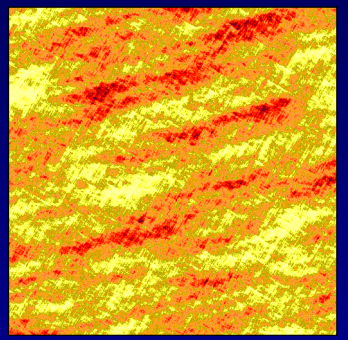
Precision Modelling Of Parametrically Defined Solar Shading Systems: Pseudo-Changi





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Solar Penetration in Buildings

Better utilisation of daylight may result in an increased likelihood of solar penetration.

Shading devices are intended to reduce solar penetration.

They come in all shapes and sizes:

Traditional Assessment Methods

Illumination of a scale model by heliodon

- 'Classic' architectural approach

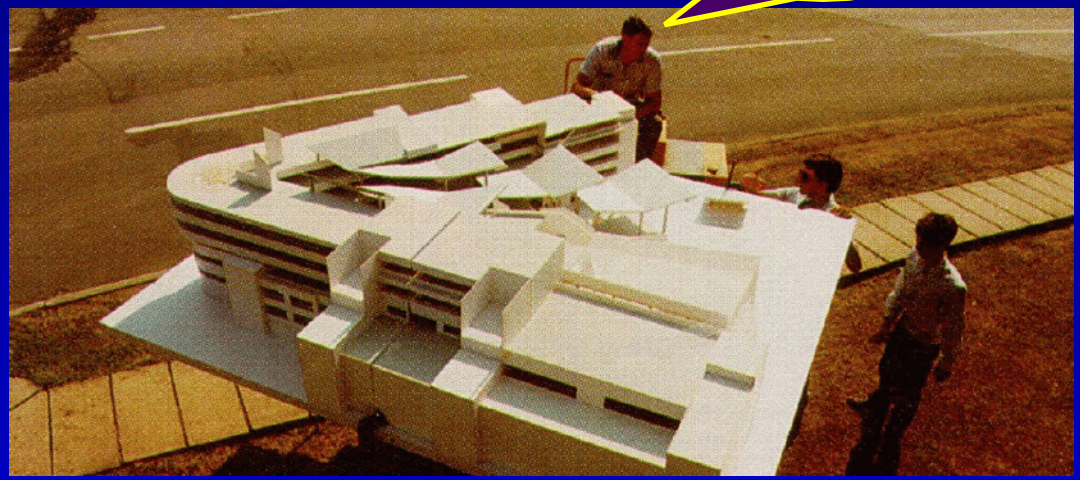
Computer rendering of 'snapshot' images

- Equivalent to 'classic' approach, greater flexibility

Animated sequence of images

- Scale model & video camera
- Computer generated

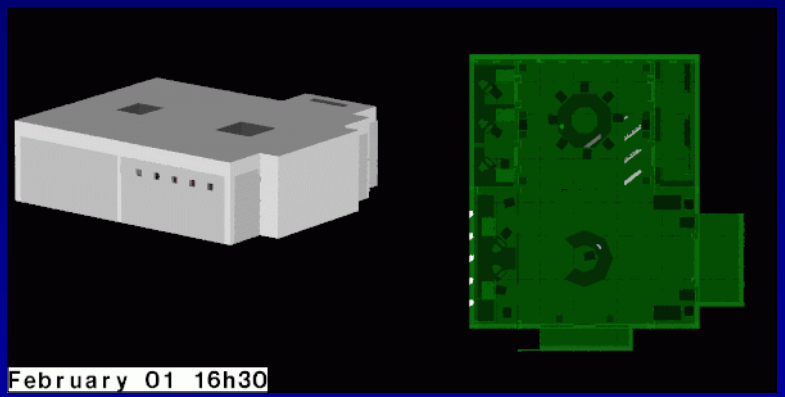
Large model tilted on a dump truck to investigate shading patterns at various times of the day or year

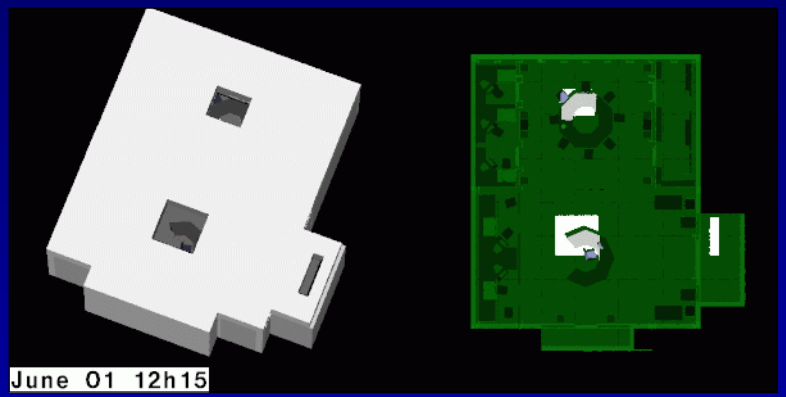


Computer Generated Images

Stills from a sequence of images

Office with skylights





Sun's view and internal view - 15min intervals on the 1st day of each month

Limitations of these Methods

Qualitative assessment

- Images reveal when insolation may occur but not how much or how often

Selective

- Usually just a few times of the year are studied, e.g. solstices and equinox
- Need an approach that accounts for the hourly, daily and seasonal variation in solar irradiation

Difficult to compare design options

- A quantitative schema is needed

New Approach - Design Goals

Quantitative measure of solar penetration

- Predict total annual irradiation (TAI) based on hourly TRY/TMY data

No practical limitations on geometrical complexity

- Work directly with CAD models
- No need to simplify designs

Image based solution

- Generate spatial and temporal maps for solar penetration

Fast computation

- Rapidly evaluate and compare many design options

STIMAP

The new approach is called Spatio-Temporal Irradiation Mapping (**STIMAP**).

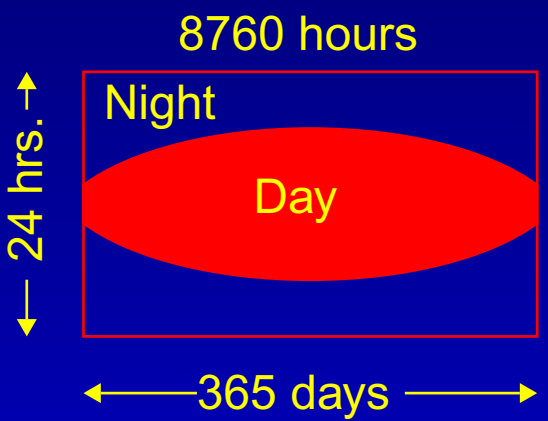
The spatial map reveals the quantity and distribution of total annual direct irradiation incident on building surfaces.

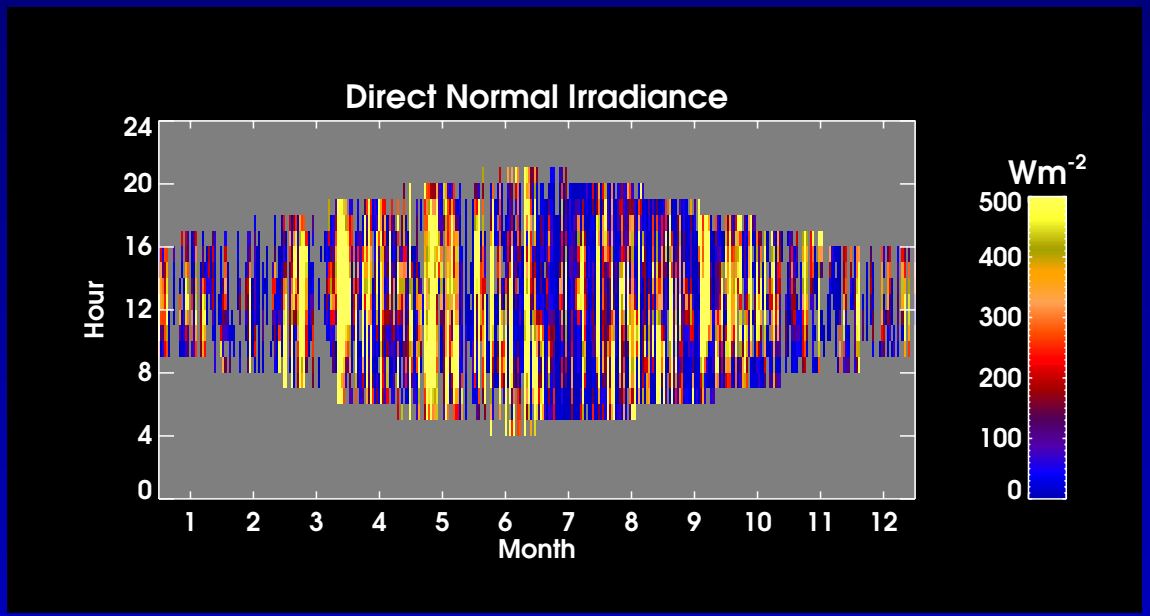
The temporal map shows the propensity for high instantaneous irradiation across those surfaces throughout the year.

The (UNIX) ***Radiance*** lighting simulation system is the underlying 'rendering engine' in **STIMAP**.

OUTLINE

The total annual irradiation (cumulation of ~4000 unique sun conditions) is accurately synthesised from only ~200 irradiation simulations. The sun conditions are based on hourly TRY data for direct normal irradiance.





Theoretical Basis

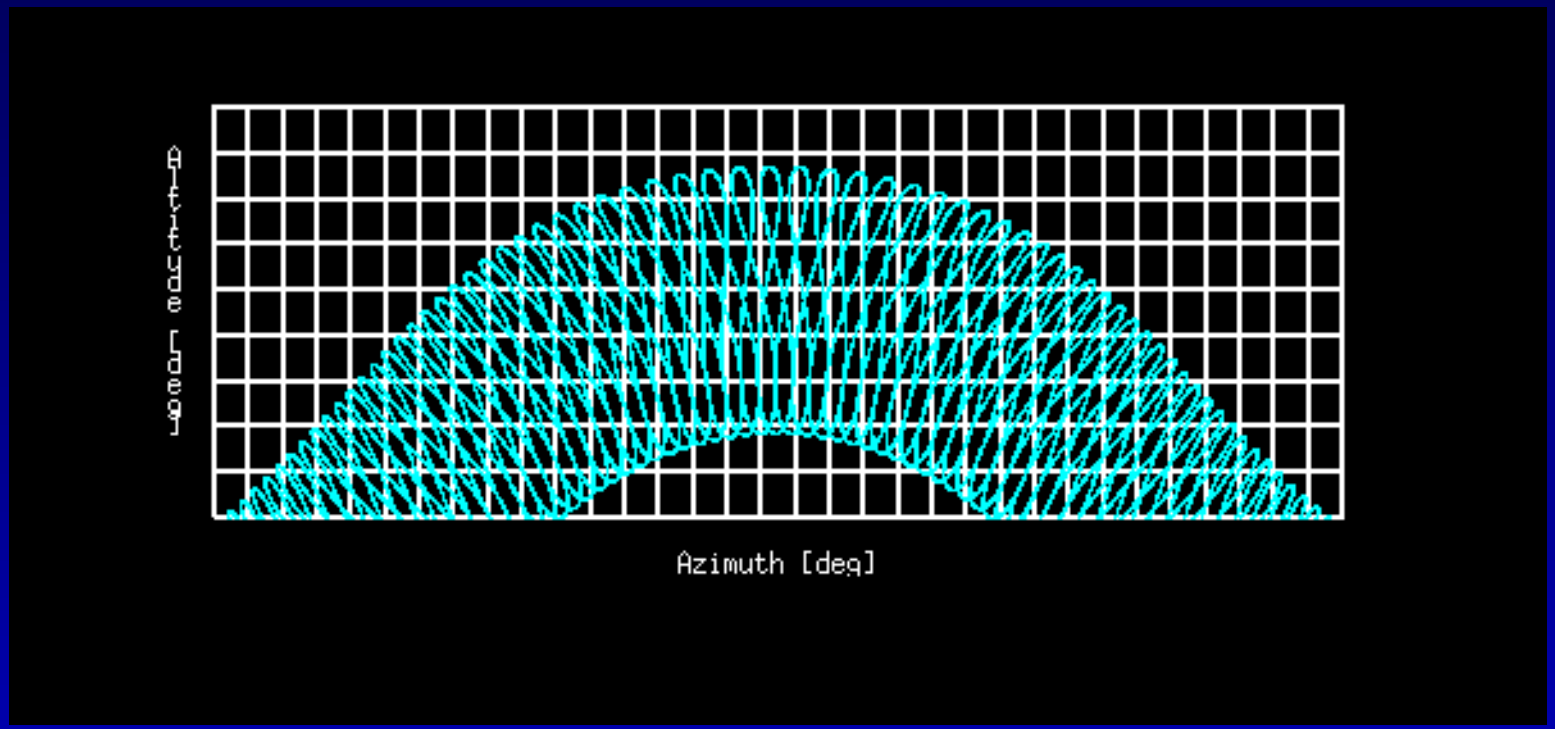
The UNIX *Radiance* program is used to predict (normalised) irradiation images of insolation.

Computation is accelerated by transforming the problem domain from that based on the time-series of annually occurring sun positions to one based on the distribution in altitude and azimuth (of annually occurring sun positions).

Whereas a brute force approach requires ~4000 irradiation images (i.e. number of daylight hours) the accelerated approach needs only ~200.

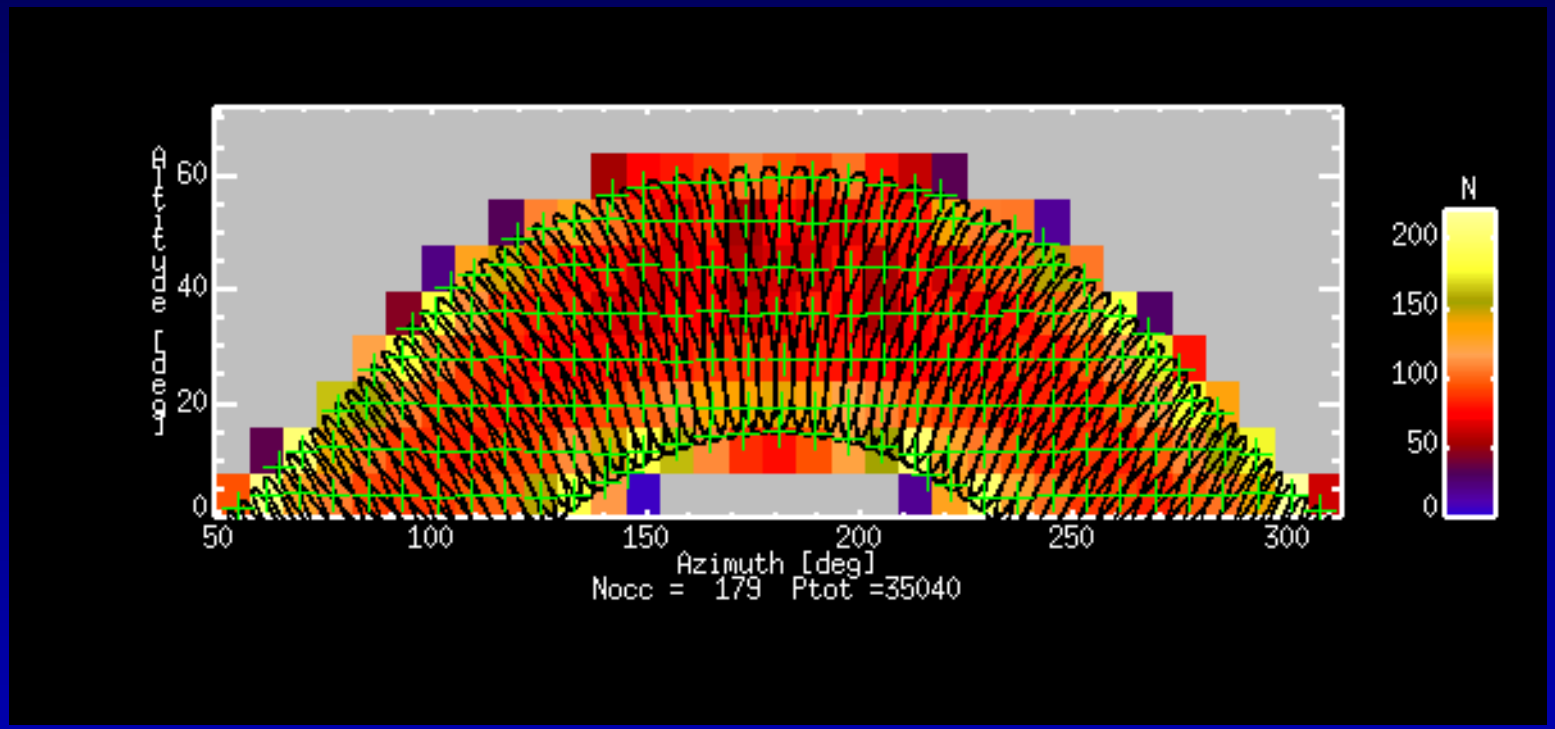
FIRST...

...generate the sun positions for the building location (time-step = 15 mins).



THEN...

...determine the number of sun positions for each bin and the bin mean sun position.



THE TOTAL ANNUAL IRRADIATION DUE TO…

...all the sun conditions in the TRY is synthesised from these (179) irradiance renderings.

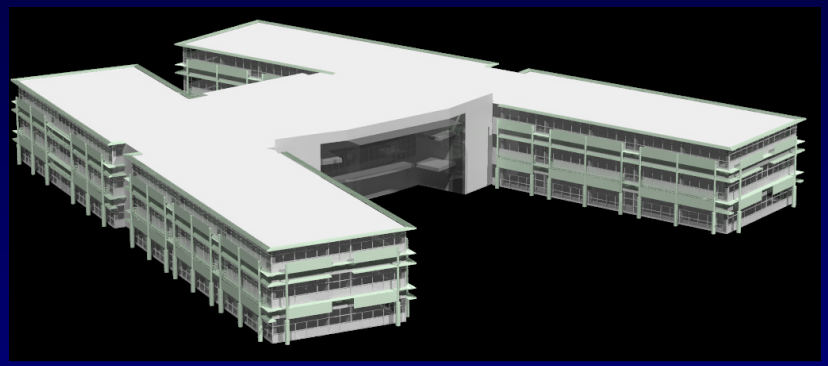
As well as the annual total, irradiation maps can be generated for any fraction of the year, e.g. winter, summer, am or pm, etc.

Also, an annual time-series for irradiation at any one point (or averaged across any area) can by synthesised from the normalised irradiation renderings.

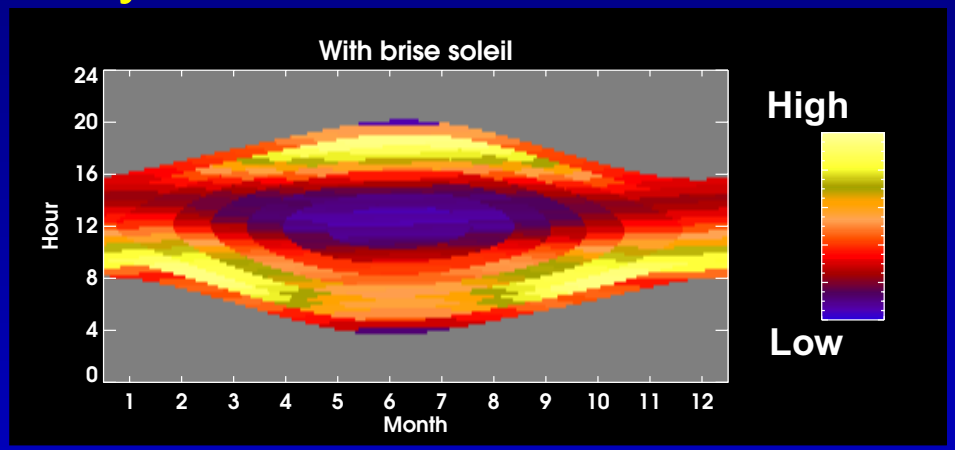
See paper in BS2003 for further information.

EXAMPLE: BUILDING WITH BRISE-SOLEIL

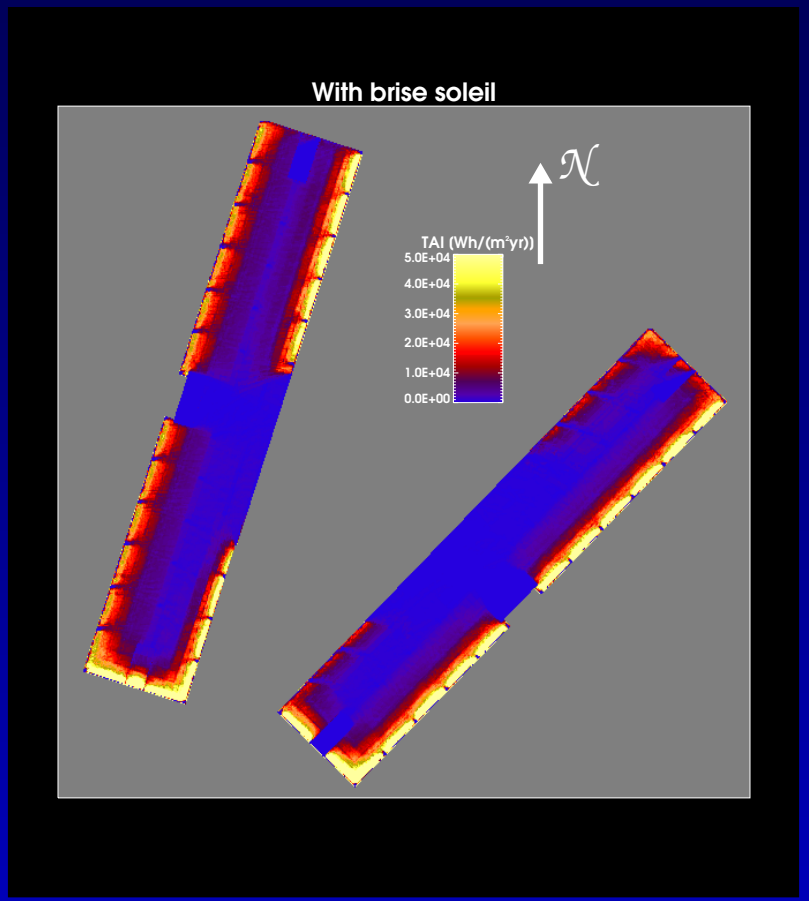
Rendering of 3D model



Temporal map showing propensity for solar penetration throughout the year



Spatial map showing TAI across floor plan



Evaluation Of Parametrically Defined Solar Shading Systems

A parametrically defined shading system is one where a key property of the system (e.g. fin orientation) is governed by some rule, i.e. equation.

The geometry of the shading system is then generated using the rule.

The STIMAP system is ideally suited for the quantitative evaluation and comparison of multiple design variants.

Example: Pseudo-Changi

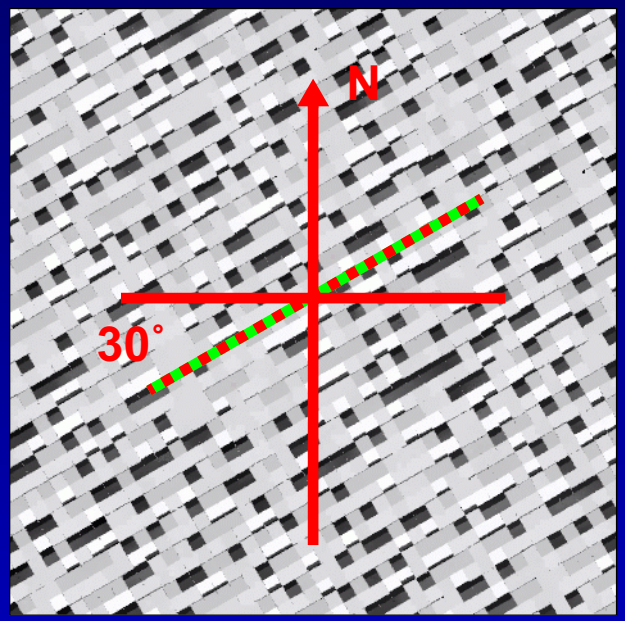
The building model used to demonstrate the new approach was inspired by the concept-rendering of Changi Airport Terminal 3 (Singapore).

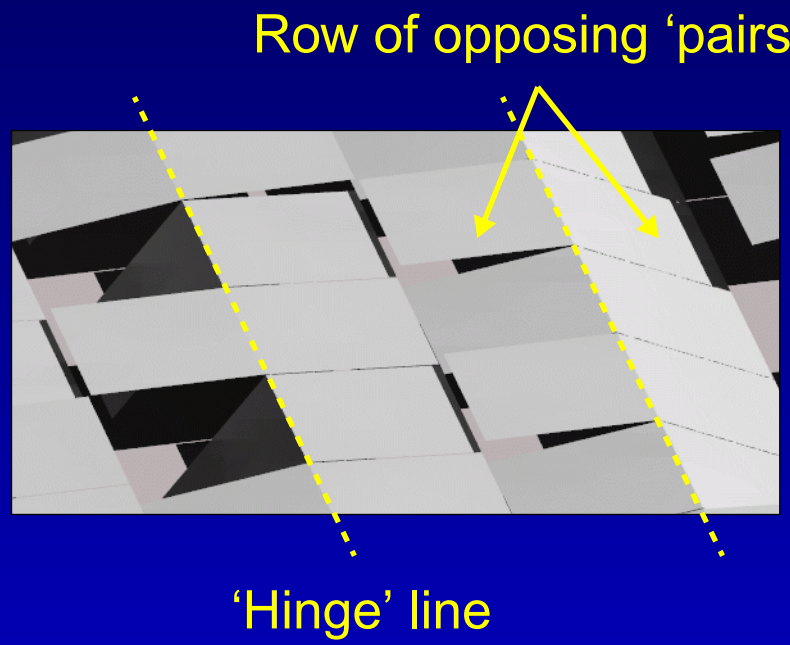
Image by J. Seagull, copyright Pixel by Pixel and Skidmore, Owings & Merrill

Many thousands of (seemingly) randomly orientated shading fins

Scenario: Evaluate 42 Design Variants for a Hypothetical Changi-Like Roof

Roof structure: 3,600 shading fins ($3m^2$) positioned just under a double-glazed roof.





Parametric Scheme to Generate Roof Shading Structure

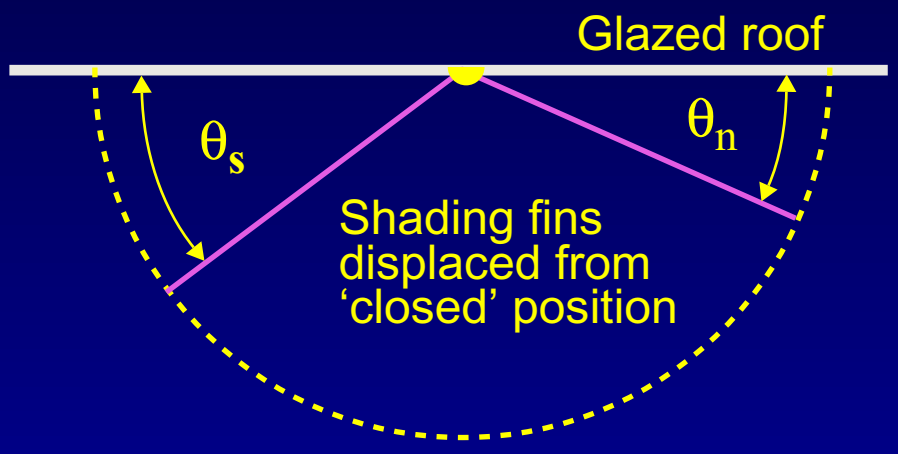
For the rows of fins on the north side of the hinge:

$$if\,(x < 0.3)\,then \qquad \theta_n = 0^\circ$$

$$if\,((x \geq 0.3)\,and\,(x < V))\,then \qquad \theta_n = 4^\circ$$

$$if\,(x \geq V)\,then \qquad \theta_n = 25^\circ$$

Where x is a uniform random number in the range 0 to 1, and V is a probability factor in the range 0.4 to 0.9.



A slightly different scheme was used to displace fins on the other side of the hinge to introduce overall North-South asymmetry into the structure.

The Design Matrix

A probability factor (0.4, 0.5,..., 0.9) for the opening angle of the fin was one design variable, the other was the azimuth orientation of the entire roof structure (0˚, 30˚,..., 180˚). All combinations were considered resulting in a 6 by 7 ‘matrix’ of design variants.

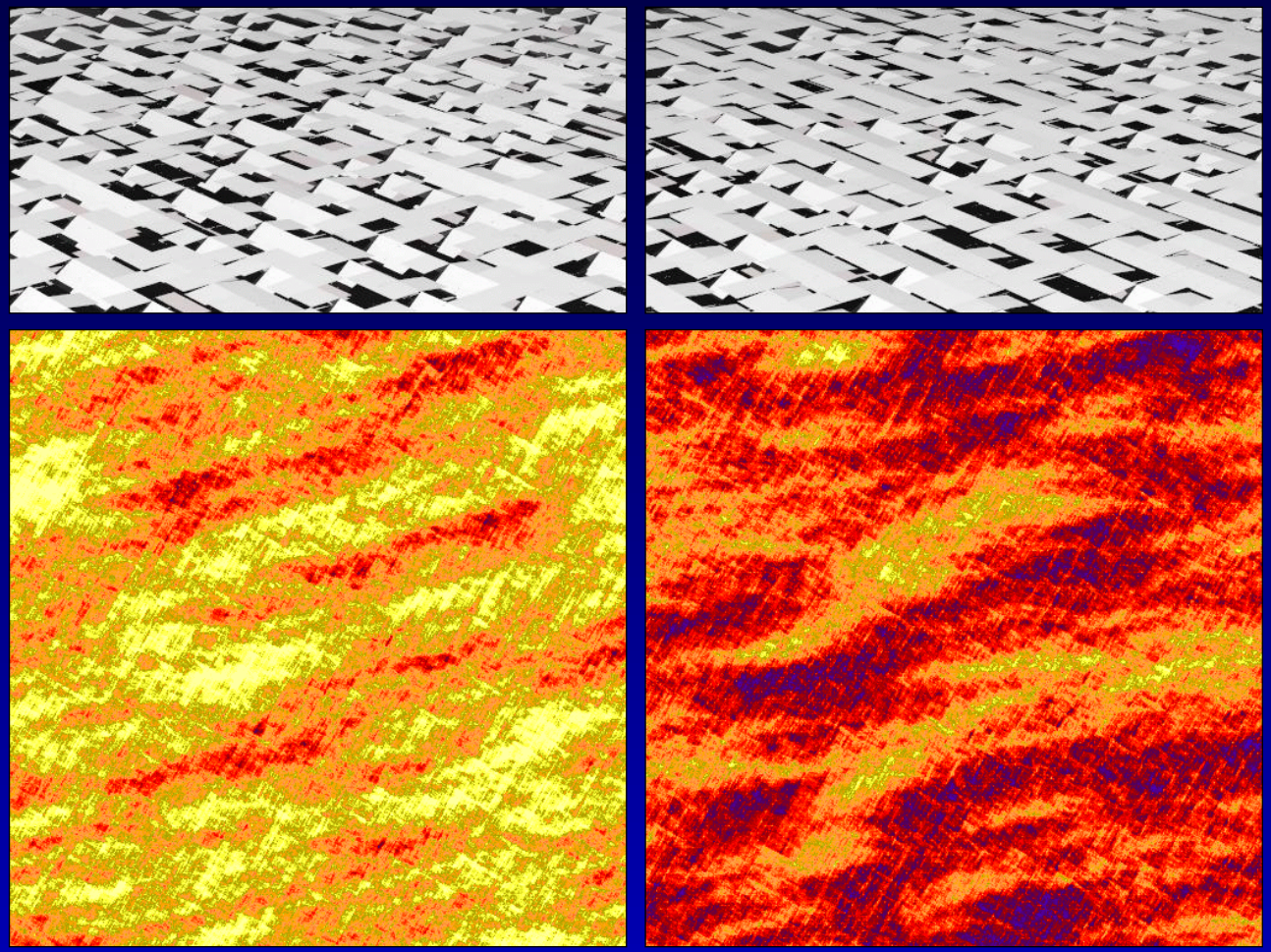
Rapid computation: CPU time for all 42 design variants was only a few hours including post-processing (Apple iMac, 800MHz, G4, Mac OS X).

Note: The entire roof structure was generated from ~10 lines of ***Radiance*** code.

RESULTS - GRAPHICAL FOR TWO VARIANTS

Renderings of the roof configuration.

Irregular pattern of total annual irradiation incident on the floor.



V = 0.5, orientation = 60˚

V = 0.8, orientation = 60˚

Tabular Results

TAI		Probability factor					
		0.4	0.5	0.6	0.7	0.8	0.9
Orientation	0˚	62.7	55.7	47.9	40.5	29.9	19.8
	30˚	59.8	53.1	44.8	37.5	29.8	18.2
	60˚	53.3	46.0	43.5	35.1	26.2	16.9
	90˚	47.1	41.9	37.2	30.4	23.9	15.3
	120˚	41.1	36.8	32.7	28.4	20.5	12.5
	150˚	35.7	33.1	29.6	24.9	18.2	10.7
	180˚	34.0	32.2	29.4	24.5	19.2	11.1

Total annual solar irradiation (TAI) averaged across floor area (kWh/m^2)

PII		Probability factor					
		0.4	0.5	0.6	0.7	0.8	0.9
Orientation	0˚	124	107	88	73	52	35
	30˚	122	110	87	72	56	33
	60˚	126	102	94	73	52	32
	90˚	122	100	92	66	50	32
	120˚	116	100	87	68	47	30
	150˚	96	85	69	55	39	24
	180˚	70	65	56	45	35	20

Peak instantaneous solar (PII) gain averaged across floor area (W/m^2)

CONCLUSION

A marked advance over traditional, largely qualitative, methods. **STIMAP** can produce irradiation images and/or numerical data on virtually any spatio-temporal aspect of solar penetration.

The analysis has demonstrated the relative ease and speed with which a large number of design variants of a complex shading system can be evaluated at high precision.

The reduction of data to summary metrics allows for the reliable comparison of any number of design variants.

'Architect friendly' - it's actually quicker to comprehend an irradiation map than it is to unpick the significance of a sequence of shadow pattern images.

(*Not me, architects have said that*.)