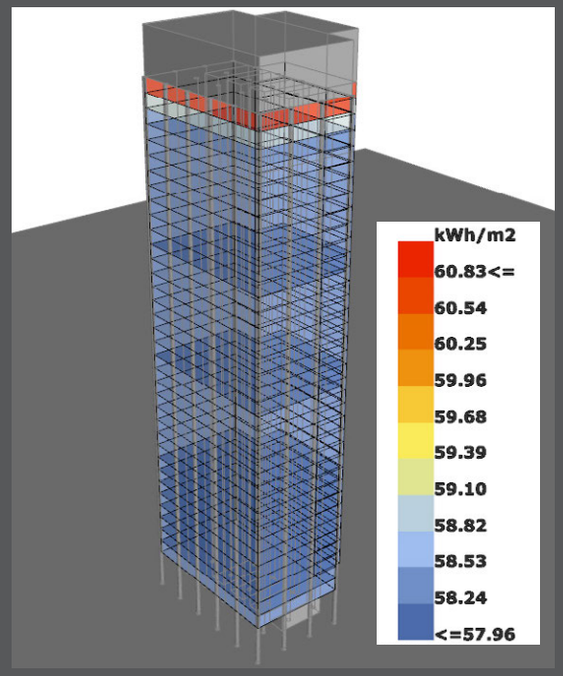
The cooling energy needed in kWh. For Ideal Air loads, this is the sum of sensible and latent heat that must be removed from each zone. For distributed OpenStudio systems like Packaged Terminal Heat Pumps (PTHP), this will be electric energy for each zone. For central OpenStudio systems, this output will be a single list for the whole building.

2. Building Scale: Analyzed with E+

Seagram Building without context or EDDS.







Analyzing Solar Radiation:

Total Solar Gains

The total solar gain in each zone(kWh).

Exterior Solar Diffuse Gains

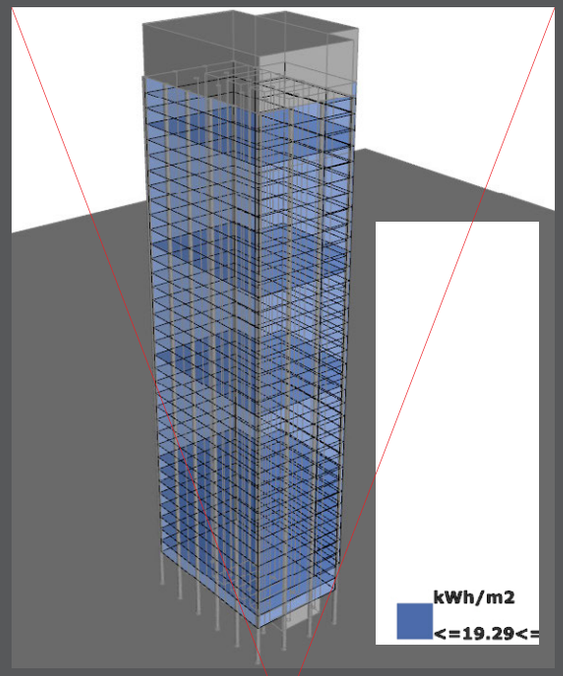
The diffuse solar gain in each zone from exterior windows (kWh).

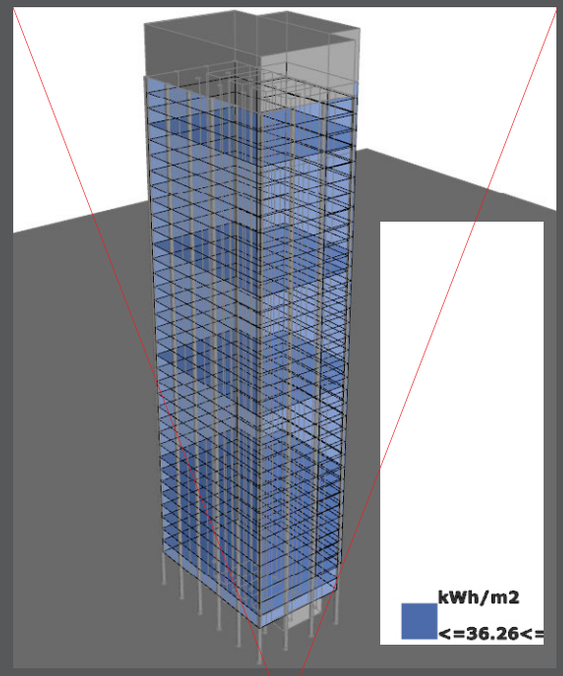
Exterior Solar Beam Gains

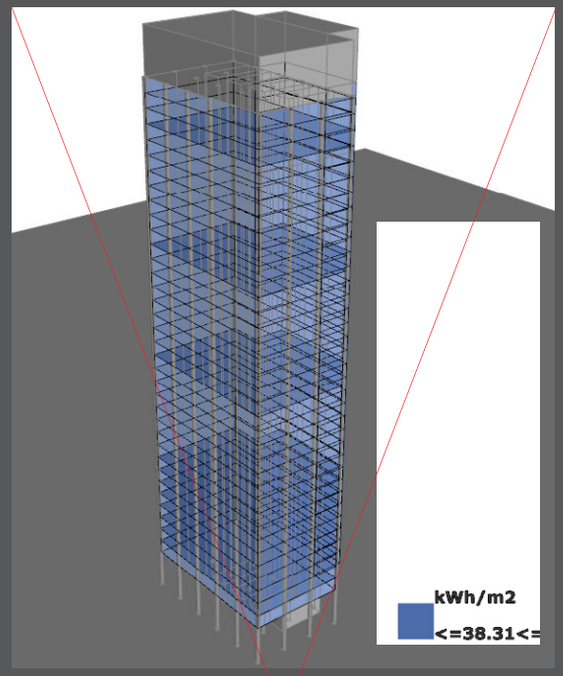
The direct solar beam gain in each zone from exterior windows (kWh).

2. Building Scale: Analyzed with E+

Seagram Building without context or EDDS.







Analyzing People/Systems:

People Gains

The internal heat gains in each zone resulting from people (kWh).

Electric Equip. Energy Usage

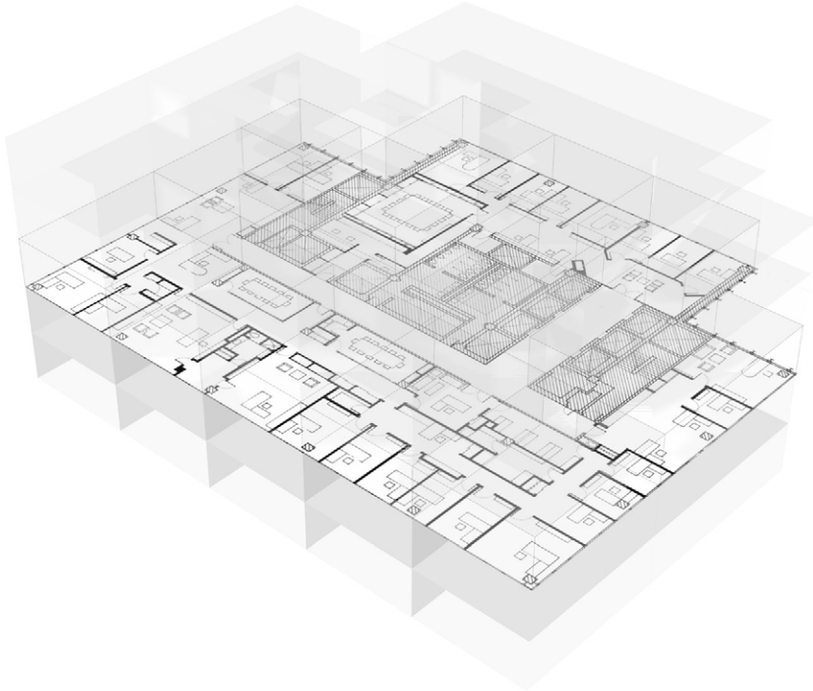
The electric equipment energy needed for each zone in kWh.

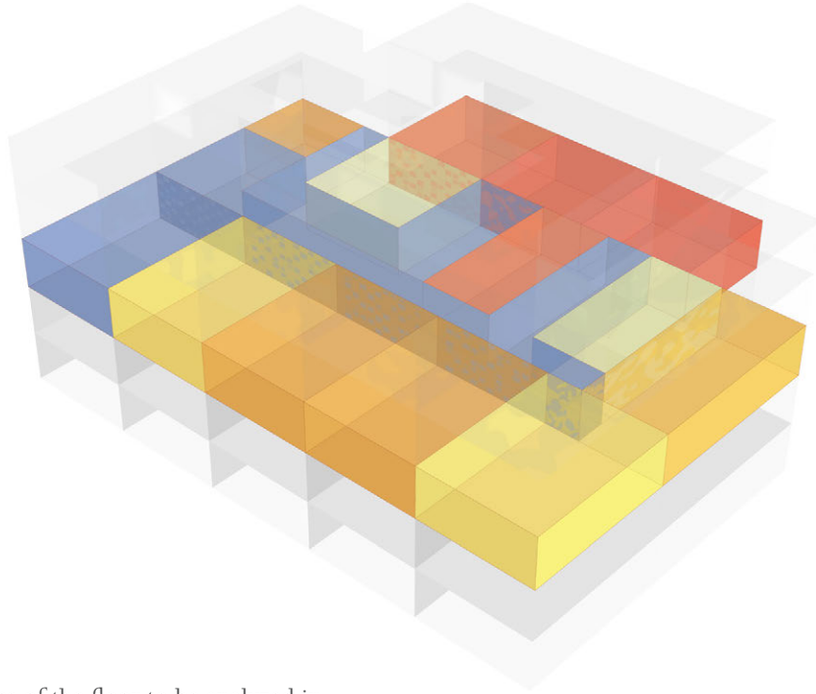
Electric Lighting Energy Usage

The electric lighting energy needed for each zone in kWh.

3. Zoomed-in Scale: Setup

Seagram Building floor without context or EDDS.

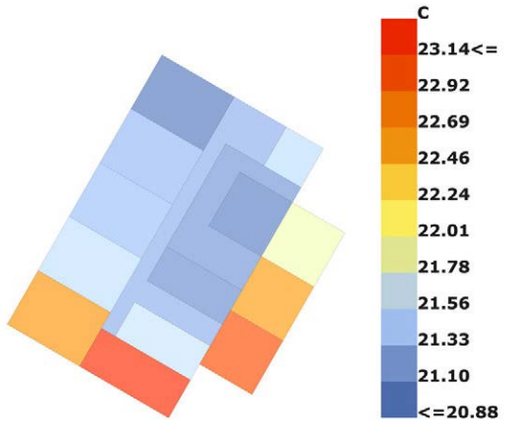




Design zones of the floor to be analyzed in place of proposed/existing rooms. This example has been generalized: 15 zones make up a floor containing 30+ rooms. Specify inputs/presets in accordance with the goal EnergyPlus simulation.

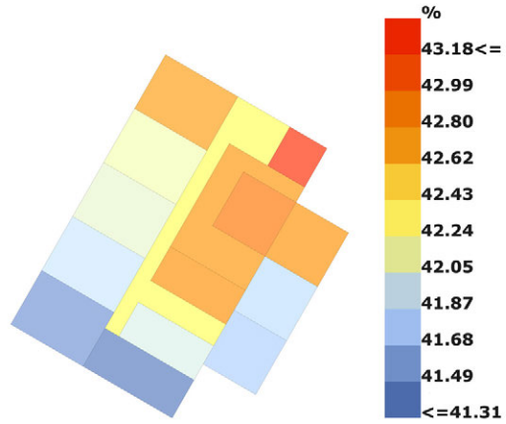
Seagram Building floor without context or EDDS.

Analyzing Temperature and Humidity:



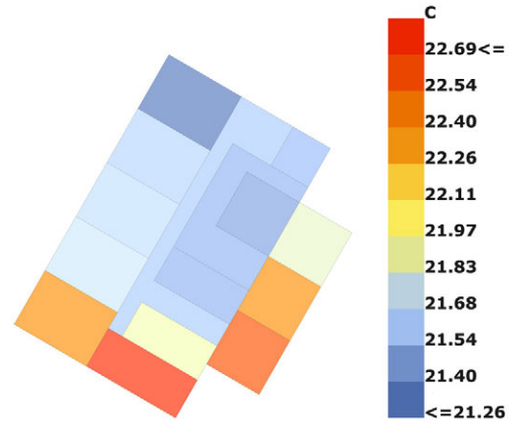
Mean Radiant Temperature

The mean radiant temperature of each zone (degrees Celsius).



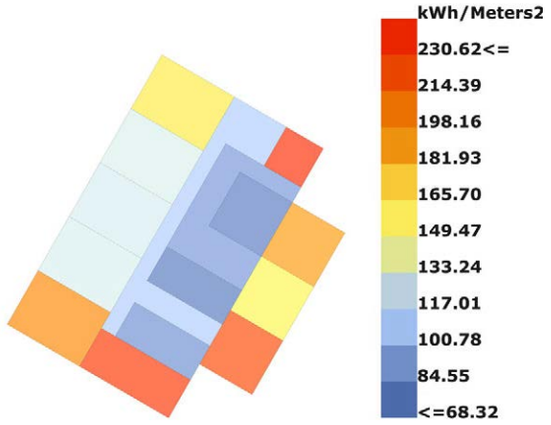
Humidity

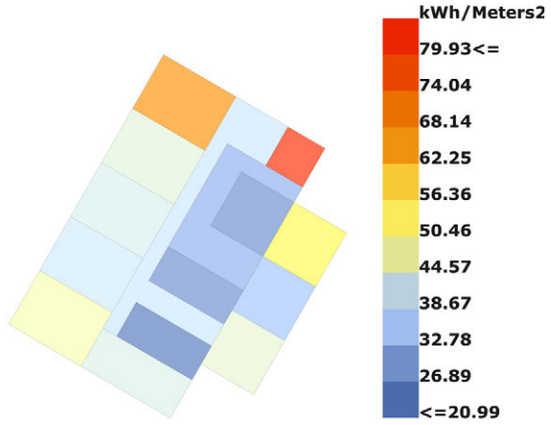
The relative humidity of each zone (%).

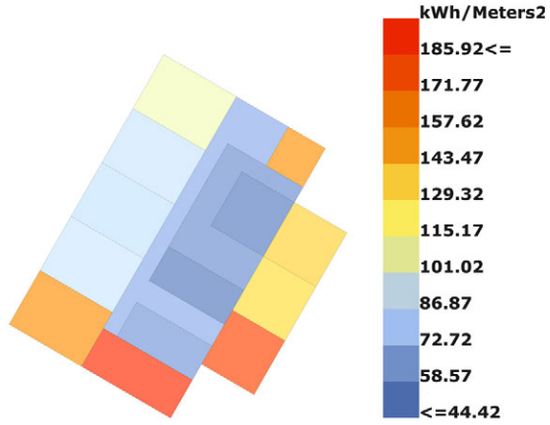


Operative Temperature

The mean operative temperature of each zone (degrees Celcius).







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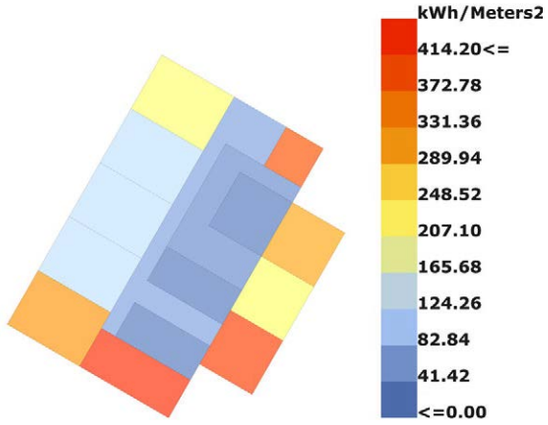
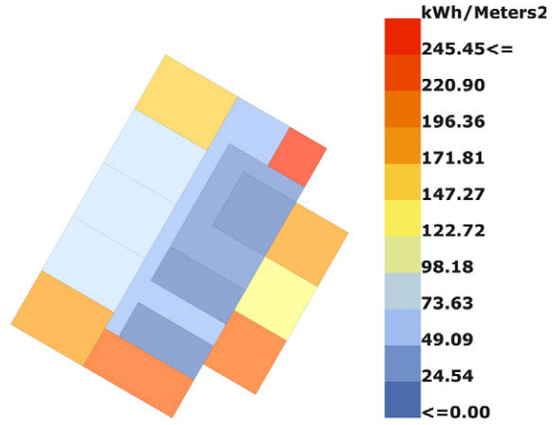
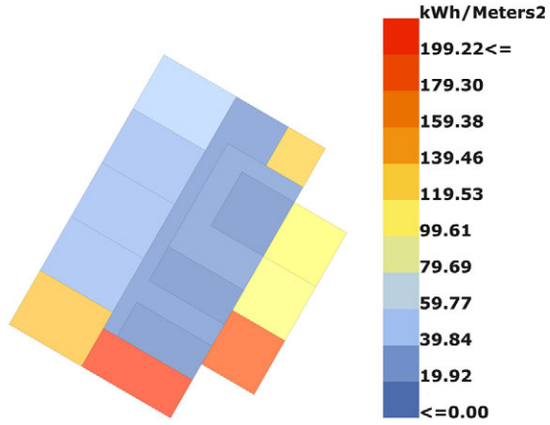
3. Zoomed-in Scale: Analyzed with E+

Seagram Building floor without context or EDDS.







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