Towards Tree Green Crown Volume: A Methodological Approach using Terrestrial Laser Scanning

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1. Introduction

Tree crown variables are relevant in a number of contexts: they are not only "engines" of tree growth (Li et al 2017, Pretzsch et al 2015), but contribute – amongst others - filtering pollutants from the air, increasing storm resistance, shadowing of lower layers (and of houses in case of urban trees), offering habitat for various taxa, etc. Crown projection area has been long used as a major variable to describe crowns and their extension. One may ask whether the crown projection area alone does for all purposes sufficiently exhaustively characterize tree crowns, as, for example, for one and the same crown projection area, tree crowns may have very different 3D crown shapes, volumes and densities.

In this study, we introduce a new 3D crown variable named tree green crown volume (*TGCvol*). We use TLS-based (Terrestrial Laser Scanning-based) *k*-means clustering as a proxy for the assessment of this complex variable: *TGCvol* is one of those crown variables that are difficult to define and difficult to assess; and research needs to resort to proxies to make empirical studies feasible. To the best knowledge of the authors, *TGCvol* has so far not been introduced nor assessment approaches presented. The goal of this study is to introduce this concept, to develop and evaluate a TLS-based approach to assess the *TGCvol*, to describe its scale dependency and to discuss challenges regarding definitions, measurements and analyses.

2. Material and Methods

2.1 Definition

While the basic idea behind *TGCVol* is easily described as "the sum of spaces in the crown filled with leaves" – it turns out to be difficult to come up with an unambiguous definition that may form the basis for a likewise unambiguous measurement protocol. Many crown variables bring the same challenge with respect to direct measurement: their observation is, therefore, based on the assessment of meaningful proxies. For example, leaf area density (LAD) is often proxied by TLS scans with 3D voxelization (Béland et al 2014). Following the basic idea, *TGCVol* is proxied in this study by k-means convex hull clustering: we use the green TLS hits identified by the RGB information to recognize "leaf clusters". *TGCVol* is then defined as the sum of all the volumes of envelopes of "leaf clusters".

2.2 Data collection

We selected 26 sample trees within the city of Göttingen, Germany. Per tree, field measurements as dbh, crown base height and tree height were taken and the tree was scanned from 6 positions to guarantee a detailed 3D representation of outer and inner parts of the crowns.

2.3 Determining tree green crown volume

Our approach to assess *TGCvol* went in three steps: (1) woody elements removal, (2) *k*-means clustering, and (3) convex hull wrapping. The woody elements (stem and branches) were removed from the point

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cloud of the single tree; the remaining points were considered as leaf hits. The *k*-means clustering approach (MacQueen 1967) was then applied to cluster groups of nearby leaf hits. *k* is the initial parameter that represents the total number of clusters to be produced. We started always with $k = 1$. The convex hull of this one single cluster is wrapping the total crown volume *CVol* (see Figure 1a). We increased *k* so that more and smaller clusters were generated separating more and more the green and empty spaces within the crown (Figure 1). Around each cluster of hits, a convex hull was wrapped. The value for *TGCvol* is calculated by summing up all the volumes of all these convex hulls. We increased *k* stepwise up to the value of k=1400. For each value of *k*, the sum of the wrapped clusters constitutes the *TGCvol* at this particular spatial resolution. A suitable or even optimal value of *k* will depend on the specific subject-matter objective of a study and was not a focus of this research.

To make the values comparable between trees of different sizes, we developed the tree green crown volume index *TGCVI* which is the percentage of tree green crown volume *TGCvol* within the total crown volume *CVol* (k=1): *TGCVI=TGCvol/CVol. TGCVI* tends towards a value of 1 when leaves occur uniformly all over the crown at a minimum density.

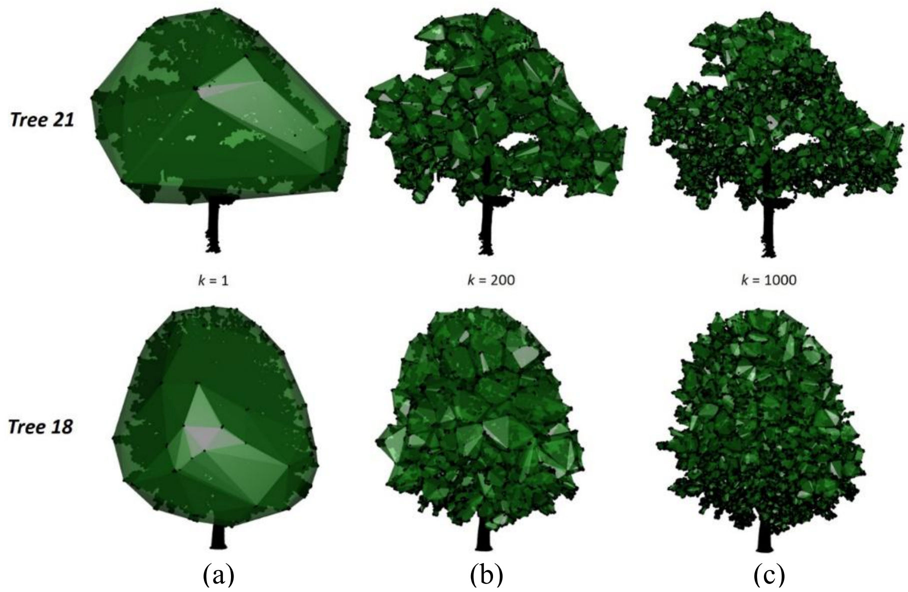

Figure 1. Illustration of the *k*-means clustering approach to generate hulls of green volume within the crown (sample trees 21 and 18): convex hulls were wrapped around: (a) k=1 cluster (wrapping the total crown volume); (b) k=200 clusters; and (c) k=1000. “Leaf clusters” can be seen more evenly distributed in the crown of Tree18 than of Tree21.

3. Results and Discussion

When refining the separation of green and empty spaces by increasing the number of clusters *k*, the green crown volume decreases. This describes the scale dependency of determining *TGCvol*. For our sample trees, *TGCvol* decreased rapidly and then levelled out for values of *k* beyond 200-300 (see also Figure 2).

TGCvol is not evenly distributed within the crown but comes in a clustered pattern: it is obvious that determining *TGCvol* is scale-dependent. This is clearly illustrated in Figure 2 when plotting *TGCvol* over the number of clusters: the finer the separation between green and empty spaces, the smaller the overall *TGCvol*. The scale is here derived from the number of clusters, which implicitly defines how fine the clustering is.

Our study is a pilot study to further develop measurement and analysis approaches towards a better description of tree green crown volume. The limited number of 26 sample trees in one single environment (urban trees) and without considering many different crown shapes does not allow further inferences about factors that determine amount and pattern of *TGCvol*; rather, our study was to introduce the concept of *TGCvol* to better describe the foliage distribution in tree crowns and present a first case study for its assessment, identifying remaining methodological challenges.

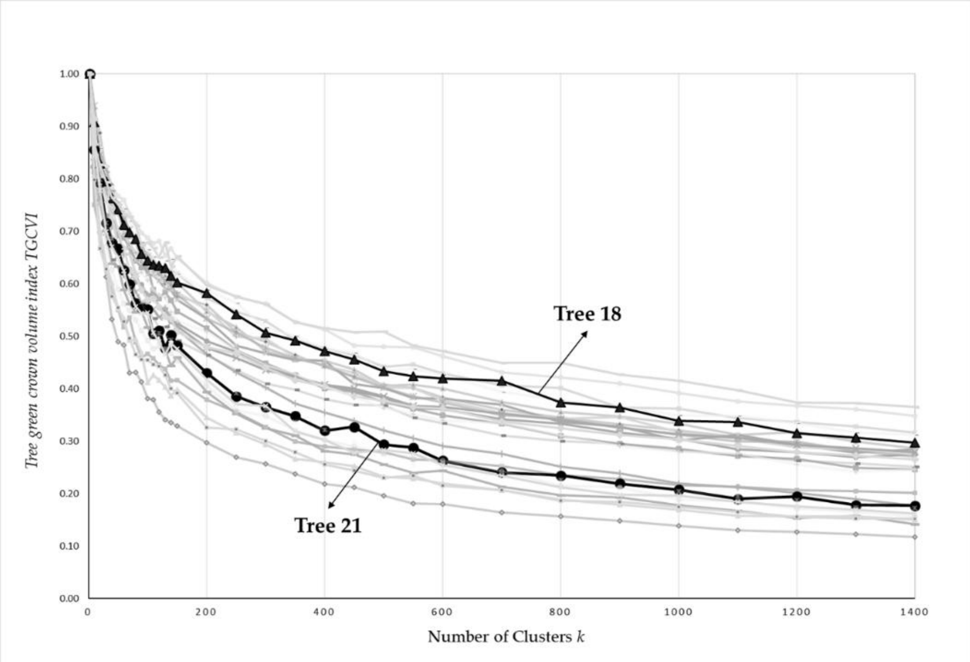

Figure 2. *TGCVI* over number of clusters *k*. As to be expected: the more clusters are formed, the finer is the separation of green and empty spaces within the crown which leads to decreasing values of *TGCVI*. The axis y is the normalized *TGCVI*. Tree 21 and tree 18 are highlighted by the bold line with markers.

4. Conclusions

We see various useful applications of *TGCvol* in particular in the context of trees outside the forest, for example in modelling of urban trees for habitat suitability and heat mitigation: a lower green volume will probably result in a lower heat mitigation and also influence the habitat quality for different taxa; but we also acknowledge (and addressed it in this paper) that there are numerous methodological challenges that wait to be resolved.

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