Application of a green infrastructure typology and airborne remote sensing to classify and map urban vegetation for climate adaptation

Conference Paper · July 2016

4 authors, including:

Carlos Bartesaghi Koc
Deakin University
32 PUBLICATIONS 59 CITATIONS

Alan H. Peters
UNSW Sydney
39 PUBLICATIONS 541 CITATIONS

Some of the authors of this publication are also working on these related projects:

Assessing the thermal performance of green infrastructure on urban microclimate View project
Application of a green infrastructure typology and airborne remote sensing to classify and map urban vegetation for climate adaptation

Carlos Bartesaghi Koc\textsuperscript{1,2,*},
Paul Osmond \textsuperscript{1,2}, Alan Peters \textsuperscript{1}, Matthias Irger

\textsuperscript{1} Built Environment, AGSU – UNSW Australia
\textsuperscript{2} CRC For Low Carbon Living

* Corresponding author: c.bartesaghikoc@unsw.edu.au
Tel. +61 (2) 9385 5023
Background

Systematic review of 85 articles* shows:

• **No common protocols & standards** to describe, compare and report the evidence of the ecosystem services of GI > *Need for a typology*

• **Spatial heterogeneity** precludes a clear identification of typologies

• **GI includes a combination** of natural, semi-natural and engineered elements.

• **Current classifications (i.e. LULC)** still inadequate > highly dependent on land-uses

• **Aspects** to consider to classify GI:
  1. Multi-functionality (trees vs parks)
  2. Spatial heterogeneity (what is GI?)
     *green-to-grey continuum*
  3. Interconnectivity (boundaries)

* Bartesaghi Koc, C. et al *(in press).*
Proposed GIT matrix

After Bartesaghi Koc, C. et al. (2016a, in press)

<table>
<thead>
<tr>
<th>GREEN INFRASTRUCTURE TYPOLOGY (GIT)</th>
<th>Ground surfaces (GS)</th>
<th>Building structures (BS)</th>
<th>Vertical Structures (VS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V.9</td>
<td>Terrestrial surfaces (TS)</td>
<td>Water bodies (WB)</td>
<td>Roof structures (RS)</td>
</tr>
<tr>
<td>Impervious surfaces</td>
<td>Artifical (hard surfaces &amp; pavements)</td>
<td>Vegetated surfaces</td>
<td>Intensive</td>
</tr>
<tr>
<td>Natural (bare rock)</td>
<td>Natural</td>
<td>Vegetated surfaces</td>
<td>Semi-intensive</td>
</tr>
<tr>
<td>Porous pavements</td>
<td>Pervious surfaces</td>
<td>Wetland (marsh, swamps, mangroves)</td>
<td>Semi-intensive</td>
</tr>
<tr>
<td>Bare soils, sands, perennial snow</td>
<td>Vegetated surfaces</td>
<td>Open water (lakes, rivers, oceans)</td>
<td>Semi-intensive</td>
</tr>
<tr>
<td>S1</td>
<td>S2</td>
<td>S3</td>
<td>S4</td>
</tr>
<tr>
<td>S6</td>
<td>S7</td>
<td>R1</td>
<td>R2</td>
</tr>
<tr>
<td>R4</td>
<td>R5</td>
<td>R6</td>
<td>V1</td>
</tr>
<tr>
<td>No Vegetation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **TS (Terrestrial surfaces)**: Artificial, natural, porous pavements, bare soils, sands, perennial snow.
- **WB (Water bodies)**: Wetland (marsh, swamps, mangroves), open water (lakes, rivers, oceans).
- **RS (Roof structures)**: Intensive, semi-intensive, extensive.
- **VS (Vertical Structures)**: Living walls (rooted on wall), elevated substrates (box, pot, bag), traditional cistern systems, double skin indirect systems.
Refined GIT

Impervious

Type 1
Highly Impervious

Type 2
Mostly impervious w/ low plants

Type 3
Mostly impervious w/ shrubs

Type 4
Mostly impervious w/ trees

Type 5
Low Plants

Type 6
Mostly low plants w/ impervious

Type 7
Mostly low plants w/ trees

Type 8
Mixed Landscape

Type 9
Trees

Type 10

Type 11
Mostly water w/ low plants

Type 12
Mostly water w/ low plants and shrubs

Type 13
Sparse water w/ low plants and shrubs

Type 14
Sparse water w/ trees

Vegetation

Water

LiDAR

Spectral imagery

Height of vegetation structures
## GIT – Classification values

Based on Irger (2014) and Stewart & Oke. (2012)

<table>
<thead>
<tr>
<th>CODE</th>
<th>TYPE</th>
<th>Impervious fraction</th>
<th>High Veg fraction</th>
<th>Med veg fraction</th>
<th>Low Veg fraction</th>
<th>Water fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Highly impervious</td>
<td>&gt;= 80</td>
<td>&lt;= 20</td>
<td>&lt;= 20</td>
<td>&lt;= 20</td>
<td>&lt;= 20</td>
</tr>
<tr>
<td>Type 2</td>
<td>Mostly impervious with low plants</td>
<td>&gt;= 40 - &lt; 80</td>
<td>&lt;= 10</td>
<td>&lt;= 10</td>
<td>&lt;= 50</td>
<td>&lt;= 10</td>
</tr>
<tr>
<td>Type 3</td>
<td>Mostly impervious with shrubs</td>
<td>&gt;= 40 - &lt; 80</td>
<td>&lt;= 10</td>
<td>&gt;= 10</td>
<td>&lt;= 50</td>
<td>&lt;= 10</td>
</tr>
<tr>
<td>Type 4</td>
<td>Mostly impervious with trees</td>
<td>&gt;= 40 - &lt; 80</td>
<td>&gt; 10 - &lt;= 40</td>
<td>&lt;= 25</td>
<td>&lt;= 40</td>
<td>&lt;= 10</td>
</tr>
<tr>
<td>Type 5</td>
<td>Low Plants</td>
<td>&lt;= 20</td>
<td>&lt;= 20</td>
<td>&lt;= 20</td>
<td>&gt;= 80</td>
<td>&lt;= 20</td>
</tr>
<tr>
<td>Type 6</td>
<td>Mostly low plants with impervious</td>
<td>&lt; 50</td>
<td>&lt;= 10</td>
<td>&lt;= 10</td>
<td>&gt;= 50 - &lt; 80</td>
<td>&lt;= 10</td>
</tr>
<tr>
<td>Type 7</td>
<td>Mostly low plants with trees</td>
<td>&lt; 50</td>
<td>&gt; 10 - &lt;= 50</td>
<td>&lt;= 25</td>
<td>&gt;= 40 - &lt; 80</td>
<td>&lt;= 10</td>
</tr>
<tr>
<td>Type 8</td>
<td>Shrub</td>
<td>&lt; 40</td>
<td>&lt;= 20</td>
<td>&gt;= 50</td>
<td>&lt; 50</td>
<td>&lt;= 20</td>
</tr>
<tr>
<td>Type 9</td>
<td>Trees</td>
<td>&lt;= 10</td>
<td>&gt;= 50</td>
<td>&lt;= 10</td>
<td>&lt; 50</td>
<td>&lt;= 10</td>
</tr>
<tr>
<td>Type 10</td>
<td>Mostly Trees with impervious</td>
<td>&gt;= 20</td>
<td>40 - 80</td>
<td>&lt;= 10</td>
<td>&lt; 50</td>
<td>&lt;= 10</td>
</tr>
<tr>
<td>Type 11</td>
<td>Water</td>
<td>&lt;= 20</td>
<td>&lt;= 20</td>
<td>&lt;= 20</td>
<td>&lt;= 20</td>
<td>&gt;= 75</td>
</tr>
<tr>
<td>Type 12</td>
<td>Mostly water with low plants and shrubs</td>
<td>&lt; 50</td>
<td>&lt;= 10</td>
<td>&lt;= 50</td>
<td>&lt;= 60</td>
<td>&gt;= 50 - &lt; 75</td>
</tr>
<tr>
<td>Type 13</td>
<td>Sparse water with low plants and shrubs</td>
<td>&lt; 50</td>
<td>&lt;= 10</td>
<td>&lt;= 50</td>
<td>&gt;= 10</td>
<td>&gt;= 10 - &lt; 50</td>
</tr>
<tr>
<td>Type 14</td>
<td>Sparse water with trees</td>
<td>&lt; 50</td>
<td>&gt;= 10</td>
<td>&lt;= 50</td>
<td>&gt;= 10</td>
<td>&gt;= 10 - &lt; 50</td>
</tr>
<tr>
<td>Type 15</td>
<td>Mixed landscape</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GIT** – *Classification values* based on Irger (2014) and Stewart & Oke. (2012).
Results – surface fractions & NDVI

Surface fractions per typology:

- Type 01: Highly impervious (89.83%)
- Type 02: Mostly impervious w/ low plants (67.94%)
- Type 03: Mostly impervious w/ shrubs (20.63%)
- Type 04: Mostly low plants w/ trees (60.46%)
- Type 05: Mostly low plants w/ impervious (25.30%)
- Type 06: Mostly low plants w/ trees (20.63%)
- Type 07: Mostly low plants w/ impervious (16.52%)
- Type 08: Shrub (25.30%)
- Type 09: Trees (16.52%)
- Type 10: Mostly trees w/ impervious (16.52%)
- Type 11: Water (0.50%)
- Type 12: Mostly water w/ low plants & shrubs (7.5%)
- Type 13: Sparse water w/ low plants & shrubs (2.4%)
- Type 14: Sparse water w/ trees (0.5%)
- Type 15: Mixed landscape (64.2%)

Fraction (hectares) of total:

- TOTAL PILOT STUDY: 4274 grids → 1068.5 ha

Mean NDVI:

- Water: 0.60
- High Vegetation: 0.50
- Medium vegetation: 0.40
- Low vegetation: 0.30
- Impervious: 0.20

NDVI values range from 0 to 1.
Method – Pilot study and datasets

- Winter data (August 6, 2012)
- 50 x 50 m analysis grid
- Imagery resolution:
  - Lidar 0.8 pts/sqm
  - Hyperspectral 2m
  - Everything resampled to 0.5m
Method – GIS-based workflow

Hyperspectral imagery
- Generate Red Edge NDVI
- Classify Red Edge NDVI
  - Pervious (>= 0.15)
    - Generate rasters for overlapping areas
    - Subtract high and medium veg. from pervious surfaces
  - Vegetation extraction
    - Water (<= -0.25)
    - Impervious (> -0.25 - < 0.15)
    - Low Vegetation (< 0.5m)
    - Med. Vegetation (0.5 - 2m)
    - High Vegetation (> 2m)

Lidar data
- Generate DEM and DSM
  - Subtract DEM from DSM
    - nDSM
  - High Vegetation (> 2m)
  - Med. Vegetation (0.5 - 2m)
  - Low Vegetation (< 0.5m)

Classification
- Tiles 50m x 50m
- Based on Irger (2014)
- Calculate surface fractions using Zonal Statistics
- Apply conditional classification (if, then → else)
GIT – classification results
Findings – Typology applicability

- Very few number of unclassified grids ($n=54 \sim 1.5\%$).

- Strong correlation between typologies’ characteristics (surface fractions) and mean NDVI values.

- Impervious surfaces were the largest by far across the whole pilot study.

- The most numerous typologies combined impervious surfaces with low plants and few trees.

- Impervious surfaces combined building and ground surfaces; future work could consider their differentiation.

<table>
<thead>
<tr>
<th>Highly impervious</th>
<th># Grids: 837</th>
<th>Properties</th>
<th>Mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NDVI</td>
<td></td>
<td>- 0.015</td>
<td></td>
</tr>
<tr>
<td>2. Impervious fraction</td>
<td>89.83 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Low vegetation fraction</td>
<td>7.32 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Medium vegetation fraction</td>
<td>1.05 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. High vegetation fraction</td>
<td>1.80 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Water fraction</td>
<td></td>
<td>0.16 %</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mostly impervious with low plants</th>
<th># Grids: 1793</th>
<th>Properties</th>
<th>Mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NDVI</td>
<td></td>
<td>0.077</td>
<td></td>
</tr>
<tr>
<td>2. Impervious fraction</td>
<td>67.94 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Low vegetation fraction</td>
<td>25.30 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Medium vegetation fraction</td>
<td>2.29 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. High vegetation fraction</td>
<td>4.72 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Water fraction</td>
<td>0.09 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Water</th>
<th># Grids: 2</th>
<th>Properties</th>
<th>Mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NDVI</td>
<td></td>
<td>-0.261</td>
<td></td>
</tr>
<tr>
<td>2. Impervious fraction</td>
<td>14.65 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Low vegetation fraction</td>
<td>9.00 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Medium vegetation fraction</td>
<td>0.02 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. High vegetation fraction</td>
<td>0.37 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Water fraction</td>
<td></td>
<td>75.98 %</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mostly low plants with trees</th>
<th># Grids: 143</th>
<th>Properties</th>
<th>Mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. NDVI</td>
<td></td>
<td>0.223</td>
<td></td>
</tr>
<tr>
<td>2. Impervious fraction</td>
<td>27.36 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Low vegetation fraction</td>
<td>53.68 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Medium vegetation fraction</td>
<td>2.00 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. High vegetation fraction</td>
<td>17.16 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Water fraction</td>
<td></td>
<td>0.24 %</td>
<td></td>
</tr>
</tbody>
</table>
Findings – Typology applicability

- Estimation of surface cover fractions results insufficient to classify tree canopy distribution → Need for differentiation between clustered and sparse arrangements in typologies 4, 7, 9, 10 & 14.

- LiDAR point cloud density and vegetation phenology have huge impacts on the accuracy and quality of vegetation / buildings extraction that potentially may lead to error (under-/overestimations).

- Red Edge NDVI thresholds should be further studied.

- The typology can be used for multiple purposes, though it is especially aimed for spatial and performance analyses (quantitative and qualitative), and for inventorying conditions to prioritise GI interventions.
Conclusions and future work

• A standardised classification scheme (conventions and protocols) to estimate the vegetation cover of large areas with high resolution and accuracy → Potential use to inform and propose climate change adaptation/mitigation strategies.

• The typology facilitates the reporting of the current state of environment, as well as Inter-site & inter-typology comparison.

• Other indicators can be estimated and assigned to each typology (i.e. biomass, carbon sequestrations, evapotranspiration, surface temperature, etc.)

• Next steps:
  - To incorporate spatial metrics to distinguish different arrangement of trees.
  - To consider urban morphology aspects by applying the GIT along with the local climate zones (LCZ) to assess the thermal profiles of GI.
  - To test different grid sizes, NDVI thresholds and LiDAR extraction parameters.


Thank you for your attention

Acknowledgments:

This paper is presented thanks to the financial support provided by the ACCARNSI NCCARF Climate Adaptation Conference Grant.

This paper is part of an ongoing research conducted at the Australian Graduate School of Urbanism, University of New South Wales (UNSW-Australia) and the Node of Excellence – Cooperative Research Centre for Low Carbon Living (CRC-LCL). This research is possible thanks to the financial support of the Graduate Research School – UNSW (University International Postgraduate Award - UIPA) and the CRC for Low Carbon Living (Top-up scholarship).

The data used in this research has been kindly provided by Dr. Matthias Irger and CSIRO.