The Visualisation of Urban Heat Island Indoor Temperatures

Iris A.H. Theunisse

06-11-2015
"The science Geomatics is concerned with the acquisition, analysis, management and visualisation of geographic data with the aim of gaining knowledge and a better understanding of the (built) environment."
"The science Geomatics is concerned with the acquisition, analysis, management and visualisation of geographic data with the aim of gaining knowledge and a better understanding of the (built) environment."
Urban Heat Island (UHI)

Urban Heat Island (UHI)

Morality & Human Well Being
Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product

Urban Heat Island (UHI)

Energy Consumption
"Sustainable is everything future generations want to inherit, use and maintain"

- Jón Kristinsson -

Energy Consumption
"Sustainable is everything future generations want to inherit, use and maintain"

- Jón Kristinsson -
Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product
Research Question:

"What is the most suitable method for the visualisation and estimation of urban heat island indoor temperatures?"
Choosing UHI

Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product
Building a virtual 3D model
Sensing temperatures
Analysing spatial environment
Modelling indoor temperatures
Choosing UHI

Introduction
Case Study
A 3D Model
Sensing Data
Spatial Analysis
Modelling Temperatures
Final Product

Choosing UHI
Introduction
Case Study
A 3D Model
Sensing Data
Spatial Analysis
Modelling Temperatures
Final Product
Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product
Building a virtual 3D model
The 'BAG data' is a spatial dataset that includes attributes among which the address information and geometry description as footprint polygons in the second dimension.

<table>
<thead>
<tr>
<th>Link</th>
<th>character varying</th>
</tr>
</thead>
<tbody>
<tr>
<td>Street</td>
<td>character varying</td>
</tr>
<tr>
<td>House Number</td>
<td>numeric</td>
</tr>
<tr>
<td>Addition</td>
<td>character varying</td>
</tr>
<tr>
<td>Nr Addition</td>
<td>character varying</td>
</tr>
<tr>
<td>Footprint</td>
<td>geometry(polygon)</td>
</tr>
</tbody>
</table>

...
The ‘BAG data’ is a spatial dataset that includes attributes among which the address description and location description, given by footprint polygons in the second dimension.
The **BAG data** is a spatial dataset that includes attributes among which the address description and location description, given by footprint polygons in the second dimension.

<table>
<thead>
<tr>
<th>Link</th>
<th>Street</th>
<th>House Number</th>
<th>Addition</th>
<th>NrAddition</th>
<th>Footprint (geometry(polygon))</th>
</tr>
</thead>
<tbody>
<tr>
<td>pstcode_nr_add</td>
<td>Toepad</td>
<td>11</td>
<td>B</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Ocarina</td>
<td>5</td>
<td></td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Schans</td>
<td>64</td>
<td>A</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Schieweg</td>
<td>57</td>
<td></td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Schieweg</td>
<td>262</td>
<td>A</td>
<td>001</td>
<td>0103000...</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Schildmeer</td>
<td>14</td>
<td>A</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Binnenwegplein</td>
<td>280</td>
<td>A</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Beukelsweg</td>
<td>91</td>
<td></td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
### A 3D Model

<table>
<thead>
<tr>
<th>Link</th>
<th>Street</th>
<th>House Number</th>
<th>Addition</th>
<th>NrAddition</th>
<th>Footprint (geometry(polygon))</th>
</tr>
</thead>
<tbody>
<tr>
<td>postcode_nr_add</td>
<td>Toepad</td>
<td>11</td>
<td>B</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>postcode_nr_add</td>
<td>Ocarina</td>
<td>5</td>
<td>B</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>postcode_nr_add</td>
<td>Schans</td>
<td>64</td>
<td>A</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>postcode_nr_add</td>
<td>Schieweg</td>
<td>57</td>
<td>A</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>postcode_nr_add</td>
<td>Schieweg</td>
<td>262</td>
<td>A</td>
<td>001</td>
<td>0103000...</td>
</tr>
<tr>
<td>postcode_nr_add</td>
<td>Schildmeer</td>
<td>14</td>
<td>A</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>postcode_nr_add</td>
<td>Binnenwegplein</td>
<td>280</td>
<td>A</td>
<td></td>
<td>0103000...</td>
</tr>
<tr>
<td>postcode_nr_add</td>
<td>Beukelsweg</td>
<td>91</td>
<td></td>
<td></td>
<td>0103000...</td>
</tr>
</tbody>
</table>

The 'BAG data' is a spatial dataset that includes attributes among which the address description and location description, given by footprint polygons in the second dimension.
Elevation data in the Netherlands is provided and freely available from the current Dutch elevations, 'AHN2 data', and used to retrieve information about building elevation.
Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling

Temperatures

Final Product

'Ground-level raster, 0.5m'

'Raw raster, 0.5m'
Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product
Surface Height \hspace{1cm} Absolute Height \hspace{1cm} Building Height

\[
m = \text{AHN filtered}
\]

\[
\text{abs}_z = \text{AHN filtered out}
\]

\[
\text{rel}_z = \text{abs}_z - m
\]

AddressHeight\( (L_z) \) = \frac{\text{rel}_z}{\text{geometry} \text{ count}}

AddressMinZ = \text{rank} \times L_z

Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product
**Introduction**

**Case Study**

**A 3D Model**

**Sensing Data**

**Spatial Analysis**

**Modelling Temperatures**

**Final Product**

---

**Surface Height**

- \( m = \text{AHN filtered} \)

**Absolute Height**

- \( \text{abs}_z = \text{AHN filtered out} \)

**Building Height**

- \( \text{rel}_z = \text{abs}_z - m \)

**Layer Height**

- \( \text{AddressHeight}(Lz) = \frac{\text{rel}_z}{\text{geometry_count}} \)

**Rank**

- \( \text{AddressMinZ} = \text{rank} \times Lz \)
Surface Height

Building Height

Layer Height

Rank

\[ \text{rel}_z = \text{abs}_z - m \]

AddressHeight(Lz) = \( \frac{\text{rel}_z}{\text{geometry_count}} \)

AddressMinZ = \( \text{rank} \times \text{Lz} \)
**Introduction**

**Case Study**

**A 3D Model**

**Sensing Data**

**Spatial Analysis**

**Modelling Temperatures**

**Final Product**

---

**Building Height**

- \( \text{rel}_z = \text{abs}_z - m \)

**Layer Height**

- \( \text{AddressHeight}(Lz) = \frac{\text{rel}_z}{\text{geometry\_count}} \)

**Rank**

- \( \text{AddressMinZ} = \text{rank} \times Lz \)
Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling

Temperatures

Final Product

Surface Height

Absolute Height

Building Height

Layer Height

Rank

\[ m = \text{AHN filtered} \]

\[ \text{abs}_z = \text{AHN filtered out} \]

\[ \text{rel}_z = \text{abs}_z - m \]

\[ \text{AddressHeight}(L_z) = \frac{\text{rel}_z}{\text{geometry\_count}} \]

\[ \text{AddressMinZ} = \text{rank} \times L_z \]
<table>
<thead>
<tr>
<th>Link</th>
<th>Street</th>
<th>House Number</th>
<th>Addition</th>
<th>NrAddition</th>
<th>Footprint</th>
<th>AddressMinZ</th>
<th>AddressHeight</th>
</tr>
</thead>
<tbody>
<tr>
<td>pstcode_nr_add</td>
<td>Toepad</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td>0103000...</td>
<td>3,288</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Ocarina</td>
<td>5</td>
<td>B</td>
<td></td>
<td></td>
<td>0103000...</td>
<td>7,524</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Schans</td>
<td>64</td>
<td></td>
<td></td>
<td></td>
<td>0103000...</td>
<td>11,758</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Schieweg</td>
<td>57</td>
<td>A</td>
<td></td>
<td></td>
<td>0103000...</td>
<td>-1,359</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Schieweg</td>
<td>262</td>
<td></td>
<td></td>
<td></td>
<td>0103000...</td>
<td>8,054</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Schildmeer</td>
<td>14</td>
<td>A</td>
<td>001</td>
<td></td>
<td>0103000...</td>
<td>2,209</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Binnenwegplein</td>
<td>280</td>
<td>A</td>
<td></td>
<td></td>
<td>0103000...</td>
<td>15,564</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>Beukelsweg</td>
<td>91</td>
<td></td>
<td></td>
<td></td>
<td>0103000...</td>
<td>10,352</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Geometry 'limitations' due to assumptions:

- not all addresses are equal to footprint
- not all address number indicators are ascending
Sensing temperatures
The main dataset used in this research is the sensed data retrieved by *van der Hoeven and Wandl (2015)* for the ‘Hotterdam’ project. In the summer of 2014, they measured the temperature in Rotterdam by using sensors.
The main dataset used in this research is the sensed data retrieved by *van der Hoeven and Wandl (2015)* for the ‘Hotterdam’ project. In the summer of 2014, they measured the temperature in Rotterdam by using sensors. About 1300 sensors were distributed.
A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product

A python script is used to run through all the sensed measurement, to store this as 'Sensed Data' dataset in the PostgreSQL database and therefore make it accessible for performing SQL queries.
A python script is written to run through all the sensed measurement, to store this as the 'Sensed Data' dataset in the PostgreSQL database and therefore make it accessible for performing SQL queries.

Sensed data 'Limitations' due to:

- Low variety in sensor distribution
- Wrong installation and lacking information of sensor positioning within the houses

<table>
<thead>
<tr>
<th>Link</th>
<th>SensorID</th>
<th>Day</th>
<th>Hour</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>pstcode_nr_add</td>
<td>02TTCL</td>
<td>2014-08-02</td>
<td>1</td>
<td>27,175</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>02T7M1</td>
<td>2014-08-02</td>
<td>5</td>
<td>26,5</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>02TTCL</td>
<td>2014-08-02</td>
<td>23</td>
<td>26,5</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>02TOGM</td>
<td>2014-08-02</td>
<td>7</td>
<td>25,558</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>02TTC9</td>
<td>2014-08-02</td>
<td>8</td>
<td>27,5</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>02T7M1</td>
<td>2014-08-02</td>
<td>11</td>
<td>25</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>02TTCY</td>
<td>2014-08-02</td>
<td>7</td>
<td>23,917</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>02TOGW</td>
<td>2014-08-02</td>
<td>18</td>
<td>26,125</td>
</tr>
</tbody>
</table>

...
Analysing spatial environment
Spatial analysis per address is done to retrieve values of variables of neighbouring characteristics that might influence the indoor temperature. Different techniques are applied on multiple datasets to retrieve these values.
Spatial analysis per address is done to retrieve values of variables of neighbouring characteristics that might influence the indoor temperature. Different techniques are applied on multiple datasets to retrieve these values.
LANDSAT 8 Satellite Images

Top10NL
Topographical vector data of the Netherlands scale 1:5000-1:25000

CBS Statistics
All statistics of the Netherlands

BAG
Basic registration of addresses and buildings in the Netherlands

Municipality Records
Document retrieved by the municipality of Rotterdam

Created 3D Model
Developed as explained before

AHN2
Current Dutch elevation model of the Netherlands

KNMI Measurements
Royal Meteorological Institute of the Netherlands

Sensed Data
Retrieved from the Hotterdam project (van der Hoeven & Wandl)
LANDSAT 8 Satellite Images

Top10NL
Topographical vector data of the Netherlands scale 1:5000-1:25000

CBS Statistics
All statistics of the Netherlands

BAG
Basic registration of addresses and buildings in the Netherlands

Municipality Records
Document retrieved by the municipality of Rotterdam

Created 3D Model
Developed as explained before

AHN2
Current Dutch elevation model of the Netherlands

KNMI Measurements
Royal Meteorological Institute of the Netherlands

Sensed Data
Retrieved from the Hotterdam project (van der Hoeven & Wandl)
LANDSAT 8 Satellite Images

Top10NL
Topographical vector data of the Netherlands scale 1:5000-1:25000

CBS Statistics
All statistics of the Netherlands

BAG
Basic registration of addresses and buildings in the Netherlands

Municipality Records
Document retrieved by the municipality of Rotterdam

Created 3D Model
Developed as explained before

AHN2
Current Dutch elevation model of the Netherlands

KNMI Measurements
Royal Meteorological Institute of the Netherlands

Sensed Data
Retrieved from the Hotterdam project (van der Hoeven & Wandl)
1. Count number of point features within a buffer

2. Calculate average value of intersecting polygon features within a buffer

3. Calculate area of intersecting polygon features within a buffer
1. Count number of point features within a buffer

2. Calculate average value of intersecting polygon features within a buffer

3. Calculate area of intersecting polygon features within a buffer
1. Count number of point features within a buffer

2. Calculate average value of intersecting polygon features within a buffer

3. Calculate area of intersecting polygon features within a buffer
1. Count number of point features within a buffer

2. Calculate average value of intersecting polygon features within a buffer

3. Calculate area of intersecting polygon features within a buffer
### Surface temperature

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Source Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface energy</td>
<td>Top10NL</td>
</tr>
<tr>
<td>Albedo</td>
<td>Topographical vector data of the Netherlands scale 1:5000-1:25000</td>
</tr>
<tr>
<td>Imperviousness</td>
<td>CBS Statistics</td>
</tr>
<tr>
<td>Vegetation</td>
<td>All statistics of the Netherlands</td>
</tr>
<tr>
<td>Surface water</td>
<td>BAG</td>
</tr>
<tr>
<td>Neighbourhood density</td>
<td>Basic registration of addresses and buildings in the Netherlands</td>
</tr>
<tr>
<td>Street orientation</td>
<td>Municipality Records</td>
</tr>
<tr>
<td>Construction year</td>
<td>Document retrieved by the municipality of Rotterdam</td>
</tr>
<tr>
<td>Address envelope</td>
<td>Created 3D Model</td>
</tr>
<tr>
<td>Roof area</td>
<td>Developed as explained before</td>
</tr>
<tr>
<td>Address height</td>
<td>AHN2</td>
</tr>
<tr>
<td>Sky view factor</td>
<td>Current Dutch elevation model of the Netherlands</td>
</tr>
<tr>
<td>Outdoor temperature</td>
<td>KNMI Measurements</td>
</tr>
<tr>
<td></td>
<td>Royal Meteorological Institute of the Netherlands</td>
</tr>
<tr>
<td></td>
<td>Sensed Data</td>
</tr>
<tr>
<td></td>
<td>Retrieved from the Hotterdam project (van der Hoeven &amp; Wandl)</td>
</tr>
</tbody>
</table>
Introduction

Case Study

A 3D Model

Sensing Data

**Spatial Analysis**

Modelling Temperatures

Final Product

- Surface temperature
- Surface energy
- Albedo
- Imperviousness
- Vegetation
- Surface water
- Neighbourhood density
- Street orientation
- Construction year
- Address envelope
- Roof area
- Address height
- Sky view factor
- Outdoor temperature
TIRS bands, band 10 and 11, of the Landsat 8 satellite images are used to calculate surface temperature by:

First, conversion to \( L_{\lambda} \), Top-of-atmosphere (TOA) spectral radiance:

\[
L_{\lambda} = M_L Q_{cal} + A_L
\]

\( M_L \) = Band-specific multiplicative rescaling factor  
\( A_L \) = Band-specific additive rescaling factor  
\( Q_{cal} \) = Digital number

Second, conversion to \( T_s \), At-satellite brightness temperature:

\[
T_s = \frac{K_2}{\ln \left( \frac{K_1}{L_{\lambda}} + 1 \right)} - X
\]

\( K_1 \) = Band-specific thermal conversion constant  
\( K_2 \) = Band-specific thermal conversion constant  
\( X \) = Transformation value to degree Celsius (272.15)

Finally, the conversion to \( T_g \), surface temperature:

\[
T_g = \frac{T_s}{1 + w} * \left( \frac{T_s}{p} * \ln (e) \right)
\]

\( T_s \) = At-satellite brightness temperature (C)  
\( W \) = Wavelength of emitted radiance  
\( p \) = 14380mK  
\( e \) = land surface emissivity
Surface temperature
Surface energy
Albedo
Imperviousness
Vegetation
Surface water
Neighbourhood density
Street orientation
Construction year
Address envelope
Roof area
Address height
Sky view factor
Outdoor temperature
Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product

Surface temperature
- Surface energy
- Albedo
- Imperviousness
- Vegetation
- Surface water
- Neighbourhood density
- Street orientation
- Construction year
- Address envelope
- Roof area
- Address height
- Sky view factor
- Outdoor temperature
Surface temperature
Surface energy
Albedo
Imperviousness
Vegetation
Surface water
Neighbourhood density
Street orientation
Construction year
Address envelope
Roof area
Address height
Sky view factor
Outdoor temperature
Surface temperature
Surface energy
Albedo
Imperviousness
Vegetation
Surface water
Neighbourhood density
Street orientation
Construction year
Address envelope
Roof area
Address height
Sky view factor
Outdoor temperature
Surface temperature

Surface energy

Albedo

Imperviousness

Vegetation

Surface water

Neighbourhood density

Street orientation

Construction year

Address envelope

Roof area

Address height

Sky view factor

Outdoor temperature
Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product

Surface temperature
Surface energy
Albedo
Imperviousness
Vegetation

Surface water

Neighbourhood density
Street orientation
Construction year
Address envelope
Roof area
Address height
Sky view factor
Outdoor temperature
Surface temperature
Surface energy
Albedo
Imperviousness
Vegetation
Surface water
Neighbourhood density
Street orientation
Construction year
Address envelope
Roof area
Address height
Sky view factor
Outdoor temperature
<table>
<thead>
<tr>
<th>Link</th>
<th>Variable1</th>
<th>VariableN</th>
<th>Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>pstcode_nr_add</td>
<td>0.483</td>
<td>4474</td>
<td>8</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.385</td>
<td>16706</td>
<td>4</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.783</td>
<td>2513</td>
<td>18</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.361</td>
<td>4474</td>
<td>3</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.845</td>
<td>7561</td>
<td>8</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.241</td>
<td>17364</td>
<td>22</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.825</td>
<td>2513</td>
<td>13</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.185</td>
<td>8013</td>
<td>5</td>
</tr>
</tbody>
</table>

- **Surface temperature**
- **Surface energy**
- **Albedo**
- **Imperviousness**
- **Vegetation**
- **Surface water**
- **Neighbourhood density**
- **Street orientation**
- **Construction year**
- **Address envelope**
- **Roof area**
- **Address height**
- **Sky view factor**
- **Outdoor temperature**
Modelling indoor temperatures
\[ Y_1 = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \cdots + \beta_p X_{i1} \]
\[ Y_1 = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \cdots + \beta_p X_{p1} \]

322,433 (addresses) * 24 (hours)
\[ Y_1 = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \cdots + \beta_p X_{p1} \]

572 (addresses) * 24 (hours)
<table>
<thead>
<tr>
<th>Link</th>
<th>Variable1</th>
<th>VariableN</th>
<th>Hour</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>pstcode_nr_add</td>
<td>0.483</td>
<td>4474</td>
<td>8</td>
<td>27.175</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.385</td>
<td>16706</td>
<td>4</td>
<td>26.5</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.783</td>
<td>2513</td>
<td>18</td>
<td>26.5</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.361</td>
<td>4474</td>
<td>3</td>
<td>25.558</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.845</td>
<td>7561</td>
<td>8</td>
<td>27.5</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.241</td>
<td>17364</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.825</td>
<td>2513</td>
<td>13</td>
<td>23.917</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.185</td>
<td>8013</td>
<td>5</td>
<td>26.125</td>
</tr>
</tbody>
</table>

**Independent variables**

**Dependent variable**
<table>
<thead>
<tr>
<th>Indoor temperature</th>
<th>Surface temperature</th>
<th>Net radiation</th>
<th>Global radiation</th>
<th>Ground flux</th>
<th>Latent heat</th>
<th>Sensible flux</th>
<th>Albedo</th>
<th>Imperviousness</th>
<th>NDVI</th>
<th>LAI</th>
<th>Trees</th>
<th>Water index</th>
<th>Footprint density</th>
<th>Height density index</th>
<th>Population density</th>
<th>Orientation index</th>
<th>Height</th>
<th>Volume</th>
<th>Envelope</th>
<th>Roof area</th>
<th>Construction year</th>
<th>SVF</th>
<th>Outdoor temperature</th>
</tr>
</thead>
</table>

### Introduction

### Case Study

### A 3D Model

### Sensing Data

### Spatial Analysis

### Modelling

### Temperatures

### Final Product
<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>SE of estimated</th>
<th>R² change</th>
<th>F change</th>
<th>df1</th>
<th>df2</th>
<th>F change df1</th>
<th>Sig.</th>
<th>Durbin Watson</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (Constant), construction year, envelope, outdoor temperature</td>
<td>0.514</td>
<td>0.265</td>
<td>0.265</td>
<td>10.379</td>
<td>0.265</td>
<td>1464.736</td>
<td>3</td>
<td>12207</td>
<td>0.000</td>
<td>0.265</td>
<td>1464.736</td>
</tr>
<tr>
<td>2. Model 1 + SVF</td>
<td>0.523</td>
<td>0.274</td>
<td>0.273</td>
<td>10.316</td>
<td>0.009</td>
<td>149.414</td>
<td>1</td>
<td>12206</td>
<td>0.000</td>
<td>0.009</td>
<td>149.414</td>
</tr>
<tr>
<td>3. Model 2 + NDVI</td>
<td>0.539</td>
<td>0.290</td>
<td>0.290</td>
<td>10.200</td>
<td>0.016</td>
<td>282.282</td>
<td>1</td>
<td>12205</td>
<td>0.000</td>
<td>0.016</td>
<td>282.282</td>
</tr>
<tr>
<td>4. Model 3 + imperviousness</td>
<td>0.542</td>
<td>0.294</td>
<td>0.294</td>
<td>10.171</td>
<td>0.004</td>
<td>69.239</td>
<td>1</td>
<td>12204</td>
<td>0.000</td>
<td>0.004</td>
<td>69.239</td>
</tr>
<tr>
<td>5. Model 4 + roof area</td>
<td>0.544</td>
<td>0.297</td>
<td>0.297</td>
<td>10.169</td>
<td>0.003</td>
<td>32.870</td>
<td>1</td>
<td>12203</td>
<td>0.000</td>
<td>0.003</td>
<td>32.870</td>
</tr>
<tr>
<td>6. Model 5 + footprint density</td>
<td>0.547</td>
<td>0.300</td>
<td>0.300</td>
<td>10.158</td>
<td>0.003</td>
<td>28.562</td>
<td>1</td>
<td>12202</td>
<td>0.000</td>
<td>0.003</td>
<td>28.562</td>
</tr>
<tr>
<td>7. Model 6 + latent heat</td>
<td>0.548</td>
<td>0.301</td>
<td>0.300</td>
<td>10.153</td>
<td>0.001</td>
<td>12.533</td>
<td>1</td>
<td>12200</td>
<td>0.000</td>
<td>0.001</td>
<td>12.533</td>
</tr>
<tr>
<td>8. Model 7 + water index</td>
<td>0.550</td>
<td>0.303</td>
<td>0.302</td>
<td>10.146</td>
<td>0.002</td>
<td>18.228</td>
<td>1</td>
<td>12199</td>
<td>0.000</td>
<td>0.002</td>
<td>18.228</td>
</tr>
<tr>
<td>9. Model 8 + height</td>
<td>0.550</td>
<td>0.304</td>
<td>0.302</td>
<td>10.144</td>
<td>0.000</td>
<td>2.731</td>
<td>1</td>
<td>12198</td>
<td>0.002</td>
<td>0.000</td>
<td>2.731</td>
</tr>
<tr>
<td>10. Model 9 + orientation index</td>
<td>0.550</td>
<td>0.304</td>
<td>0.302</td>
<td>10.144</td>
<td>0.000</td>
<td>2.731</td>
<td>1</td>
<td>12198</td>
<td>0.002</td>
<td>0.000</td>
<td>2.731</td>
</tr>
</tbody>
</table>
Regression analysis:
the presence of a relationship is used to estimate the weight of a dependent variable based on the value of an independent variable

\[ Y_1 = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \cdots + \beta_p X_{ip} \]

\[ Y_1 \text{ Indoor temperature} \]

\[ = \beta_0 + \beta_1 \cdot X_1 \text{ Construction year} + \beta_2 \cdot X_2 \text{ Outdoor temperature} + \beta_3 \cdot X_3 \text{ Address envelope} + \beta_4 \cdot X_4 \text{ SVF} + \beta_5 \cdot X_5 \text{ NDVI} + \beta_6 \cdot X_6 \text{ Imperviousness} + \beta_7 \cdot X_7 \text{ Roof area} + \beta_8 \cdot X_8 \text{ Footprint density} + \beta_9 \cdot X_9 \text{ Height} \]
<table>
<thead>
<tr>
<th>Link</th>
<th>Variable1</th>
<th>...</th>
<th>VariableN</th>
<th>Hour</th>
<th>Indoor_temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>pstcode_nr_add</td>
<td>0,483</td>
<td></td>
<td></td>
<td>4474</td>
<td>8</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0,385</td>
<td></td>
<td></td>
<td>16706</td>
<td>4</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0,783</td>
<td></td>
<td></td>
<td>2513</td>
<td>18</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0,361</td>
<td></td>
<td></td>
<td>4474</td>
<td>3</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0,845</td>
<td></td>
<td></td>
<td>7561</td>
<td>8</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0,241</td>
<td></td>
<td></td>
<td>17364</td>
<td>22</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0,825</td>
<td></td>
<td></td>
<td>2513</td>
<td>13</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0,185</td>
<td></td>
<td></td>
<td>8013</td>
<td>5</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td></td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
Final Product

Introduction
Case Study
A 3D Model
Sensing Data
Spatial Analysis
Modelling Temperatures
<table>
<thead>
<tr>
<th>Link</th>
<th>Variable1</th>
<th>VariableN</th>
<th>Hour</th>
<th>Indoor temp.</th>
<th>Footprint</th>
<th>AddressMinZ</th>
<th>AddressHeight</th>
</tr>
</thead>
<tbody>
<tr>
<td>pstcode_nr_add</td>
<td>0.483</td>
<td></td>
<td>8</td>
<td>27,175</td>
<td>0103000...</td>
<td>3,288</td>
<td>4,236</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.385</td>
<td></td>
<td>4</td>
<td>26.5</td>
<td>0103000...</td>
<td>7,524</td>
<td>1,758</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.783</td>
<td></td>
<td>18</td>
<td>26.5</td>
<td>0103000...</td>
<td>11,758</td>
<td>5,123</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.361</td>
<td></td>
<td>3</td>
<td>25,558</td>
<td>0103000...</td>
<td>-1,359</td>
<td>9,363</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.845</td>
<td></td>
<td>8</td>
<td>27.5</td>
<td>0103000...</td>
<td>8,054</td>
<td>1,042</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.241</td>
<td></td>
<td>22</td>
<td>25</td>
<td>0103000...</td>
<td>2,209</td>
<td>3,148</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.825</td>
<td></td>
<td>13</td>
<td>23,917</td>
<td>0103000...</td>
<td>15,564</td>
<td>6,521</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.185</td>
<td></td>
<td>5</td>
<td>26,125</td>
<td>0103000...</td>
<td>10,352</td>
<td>3,864</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td></td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Link</td>
<td>Variable1</td>
<td>VariableN</td>
<td>Hour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
<td>------------</td>
<td>------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.483</td>
<td>4474</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.385</td>
<td>16706</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.783</td>
<td>2513</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.361</td>
<td>4474</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.845</td>
<td>7561</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.241</td>
<td>17364</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.825</td>
<td>2513</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.185</td>
<td>8013</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
### Introduction

This case study explores the integration of 3D models with sensing data to enhance spatial analysis and modelling of temperatures. The final product combines these elements to provide comprehensive insights.

<table>
<thead>
<tr>
<th>Link</th>
<th>Variable1</th>
<th>VariableN</th>
<th>Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>pstcode_nr_add</td>
<td>0.483</td>
<td>4474</td>
<td>8</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.385</td>
<td>16706</td>
<td>4</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.783</td>
<td>2513</td>
<td>18</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.361</td>
<td>4474</td>
<td>3</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.845</td>
<td>7561</td>
<td>8</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.241</td>
<td>17364</td>
<td>22</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.825</td>
<td>2513</td>
<td>13</td>
</tr>
<tr>
<td>pstcode_nr_add</td>
<td>0.185</td>
<td>8013</td>
<td>5</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

The table above illustrates the mapping of various codes (Link) to corresponding data points (Variable1, VariableN) and their respective timestamps (Hour). The graph on the right visualizes the spatial distribution of these data points within a 3D model, providing a real-world context to the analysis.
Introduction

Case Study

A 3D Model

Sensing Data

Spatial Analysis

Modelling Temperatures

Final Product
Introduction
Case Study
A 3D Model
Sensing Data
Spatial Analysis
Modelling Temperatures
Final Product
Student from the department of Urbanism were asked to give their opinion upon these possibilities, resulting in a 3D model with a black background including background features in which the strength of indoor temperatures is visible by a blue-yellow-red colour ramp.
Research Question:

"What is the most suitable method for the visualisation and estimation of urban heat island indoor temperatures?"
Research Question:

"What is the most suitable method for the visualisation and estimation of urban heat island indoor temperatures?"

Research Answer:

"The most suitable method is a method in which data from multiple data sources is acquired and processed so that it can be linked in order to model and visualize indoor temperature estimations in a 3D model."
Future Work:

Inaccuracy of the model due to address geometry
In future research, the address geometry should be upgraded to improve the modelling accuracy of indoor temperatures.

Inaccuracy of the model due to sensor data
In future research, measured temperature data should be acquired differently to improve the modelling accuracy of indoor temperatures.

Research Answer:
"The most suitable method is a method in which data from multiple data sources is acquired and processed so that it can be linked in order to model and visualize indoor temperature estimations in a 3D model."