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The impact of urban geometry on the radiant environment in outdoor spaces

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Outline of presentation

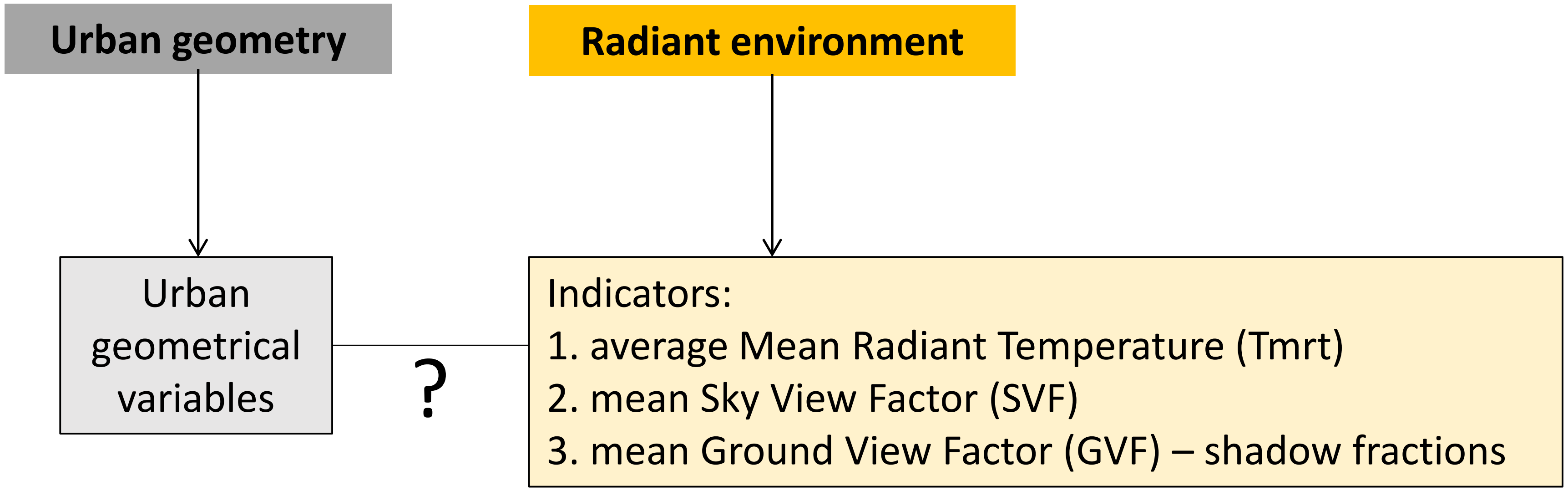
- Introduction
- Methodology
- Results
- Conclusions

References

Introduction

Research questions

To what extent simple urban geometrical variables can predict the radiant environment?
Which urban variables affect it the most?



Introduction

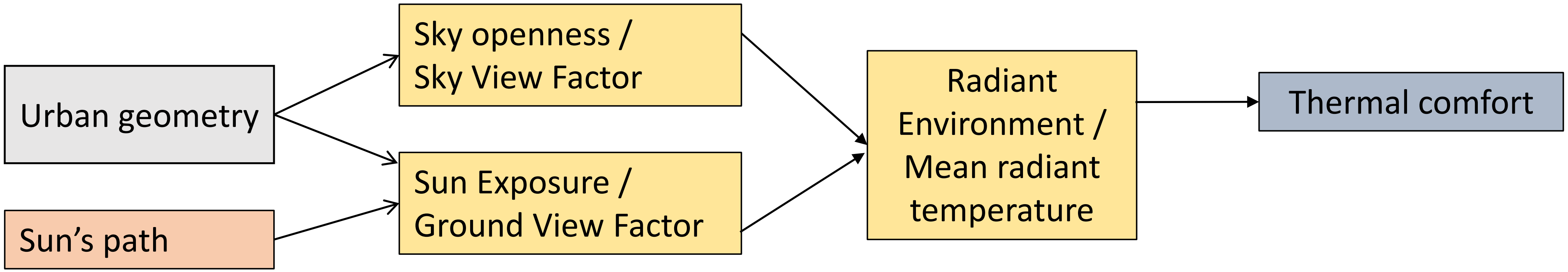
Indicators of radiant environment

- **Mean radiant temperature** (Tmrt), [ºC] – is the sum of all radiation fluxes to which a human body is exposed – governs the human thermal comfort

- **Sky View Factor** (SVF) – is a measure of the openness to the sky vault (related to the diffuse solar and sky component). For a given point, its value is constant and ranges between 0 (completely obstructed) and 1.

- **Ground View Factor** (GVF) – is a measure of the exposure to the sun (related to the direct solar component). For a point, its value varies in time and can be either 0 (in shade) or 1 (sunlit).

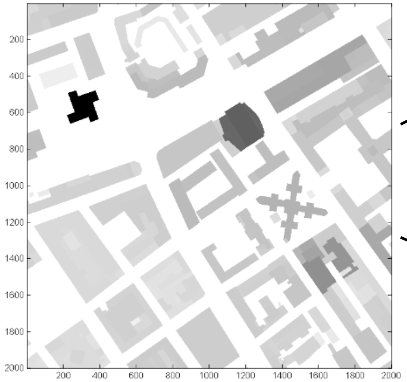
Diagram of 3 indicators' relation to each other and urban geometry



Introduction

SUNNY CONDITIONS

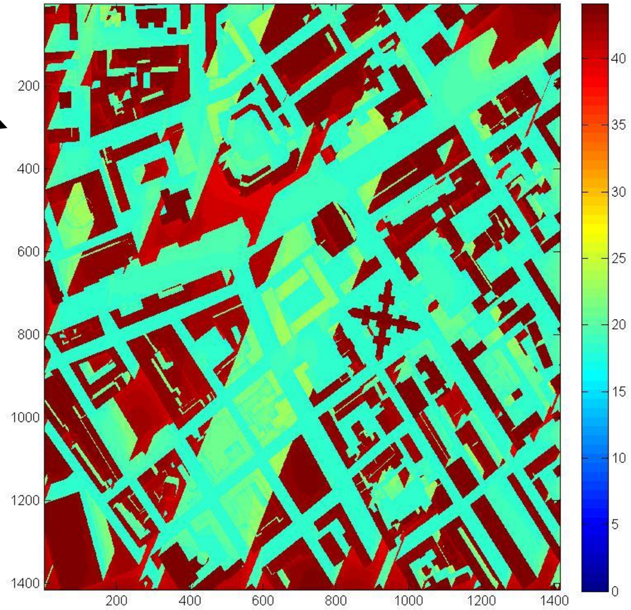
3D urban geometry



Sun's path

SVF map

GVF map – shadow pattern
(13 p.m. on 23 April)

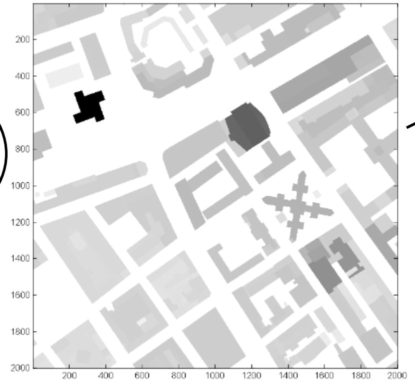


Mean Radiant Temperature map
(13 p.m. on 23 April)

Introduction

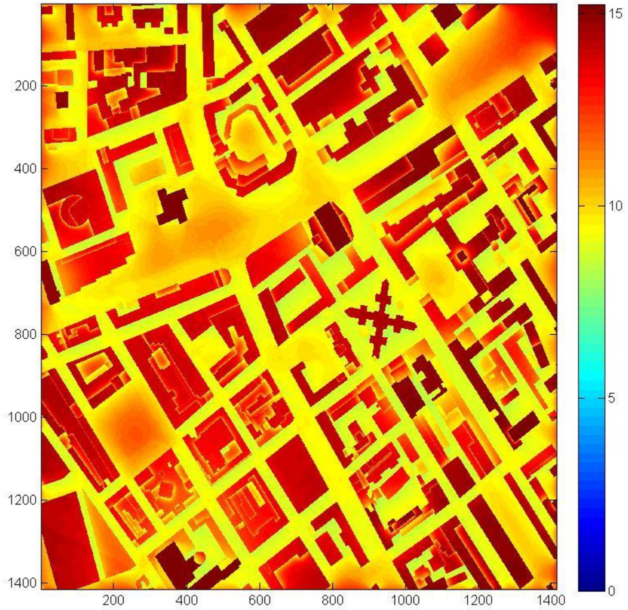
CLOUDY CONDITIONS

3D urban geometry



SVF map

GVF map – shadow pattern
(9 a.m. on 19 October)



Mean Radiant Temperature map
(9 a.m. on 19 October)

Introduction

What is special in this study?

Unique features of the study and relatively new in the literature:

- It uses **real urban forms** (areas of London);
- It has 72 urban forms as case studies which allows for the **statistical exploration of the topic;**
- And, the **spatial scale** (i.e. 500 x 500m) at which the particular topic is studied.

Methodology

3 stages of the study

Three distinct stages:

(i) the **morphological analysis** using image processing techniques in Matlab software (Ratti and Richens, 2004),

(ii) **radiation simulations** with the use of SOLWEIG software (Lindberg and Grimmond, 2008), and

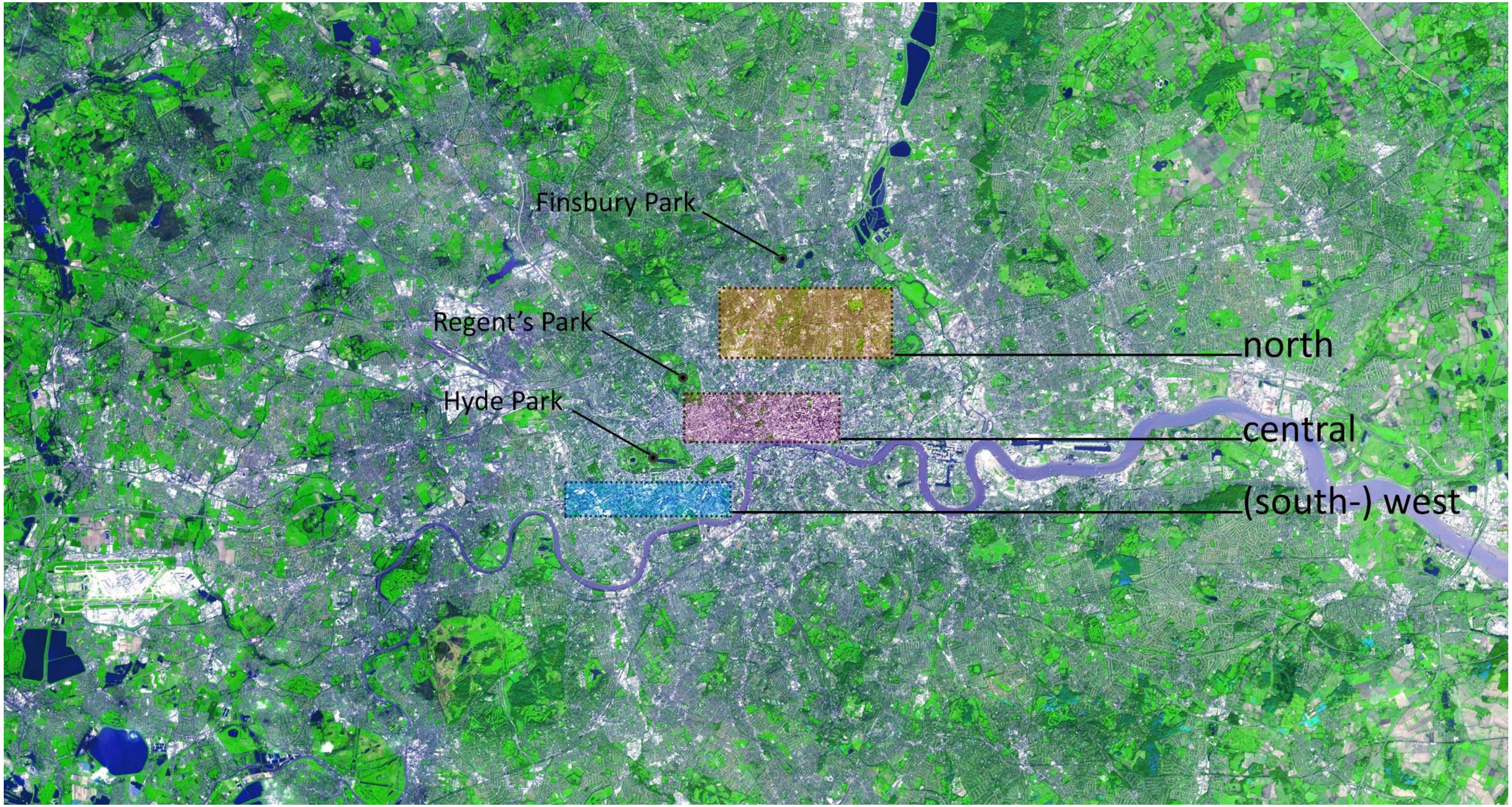
(iii) the **statistical analysis** of the results of the two previous stages investigating potential correlations.

In the morphological analysis and SOLWEIG simulations, urban geometry is represented in DEM format (Digital Elevation Model) which is a compact way of storing urban 3D information using a 2D matrix of building height values.

Example of an urban DEM image

Methodology

3 areas of London studied



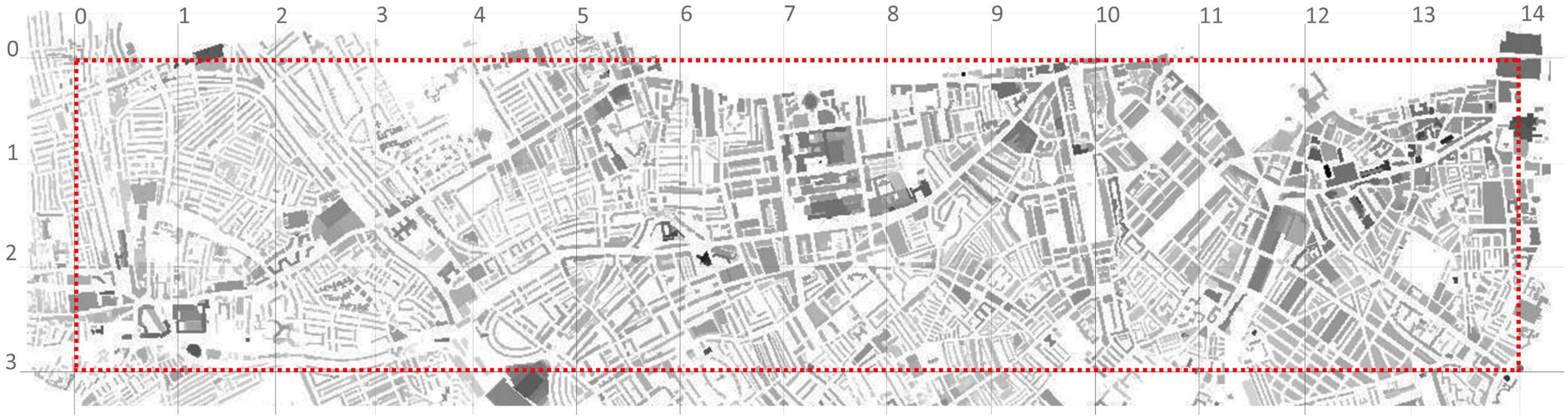
Satellite view of London (Created by NASA, Source: Wikipedia Commons)

Methodology

DEM of the area in **central London**, divided into squares of 500 x 500m

Methodology

DEM of the area in **west London**, divided into squares of 500 x 500m



Methodology

DEM of the area in **north London**, divided into squares of 500 x 500m

Methodology

Selection of squares

From the studied areas, **72 squares** were selected to be studied:

- 28 squares of central London – high density (values: 9-33 m^3/m^2)
- 25 squares of west London – medium density (values: 4-14 m^3/m^2)
- 19 squares of north London – low density (values: 3-6 m^3/m^2)

Criteria of selection:

- Continuity of urban fabric
- Representativeness of different typologies

Methodology

STAGE ONE_ **Morphological analysis**

Computation of urban variables:

Urban density

- *Density* - total built volume on a given site over site area [m^3/m^2].

Urban layout descriptors

- *Site coverage* (Coverage) – buildings' footprint area over site area, [m^2/m^2];
- *Frontal area density* (FAD) – buildings' façades area over site area, [m^2/m^2];
- *Number of built volumes* (NoB) – attached buildings considered as one volume;
- *Mean outdoor distance* (mDistance) – mean distance between built volumes on the ground level, [m];
- *Standard deviation of outdoor distance* (sDistance), [m];
- *Standard deviation of building height* (sHeight) – weighted by footprint area, [m];
- *Standard deviation of built volumes* (sVolume), [m^3].

Methodology

STAGE TWO_ **Radiation simulations**

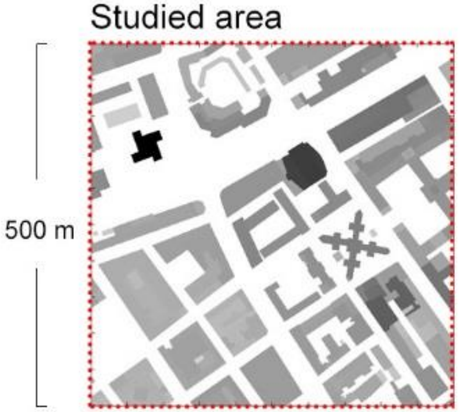
- The **solar and longwave environmental irradiance geometry** (SOLWEIG) model simulates spatial variations of 3D radiation fluxes (incoming to / outgoing from the ground, direct and reflected) and mean radiant temperature (T_{mrt}) as well as shadow patterns in complex urban settings.

- SOLWEIG's inputs: **3-D urban geometry** (in DEM format), a **24-hour weather file** (temperature, humidity, global, direct and diffuse solar radiation) and **geographical information** (latitude, longitude and elevation of London: 51.5^o, -0.17^o and 0m).

- Simulations were run for **8 days** (21 Jun, 26 Jul, 23 Apr, 20 Mar, 19 Oct, 23 Nov, 19 Jan and 29 Dec). **Sunny and cloudy days** have been considered, **evenly distributed in the year** in order for the effect of solar elevations to be examined.

Methodology

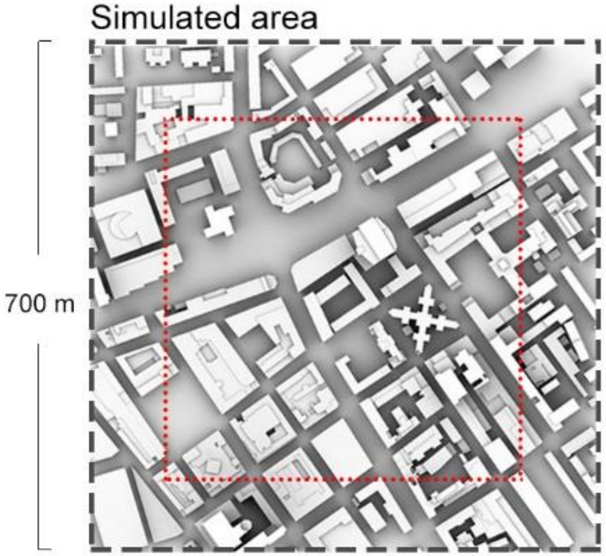
STAGE THREE _ **Statistical analysis**



DEM

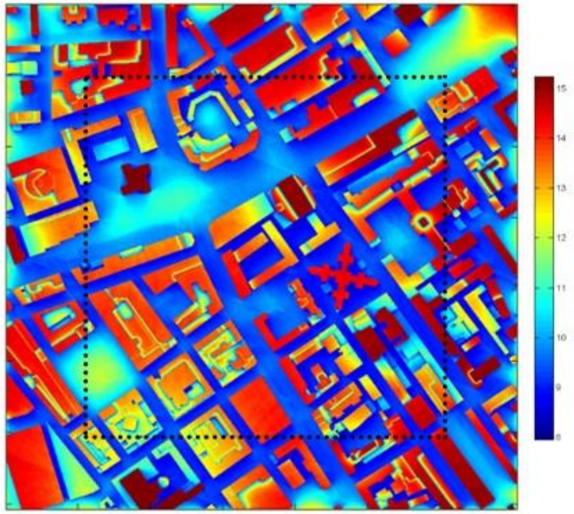
Independent variables

- Density
- Coverage
- FAD
- NoB
- mDistance
- sDistance
- sHeight
- sVolume



SVF

Shadow pattern



Tmrt

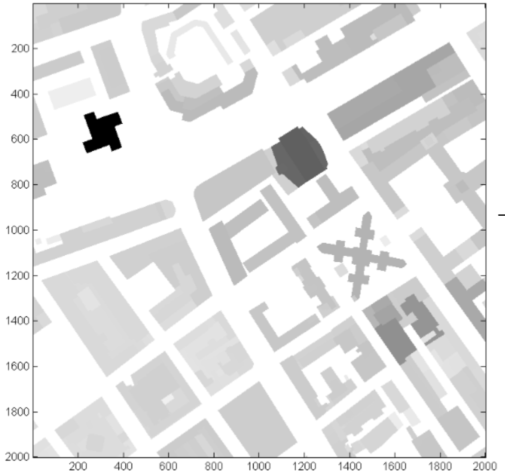
Extraction and averaging of outdoor space's values

Dependent variables

- **Mean SVF**
- **Hourly mean GVF**
- **Hourly mean MRT**

Results

A. Urban variables – mean SVF



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Results

A. Urban variables – mean SVF

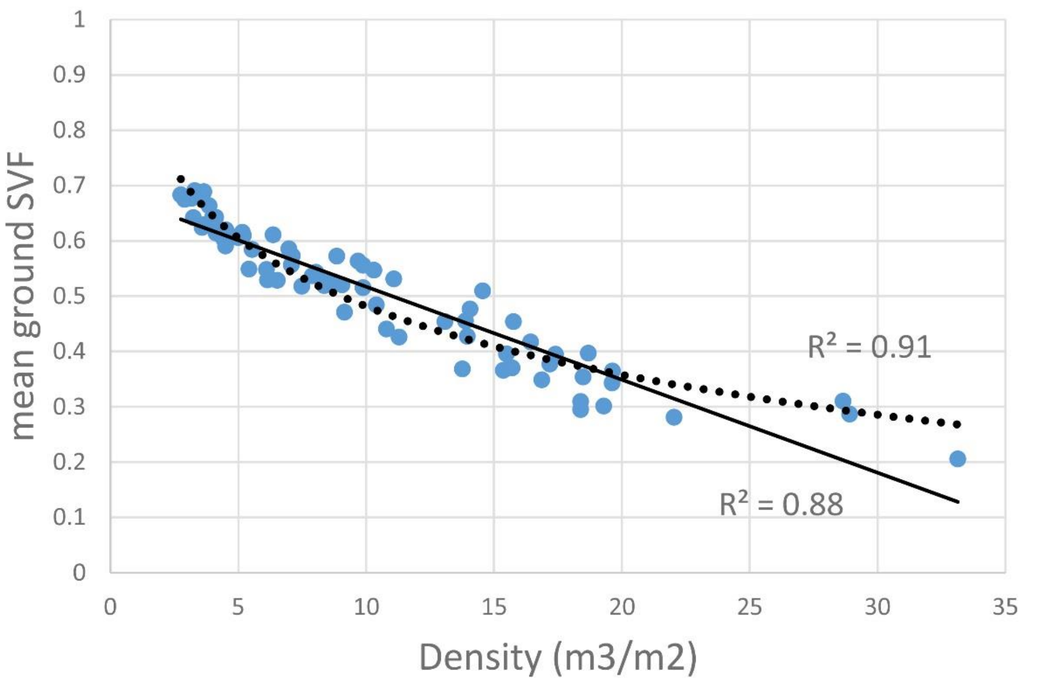
Pearson Correlation and Linear Regression tests revealed a strong correlation between urban variables and mean SVF values.

- **Density – Mean SVF**:

  strong negative correlation >>> r= -0.94

  linear relationship >>> R^2= 0.88 (mSVF=0.685 – 0.017 * density)

  best curve fit >>> logarithmic, R^2 = 0.91



- **7 Urban layout descriptors – Mean SVF:**

  strongest variables (partial correlation for density) >>>

  Coverage (r=-0.70), **mDistance** (r=0.53), **FAD** (r= -0.47), sVolume (r=0.37), sHeight (0.36), sDistance (r=0.32) & NoB (r=0.29)

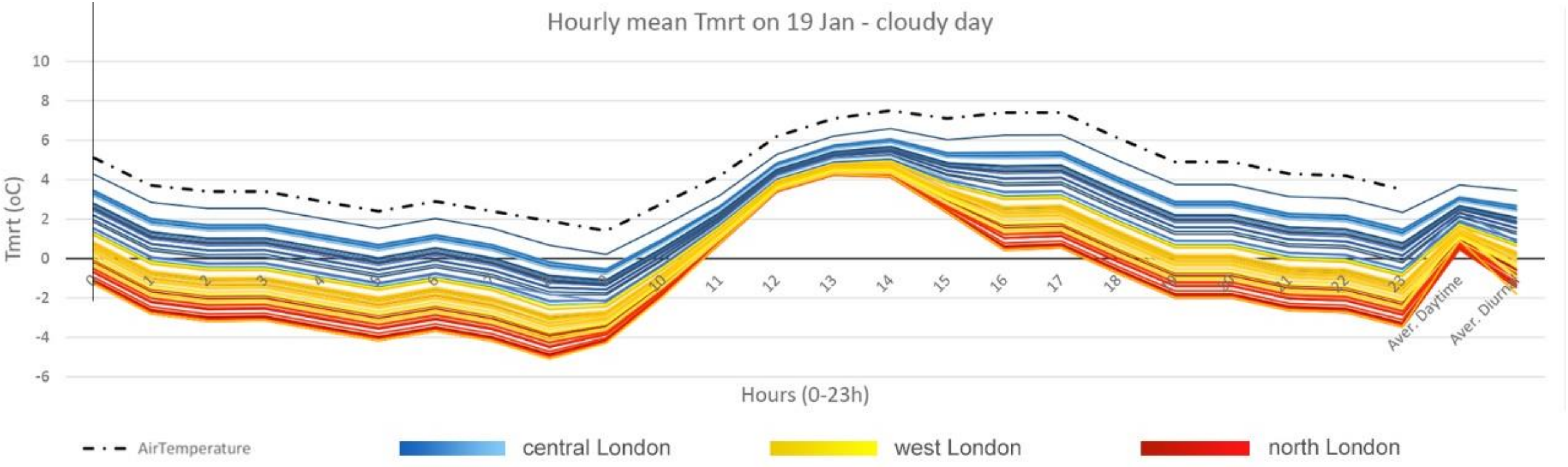
  Linear model (Coverage, mDistance, FAD)>>> **R^2=0.98**

Results

Mean Radiant Temperature (Tmrt) in the absence of direct solar radiation

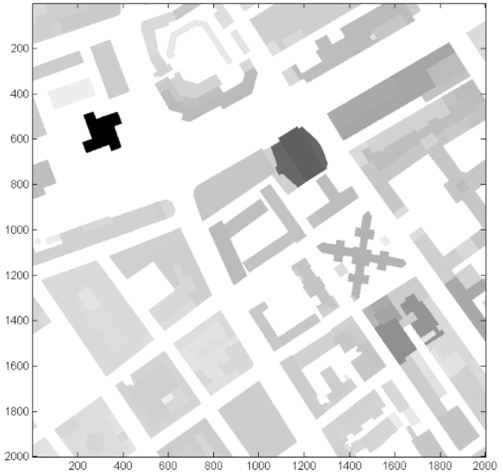
- The strong relationship between urban variables and mean SVF explains the **high correlation (R^2 > 0.95) between urban variables and average Tmrt at night and under cloudy conditions**.

- The outdoor spaces of central London's squares (of higher density) are warmer than those of west and north London, due to greater longwave radiation emitted and reflected by building volumes.



Results

B. Urban variables and mean SVF – Hourly mean GVF



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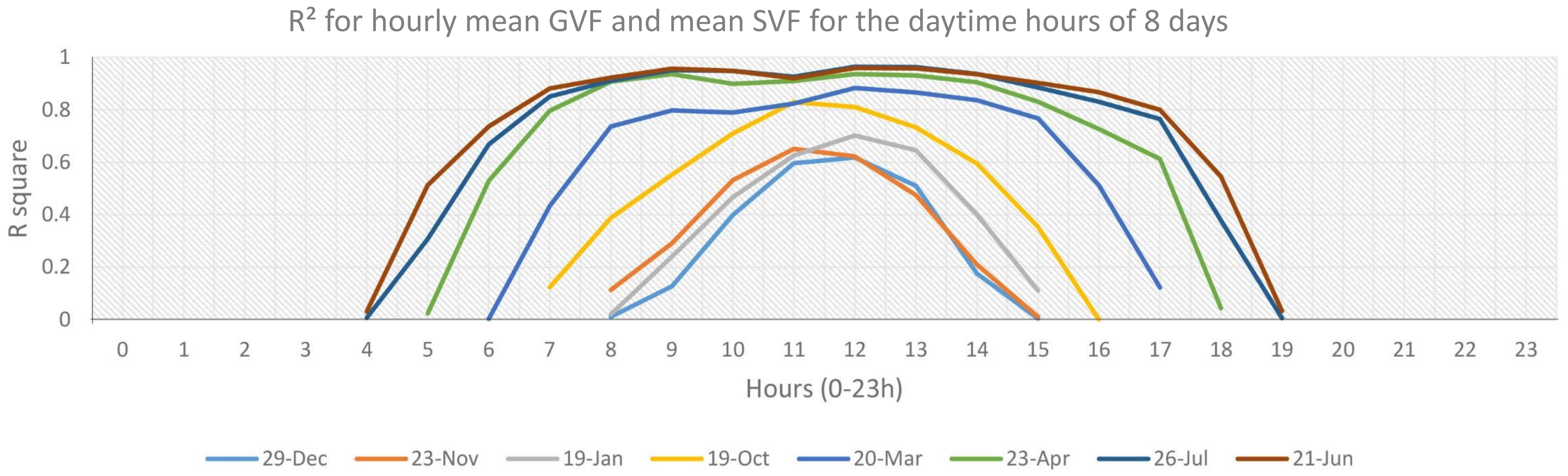
Results

B. Urban variables and mean SVF – Hourly mean GVF

- The strength of the correlation **varies with the sun's altitude angle; the higher the altitude, the higher the correlation** (days closer to summer solstice, hours closer to midday).

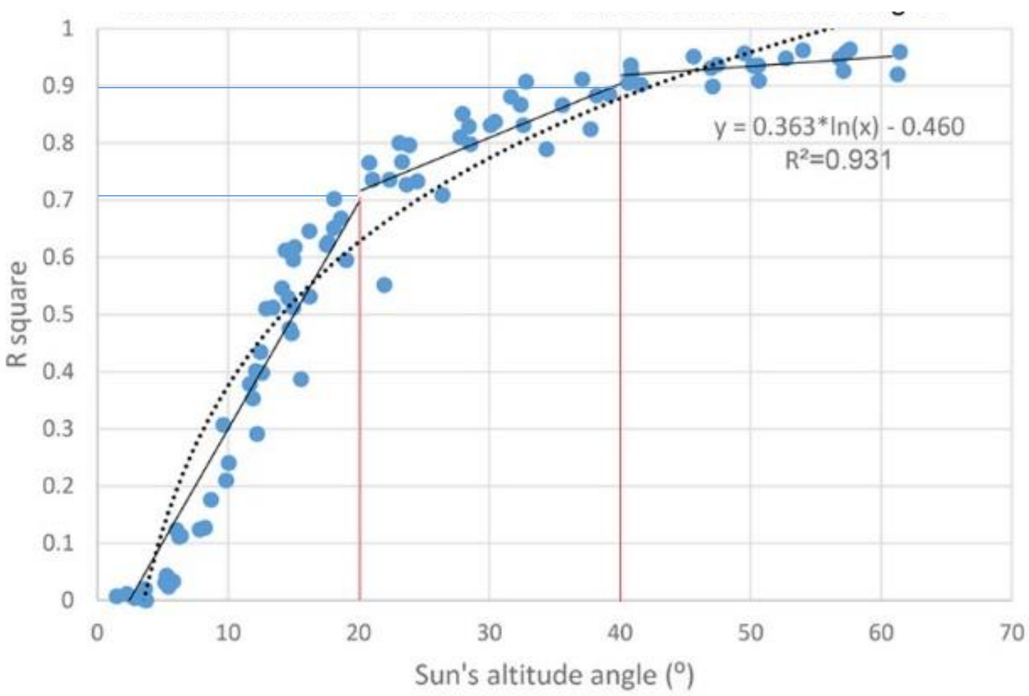
- **The higher the sun is in the sky vault, the more the exposure of the urban form to the sun approximates to that of the sky**.

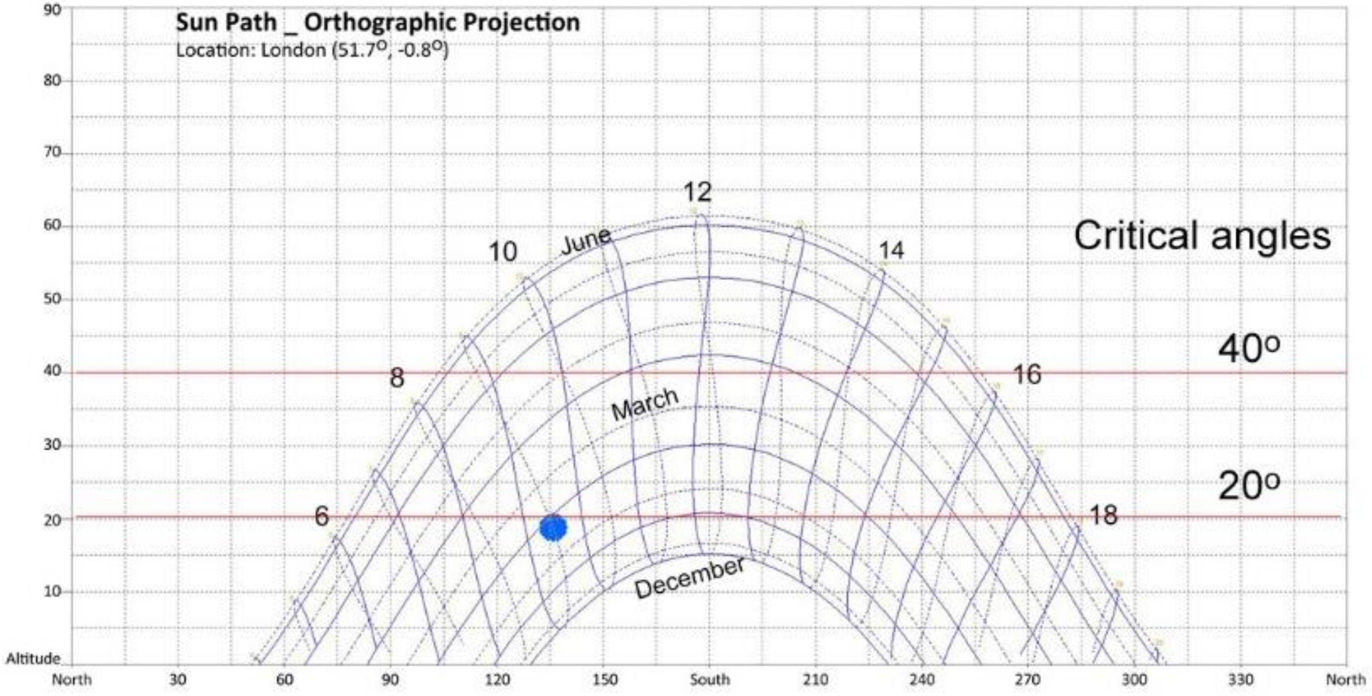


Results

Mean SVF – Hourly mean GVF

Their correlation (R^2) versus sun's altitude angles





Results

Which urban layout descriptors affect hourly shadow fractions the most?

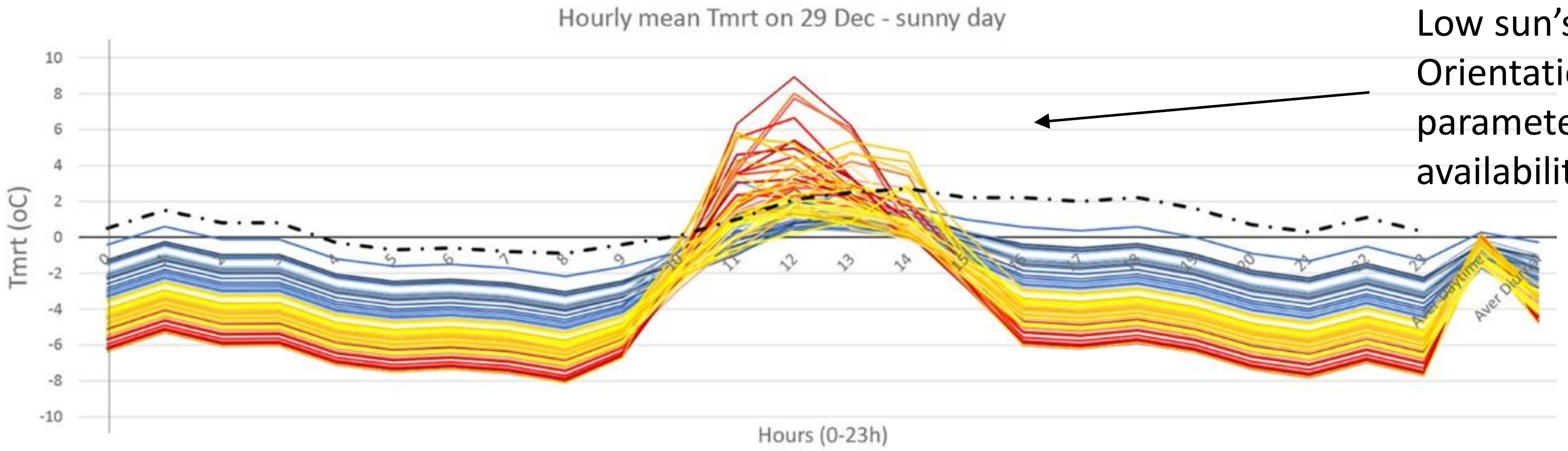
Partial Correlation analysis was performed for the daytime hours of 21st June (summer solstice) controlling density variable.

- 7 am to 9 am & 3pm to 6 pm (morning and late afternoon hours) >>> **Site Coverage** (r= -0.47 to -0.77)
- 10 am to 2 pm (hours close to midday) >>> **mean Distance** or **Frontal Area Density**
- **sDistance**, **sVolume** and **sHeight**, all referring to the homogeneity of the urban form, were also found to be significant in the different hours of the 21st of June

Results

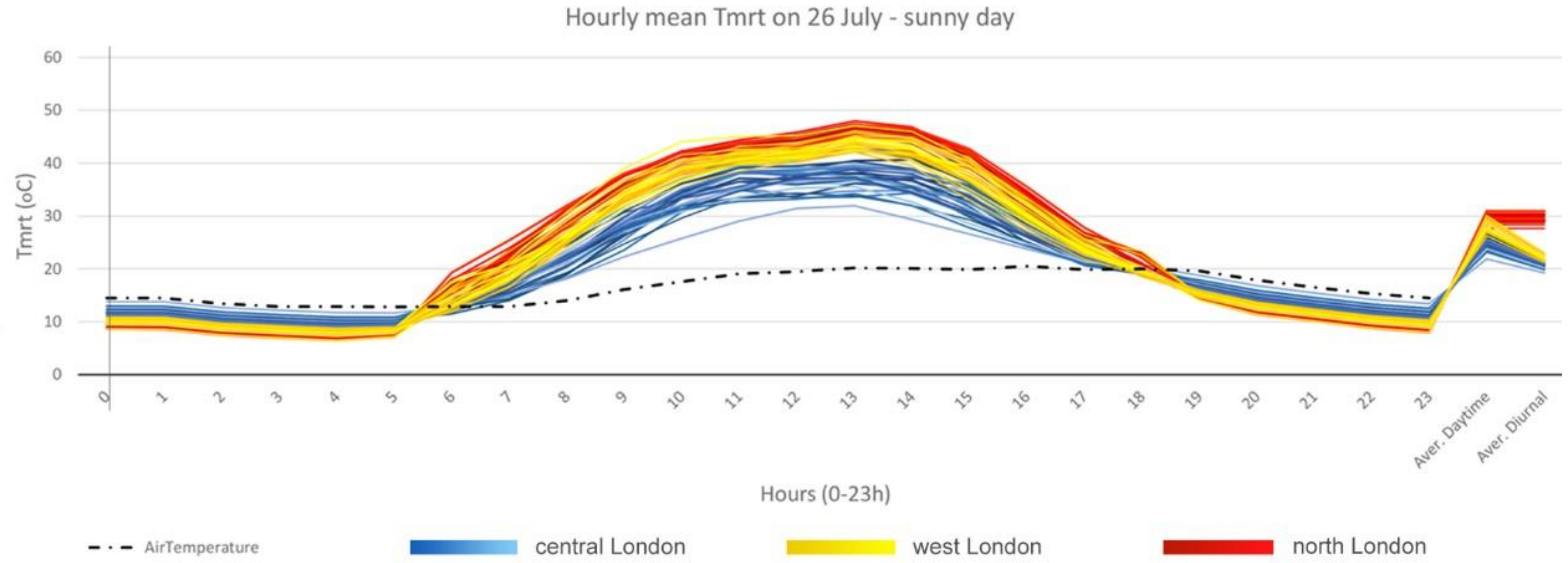
Mean Radiant Temperature (Tmrt) in the presence of direct solar radiation

Sunny winter day
(29 December)



Low sun's altitude angles: Orientation becomes a decisive parameter for the solar availability in outdoor spaces

Sunny summer day
(26 July)



Results

Sensitivity of the results to the spatial scale?

Test:
Division of 72 squares of 500 x 500 m into 288 squares of 250 x 250 m size.
Repetition of statistical tests (for mean SVF).

Result:
The sensitivity of the results to the spatial scale was found to be low.

	500 X 500m	250 x 250 m	Change
Pearson Correlation: Density – mean SVF	r= -0.94	r= - 0.89	- 5.3 %
Partial Correlation: strongest urban variables for mean SVF	Coverage (r= -0.70)	Coverage (r= -0.66)	-5.7%
	mDistance (r= 0.53)	mDistance (r= 0.66)	
	FAD (r= -0.47)	FAD (r= -0.52)	

Conclusions

To what extent simple urban geometrical variables can predict the radiant environment?

Overall, the radiant environment at the district level can be predicted to a great degree by urban variables and thus, is amenable to being modified through urban planning.

- **Absence of solar radiation:**

The correlation with mean outdoor SVF value is significantly strong. As a consequence, the urban variables can predict the average outdoor Tmrt in the night time and under cloudy conditions.

- **Presence of solar radiation:**

The correlation with the hourly mean GVF (hourly shadow fractions) and therefore, with average Tmrt in sunny conditions, varies with sun's altitude angle, and can be significantly strong for a specific range of angles.

The critical angles identified are essentially independent of location; thus, they could be advised for other parts of the world.

Conclusions

Which urban variables affect the radiation availability in outdoor spaces the most?

- **Site coverage** was found to be the strongest variable followed by **mean distance between building volumes** and **frontal area density**. As regards site coverage, in agreement with Lindberg and Grimmond (2011).

- Urban layout descriptors capturing **the randomness of urban layout** also present a significant positive correlation. In general agreement with those studies (e.g. Cheng et al., 2006) arguing that increasing urban randomness enhances the solar availability in the urban fabric.

References

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The End

Thank you for your attention!

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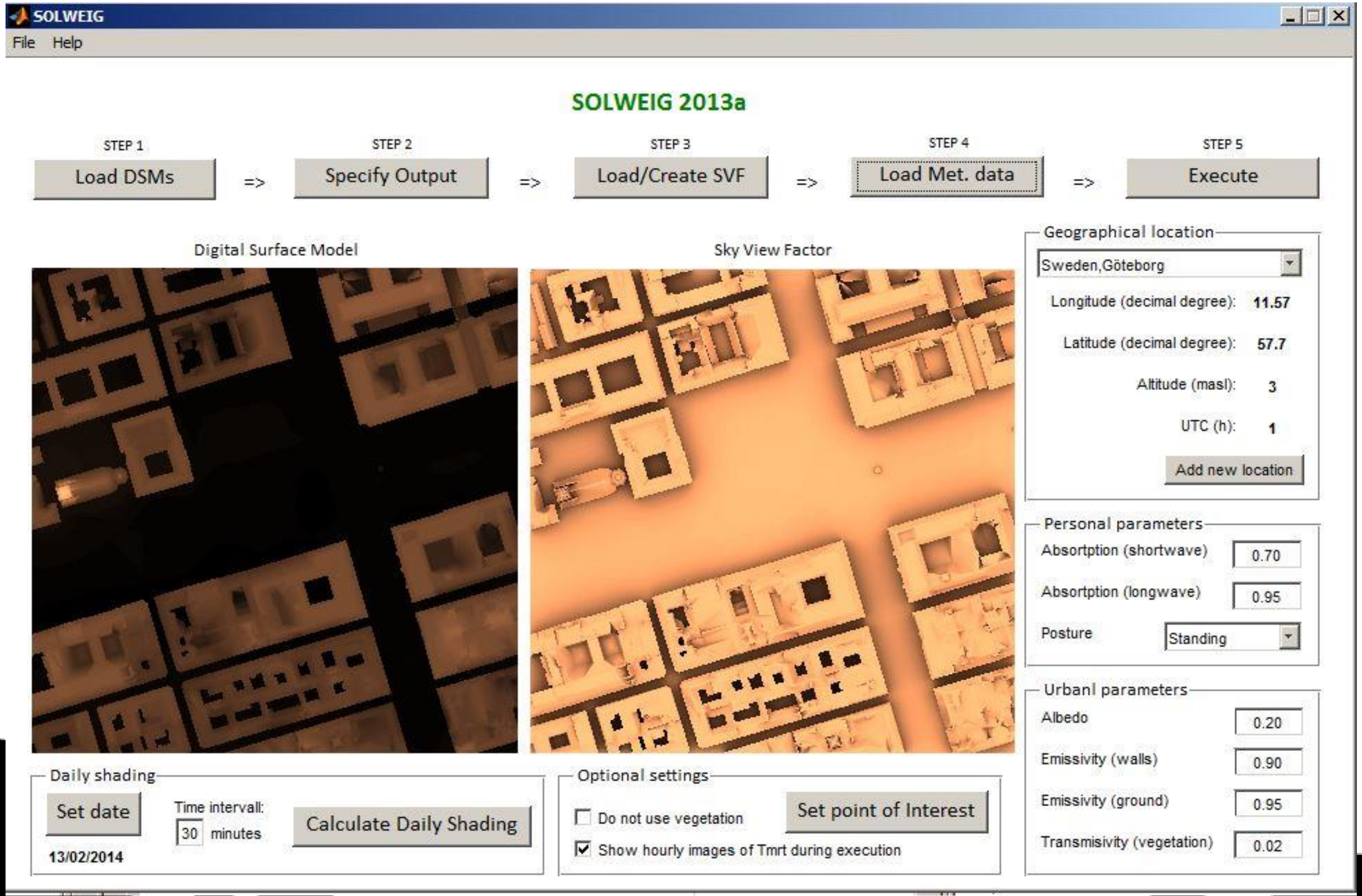
Appendix


SOLWEIG
File Help
SOLWEIG 2013a
STEP 1
Load DSMs
=>
STEP 2
Specify Output
=>
STEP 3
Load/Create SVF
=>
STEP 4
Load Met. data
=>
STEP 5
Execute
Digital Surface Model
Sky View Factor
Geographical location
Sweden,Göteborg
Longitude (decimal degree): 11.57
Latitude (decimal degree): 57.7
Altitude (masl): 3
UTC (h): 1
Add new location
Personal parameters
Absortption (shortwave) 0.70
Absortption (longwave) 0.95
Posture Standing
Urbanl parameters
Albedo 0.20
Emissivity (walls) 0.90
Emissivity (ground) 0.95
Transmisivity (vegetation) 0.02
Daily shading
Set date
13/02/2014
Time intervall:
30 minutes
Calculate Daily Shading
Optional settings
Do not use vegetation
Show hourly images of Tmrt during execution
Set point of Interest

Appendix

Correlations

		Density	Coverage	sHeight	FAD	NoB	mDistance	sDistance	sFootprint	sVolume
Density	Pearson Correlation	1								
	Sig. (2-tailed)									
Coverage	Pearson Correlation	.901**	1							
	Sig. (2-tailed)	.000								
sHeight	Pearson Correlation	.805**	.582**	1						
	Sig. (2-tailed)	.000	.000							
FAD	Pearson Correlation	.944**	.830**	.794**	1					
	Sig. (2-tailed)	.000	.000	.000						
NoB	Pearson Correlation	-.757**	-.829**	-.531**	-.691**	1				
	Sig. (2-tailed)	.000	.000	.000	.000					
mDistance	Pearson Correlation	-.306**	-.389**	-.208	-.364**	-.019	1			
	Sig. (2-tailed)	.009	.001	.079	.002	.876				
sDistance	Pearson Correlation	-.070	-.063	-.135	-.144	-.283*	.905**	1		
	Sig. (2-tailed)	.559	.600	.257	.227	.016	.000			
sFootprint	Pearson Correlation	.790**	.839**	.504**	.639**	-.762**	-.155	.079	1	
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.193	.507		
sVolume	Pearson Correlation	.715**	.633**	.584**	.524**	-.569**	-.087	.038	.865**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.466	.752	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).