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Research Paper

Visualising the urban green volume: Exploring LiDAR voxels with tangible technologies and virtual models

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ABSTRACT

The distribution of vegetation within urban zones is well understood to be important for delivery of a range of ecosystem services. While urban planners and human geographers are conversant with methodologies for describing and exploring the volumetric nature of built spaces there is less research that has developed imaginative ways of visualising the complex spatial and volumetric structure of urban vegetation from the treetops to the ground. Using waveform LiDAR data to measure the three-dimensional nature of the urban greenspace, we explore different ways of virtually, and tangibly engaging with volumetric models describing the 3D distribution of urban vegetation. Using waveform LiDAR data processed into voxels (volumetric pixels) and experimenting with a variety of creative approaches to visualise the volumetric nature of the data, we describe the development of new methods for mapping the urban green volume, using a combination of Geographic Information Systems (GIS), Minecraft, 3D printing and Computer Numerical Control (CNC) milling processes. We demonstrate how such methodologies can be used to reveal and explore the complex nature of the urban green volume. We also describe the outcome of using these models to engage diverse audiences with the volumetric data. We explain how the products could be used readily by a range of urban researchers and stakeholders: from town and city councils, to architects and ecologists.

1. Introduction

1.1. The urban green volume

Cities and towns are volumetric entities and their social, political, natural and economic functions are played out in three dimensions. When considering the volumetric structure of urban landscapes, one must consider heterogeneous mixtures of built structures extending into the sky (Graham & Hewitt, 2012), coupled with subterranean excavations (Garrett, 2016), interspersed with landscape and vegetation structures also exhibiting vertical and subterranean characteristics (Davison, Huck, Delahay, & Roper, 2008; Gaston, Warren, Thompson, & Smith, 2005), all at varying heights, depths and spatial scales. In human geography this three-dimensional (3D), vertical urban axis has received considerable academic attention. For example, Hewitt and Graham (2015) argue that the vertical nature of urban spaces is "fundamental to the nature of modern cities", while Graham (2012) suggest the need for a fully volumetric urbanism to address "the ways in which horizontal and vertical extensions, imaginaries, materialities and lived practices intersect and mutually construct each other".

1.2. Urban volumetric modelling and visualisation

A major research challenge with this volumetric urbanism lies in the production of urban plans that are able to capture and communicate the diverse and complex forms that comprise the volumetric character of the city. This challenge exists, write Ahmed and Sekar (2015), because "urban planners are reluctant to use 3D tools" – suggesting that this is caused by the cost and complexity of data processing, modelling and integration coupled with "the lack of appropriate skills available for incorporating 3D models into everyday planning processes". Corroborating this, Ireson (2000) adds that "it is a challenge to rethink our perspective on the significance of the vertical zones […] as contexts for specific patterns of architectural design, or types of interaction between people, or people and the city itself". Of course, tools such as Geographic Information Systems (GIS) are widely employed by urban

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planners and architects to facilitate decision-making and allow "more meaningful public involvement in planning processes" (Foster & Brostoff, 2016); while architectural research and practice has long used computing technology to visualise urban landscapes in various ways (Shiode, 2000). However, many examples of urban planning models distil the 3D complexity of urban spaces to a planar 'raster' surface. Where volumetric entities can be embraced within GIS (e.g. within ESRI's 'City Engine' software, to provide one example), the focus is placed on improved 3D description of built environment elements, and does not include an accurate way of modelling volumetric urban ecology. In parallel, many of the critical discussions concerning urban volumes amongst geographers have focused on built structures in cities, i.e. the anthropocentric nature of that volume. The lack of integration of volumetric vegetation-scapes into such models may well be driven by the anthropocentric city, but we propose that it is likely also a product of the lack of academic work that evaluates the three-dimensional characteristics of urban nature. This oversight, until recently has been driven by the lack of data describing at sufficiently fine-scale, the 3D qualities of urban vegetation. Landscape research is not solely to blame for this oversight: urban greenspace research is itself heavily reliant on non-volumetric representations with planning maps and GIS analyses replete with 2D models describing the spatial arrangements of urban vegetation primitives (e.g. simplified maps showing classified areas of grass, shrubs or trees; (Grafius et al., 2016; Gupta, Roy, Luthra, Maithani, & Mahavir, 2016)). 3D greenspace modelling is also inconspicuous within architectural praxes, we suggest largely because the planning system doesn't require it. And yet, the latest research suggests that failing to include volumetric representations of the urban greenspace into models describing ecological connectivity results in biases and over-estimations of the connectedness of patches within urban areas (Casalegno, Anderson, Cox, Hancock, & Gaston, 2017). There is a need to address this problem experimentally by making the first attempts to visualise new volumetric information describing the urban green volume to progress research into urban ecology and landscape planning.

1.3. Volumetric urban vegetation

Humans instinctively understand that all greenspace (urban and non-urban) is volumetric rather than two-dimensional. The structure of the urban green volume is alive, and determines how humans and animals interact with it and each other: the urban space influences songbird movement between garden feeders (Cox, Inger, Hancock, Anderson, & Gaston, 2016); human behaviour is modified by the presence of trees (Rasmussen, 2004); and the dynamic movements of other taxa are affected by it, e.g. bumblebees vault hedges to forage amongst allotment plants (Ahrné, Bengtsson, & Elmqvist, 2009). Alongside, a growing body of work points to the importance of urban vegetation for delivering multiple ecosystem services (Gaston, Ávila-Jiménez, & Edmondson, 2013), for example, vegetation cover is positively associated with a lower prevalence of depression, anxiety and stress (Cox, Shanahan, Hudson, Plummer et al., 2017). Using LiDAR to visualise urban topographic models aimed at informing the work of planners and architects is not new (Batty et al., 2001; Shiode, 2000). However, the inclusion of accurate three-dimensional depictions of greenspace in architectural modelling and UK planning processes is not yet widespread. Certainly, greenspace data repositories, such as Greenspace Information for Greater London CIC (GiGL) [http://www.gigl.org.uk/about-gigl] inform these processes, but the requirement for three-dimensional analysis and submission is limited. However, there remain uncertainties in understanding the quantifiable functional relationships between greenspace quality (where the 3D structure of urban vegetation is a useful proxy (Lehmann, Mathey, Rößler, Bräuer, & Goldberg, 2014) and delivery of many critical ecosystem services (Jim & Chen, 2009).

1.4. Waveform laser scanning

While there are plentiful examples of discrete return LiDAR data being used within landscape planning models to understand urban vegetation distribution and its implications (Davies, Edmondson, Heinemeyer, Leake, & Gaston, 2011; Shanahan, Lin, Gaston, Bush, & Fuller, 2014; Vukomanovic, Singh, Petrasova, & Vogler, 2018) such work only provides either a 2.5 dimensional view of urban vegetation or else a coarse resolution (tens of metres) volumetric map unsuitable for urban studies (Hancock, Anderson, Disney, & Gaston, 2017). This is because discrete return LiDAR provides only limited information on the understory characteristics (Anderson, Hancock, Disney, & Gaston, 2015). In this work, we exploited the additional 3D canopy information present in waveform laser scanning data. Waveform LiDAR provides information from the vegetation canopy top all the way down to the ground, allowing understory information to be retrieved (Anderson, Hancock, Disney, & Gaston, 2016; Hancock et al., 2017). Using such information we set out to explore new ways visualising the urban green volume in its full 3D volumetric complexity. We wanted to explore whether virtual and tangible technologies could bring to life the three dimensional complexity of urban vegetation for the benefit of scientists, planners and architects alike. In this paper we address a critical research challenge in translating volumetric waveform LiDAR data into interactive information for general exploration. In this work, waveform LiDAR data (Anderson et al., 2016) were used to generate 'voxel' (volumetric pixel – see Hancock et al. (2017) for details) models showing the three-dimensional arrangement of urban vegetation density in three UK towns. To achieve this and explore different approaches to the research problem, we worked as an interdisciplinary art-science collaboration comprising remote sensing scientists, digital craft makers, artists, ecologists and programmers, and experimented with various methods for visualising the complex voxel data from Hancock et al. (2017) including 3D printing, Computer Numerical Control (CNC) milling, and interactive visualisation in the game Minecraft. We displayed the results in various venues engaging a variety of stakeholders and passively observed participants' reactions. The paper reports on the process of delivering these visualisations and tangible models and we explore the extent to which such representations could be used for enhancing citizens' and scientists' understanding of the urban green volume in an accessible way.

2. Methods

2.1. Study areas: The "cranfield Triangle" – An urban zone north of London, UK

This study was conducted in the 'Cranfield triangle'. This defines a region in southern England, UK, comprising the three adjacent towns of Milton Keynes (52°02′N, 0°45′W), Luton (51°53′N, 0°25′W), and Bedford (N52°58′N, 0°28′W). This area has a human population of c. 609,501 (2011 Census, UK), and covers 166 km^2. Several other research papers describe the study system and provide a full rationale for situating the work in this area (Anderson et al., 2016; Cox & Gaston, 2016; Cox et al., 2016; Cox, Shanahan, Hudson, Fuller et al., 2017; Hancock et al., 2017). In summary, the Cranfield triangle provided a continuum of urban spatial structural forms, including a Victorian industrialised town (Luton), a 'new town' development with designed urban greenspace (Milton Keynes), and a historic medieval market town containing mixed urban forms including Victorian features and modern industrial zones (Bedford).

2.2. Remote sensing data

The Natural Environment Research Council Airborne Research and Survey Facility collected remote sensing data from a piloted Dornier 228 aircraft between June and September 2012 during four flights. The