MEASURING AND MODELLING SPECTRAL COMPOSITION OF EQUATORIAL LIGHT

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Colours in an urban context

Spectral reflectance of the surface properties of buildings, vegetation and ground

Spectral characteristics of the Sky --- the source of light

Photo by Phil, Flickr, Rochor Centre, Singapore
Colours around us---the source of light

Varying spectral characteristics of the Singapore skies

This source of light is not constant, rather it changes in both intensity and its spectral distribution with time of the day as well as the atmospheric conditions.

Singapore in particular positioned close to the equator---one can experience partly blue skies, uniform overcast skies, cloudy grey skies to clear blue morning and evening skies with warm orange undertones all within a span of a day.
Colours around us---effects of the changing sky

Introduction

The changing spectral properties of the sky is what changes the tints, tones and shades of the colours we see. In cases of sunrise and sunsets it also changes our perception of the hues around us.

Our perceptions of time and scale, emotional and cultural responses of visual quality and identity also change with the changing qualities of light and colour.
Colours around us---effect of change in surface colours

Introduction

Plaster colour - beige and brown

Plaster colour - white and grey
Colours around us---effect of change in source colour

19:05, 28th March 2018, Singapore

19:05, 24th August 2018, Singapore
Current daylight simulation practices

Introduction

SINGAPORE SKIES

CIE SKIES

Clear Sky 11:50

Intermediate Sky 13:50

Overcast Sky 11:55
Architectural rendering versus Reality

Renderings of architectural projects do not represent the contextual colour and materiality.

source: designboom.com

source: archdaily.com, aedas

source: asiaone.com
Introduction

Architects are particular about the materials and colours they use---but it takes an experienced intuition to mix ‘n’ match as well as chose based on contextual information.

.. “Lou didn’t like the first samples he was seeing from California---they were too green, too blue, not warm enough.....” and he finally chose “..the warmest tone---pinkish like...”

Fred Langford on Louis Kahn’s choice of choosing a cement colour for the concrete to use in the Salk Institute.
Goals

Especially in cases where there are more than two or three bold colours working in confluence to contrast as well as synchronize against the local backgrounds.

Architecture, colour and materiality

The red wall, housing project, Spain, designed by Ricardo Bofill, Photo source: ArchDaily
Goals

The red wall, housing project, Spain, designed by Riccardo Bofill, Photo source: Ricardo Bofill
Can predictive renderings for daylight also represent physically accurate colour perceptions in the scene?

- Measure and analyze changes in colour and spectra in complex urban environments with different materiality.
- Validate two spectral simulation softwares developed to predict non-visual quality of light for visual difference in both colour and spectra of light in these urban environments.
Choosing different sites in Singapore

Urban materiality in Singapore

25% of Singapore's urban areas constitute the Housing Development Board (HDB) units which are essentially plaster facades. 80% of the population in Singapore live in these HDB’s.

30% of the urban areas are covered by vegetation.

The central business districts and the business parks all constitute of reflec-
Choosing different sites in Singapore

The sites are chosen such that these urban materials enclose the space.

Also that with a 5 to 8 mins walk there is an open to sky site where the global spectral irradiance measurements of the sky can be taken.
Choosing different sites in Singapore

Methodology

Choosing different sites in Singapore:

- **PLASTER**
  - ~ 5 to 8 minutes

- **VEGETATION**
  - ~ 5 to 8 minutes

- **REFLECTIVE/GLASS**
  - ~ 5 to 8 minutes

Open sky
Choosing different sites in Singapore

Measurements are taken looking at four directions

PLASTER

NORTH EAST  NORTH WEST  SOUTH EAST  SOUTH WEST
Choosing different sites in Singapore

Measurements are taken in four different sky conditions---clear, intermediate/overcast, evening and morning sky.
**Equipment setup**

Vertical spectral measurements---urban surfaces

- Spectrophotometer measures global spectral distribution
- HDR photography with fish eye lens

Horizontal spectral measurements---open sky

- Spectrophotometer measures global spectral distribution
- HDR photography with fish eye lens
**Equipment setup**

Konica Minolta 2600d spectrophotometer to measure spectral reflectance of materials
Spectral simulation platforms currently available

LARK and ALFA

SPECTRAL SIMULATION PLATFORMS

Based on Radiance

Adaptive Lighting for Alertness
A new circadian lighting design software.

Based on radiative transfer library called libRadtran
Spectral simulation platform --- LARK

**INPUTS**

- **Spectral global spectral irradiances of the sky (W/m^2)** from 360nm - 780nm

- **Gendaylit input**
  - Latitude, longitude, time, month, hour and global horizontal irradiation.

- **Spectral reflectance of the material** 360nm to 800nm

**OUTPUTS**

- **LARK 9 - CHANNEL SIMULATIONS**
  - **Blue channel simulation**
    - 380 nm - 422 nm
    - 422 nm - 460 nm
    - 460 nm - 498 nm
  - **Green channel simulation**
    - 498 nm - 524 nm
    - 524 nm - 550 nm
    - 550 nm - 586 nm
  - **Red channel simulation**
    - 586 nm - 650 nm
    - 650 nm - 714 nm
    - 714 nm - 780 nm
Spectral simulation platform---ALFA

**Methodology**

**INPUTS**

- Precomputed sky based on location
- Location, month, hour
- **Sky condition**
  - Clear, overcast, hazy,
- **Spectral reflectance of the material** 360 to 800nm
- Geometry

**OUTPUTS**

ALFA - LIBTRAN COLOURED SKY SIMULATIONS
Difference between LARK and ALFA

Lark uses measured global spectral irradiance and ALFA uses precomputed skies.

The sun in LARK is an equal energy white source whereas in ALFA the sun is colored.
Visual Comparisons

Results

NORTH EAST  NORTH WEST  SOUTH EAST  SOUTH WEST

CLEAR SKY  13 FEB 11:22 PM 723 W/m²

HDR

Non-spectral

Gendaylit luminance values

Spectral

6800 K
Visual Comparisons

Between the spectral and non-spectral simulations, it is visually clear that the non-spectral simulations appears more ‘beige’ because of the lack of blue reflectance from the sky dome.
Visual Comparisons

The bluish reflectance from diffuse sky component is also not represented in PEREZ and very slightly in ALFA and LARK.

Blue reflectance from the diffuse part of the sky.
Visual Comparisons

Results

NORTH EAST  NORTH WEST  SOUTH EAST  SOUTH WEST

MORNING SKY 18 FEB 07:48 PM 67 W/m²

HDR

Spectral

Perez

Non-spectral

Lark

Spectral

Alfa

7400 K
In the morning sky scenario, all the facades appear bluish and PEREZ simulations appear as a stark contrast.
**Visual Comparisons**

**Results**

Between LARK and ALFA, ALFA has a stronger blue reflectance than LARK.

<table>
<thead>
<tr>
<th>NORTH EAST</th>
<th>NORTH WEST</th>
<th>SOUTH EAST</th>
<th>SOUTH WEST</th>
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</thead>
</table>

**MORNING SKY**

18 FEB 07:48 PM 67 W/m²

![Visual Comparisons between LARK and ALFA](image_url)
Visual Comparisons

Results

NORTH EAST  NORTH WEST  SOUTH EAST  SOUTH WEST

EVENING SKY  18 FEB 18:42 PM 51 W/m²

HDR

Non-spectral

7100 K

Spectral

Perez

Lark

Alfa
Visual Comparisons

The orange reflectance of the sun is only seen ALFA because the sun is coloured in ALFA.
Spectral distribution comparisons

Results

Spectral distribution comparisons for different conditions: Clear, Morning, Evening, Overcast. The graphs show the normalized spectral irradiances across wavelengths ranging from 400 to 800 nm. The measurements and model comparisons are indicated with different lines and markers.
Spectral distribution comparisons

**Results**

North West is the view that has the least sky exposure and LARK has lower RMSE values than ALFA.

For the morning and evening sky ALFA has a relatively higher spectral irradiance values in the red region because of the colour of the sun.

Lark drops in the red bandwidths because its equal energy white sun.
Spectral distribution comparisons

Results

North West

North East

South West

South East

North West

North East

South West

South East

Spectrophotometer

ALFA

LARK (linearly interpolated)
Measuring and Modelling Spectral Composition of Equatorial Light  |  Priji Balakrishnan and J.Alstan Jakubiec

Methodology

**Colour difference comparisons**

**colours in shade**

- HDR: $L = 56.6$, $a = 0.19$, $b = 2.05$
- PEREZ: $\Delta L = -6.2$, $\Delta a = 0.1$, $\Delta b = 1.4$, $\Delta E = 6.5$
- LARK: $\Delta L = -8.2$, $\Delta a = -1.4$, $\Delta b = -2.2$, $\Delta E = 8.7$
- ALFA: $\Delta L = -7.9$, $\Delta a = -2.2$, $\Delta b = 0.7$, $\Delta E = 8.2$

**HDR**

**Perez**

**LARK**

**ALFA**

**colours in direct light**

- HDR: $L = 58.9$, $a = -0.8$, $b = 4.5$
- PEREZ: $\Delta L = 3.8$, $\Delta a = -0.7$, $\Delta b = 4.7$, $\Delta E = 6.0$
- LARK: $\Delta L = -2.0$, $\Delta a = -1.2$, $\Delta b = 1.0$, $\Delta E = 2.6$
- ALFA: $\Delta L = 1.2$, $\Delta a = -2.0$, $\Delta b = 4.5$, $\Delta E = 5.1$

**Colour Difference**  
$\Delta E = \sqrt{(L_1 - L_2)^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2}$
Work in Progress ....

<table>
<thead>
<tr>
<th>EAST</th>
<th>NORTH</th>
<th>SOUTH</th>
<th>WEST</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image of East" /></td>
<td><img src="image2.png" alt="Image of North" /></td>
<td><img src="image3.png" alt="Image of South" /></td>
<td><img src="image4.png" alt="Image of West" /></td>
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</tbody>
</table>

HDR

CLEAR SKY 24 May 12:39 PM 844 W/m²

Thank You

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