

Application of terrestrial LiDAR and modelling of tree branching structure for plant-scaling models in tropical forest trees

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Highlights: Terrestrial laser scanning, with automated data processing techniques, provides a powerful alternative for estimating tree characteristics. Nevertheless, TLS also offers an unexplored potential where tree architecture plays a major role: forest ecology.

Key words: *terrestrial laser scanning, plant scaling modelling, quantitative structure model.*

Introduction

The whole-organism metabolic rate expresses the rate at which energy and materials are taken up from the environment, transformed in biochemical reactions and allocated for maintenance, growth and reproduction [1]. To relate metabolic rate to size, the theoretical model of West, Brown and Enquist (WBE) proposed the fractal geometry of transport systems as the origin of the allometric scaling laws observed in nature at both, internal (vascular) and external (branching) networks [2].

In the context of the WBE model for plants, a tree's external architecture is defined by branching, furcation numbers, branch diameters and branch lengths. The tree's external branching network is assumed to be symmetrical, self-similar and hierarchical; and values for WBE scaling exponents should not vary throughout branch level and the whole-tree. Therefore, a small piece of the tree is representative of the whole tree and we would be able to use a subset only to estimate whole-tree scaling exponents and predict the whole-tree metabolic rate [2].

Despite its importance, few studies have assessed the external branching patterns from individual trees at branch-level, whole tree-level and analysed data in context of plant-scaling models. Within this scope, TLS has the ability to capture the complex 3D structure of trees, and 3D tree reconstruction models based on TLS point clouds, which allow us to model the shape of the trunk and main branches. [3], [4]. The aim of this study is to assess the feasibility of 3D structure models from TLS pointcloud data to estimate plant scaling parameters from tropical trees.

Materials and Methods

Data were acquired using a RIEGL VZ-400 V-Line 3D[®] Terrestrial laser scanner [RIEGL Laser Measurement Systems GmbH, Horn, Austria, www.riegl.com], mounted on a survey tripod 1.5 m above ground. The instrument is a full waveform LiDAR, operating at 1500 nm with an angular resolution between 0.0024 and 0.5 degrees, and a laser beam divergence of 0.35 mrad. Since the TLS only collects 100 degrees of vertical angle per scan, a full-hemispherical scan was acquired by scanning two times on the same position; one in an upright position (perpendicular to the ground) and one in a tilted position (parallel to the ground).

The dataset was acquired during November 2013. The plot is located in latitude -12.83 degrees and longitude -69.27 degrees with an elevation of 223 masl and is located inside the Tambopata National Reserve, in Madre de Dios region, Peru. The plot is currently managed by the Global Ecosystem Monitoring network (GEM) from the University of Oxford, under the Andes to Amazon Transect Project.

The plot comprises an area of 100 by 100 meters with a regular square sample grid of 20 by 20 meters. Each intersection of the grid was used as a scan position. A total of 72 scan positions (2 scans per intersection, one upright and one tilted) were collected per plot. Individual scans were merged using the RIEGL proprietary software RiScan Pro and manual extraction was done to select individual trees in the plot. For this study 3 trees were manually extracted from the pointcloud data as seen in Figure 1. Finally, the pointcloud of each tree was exported to ASCII format.

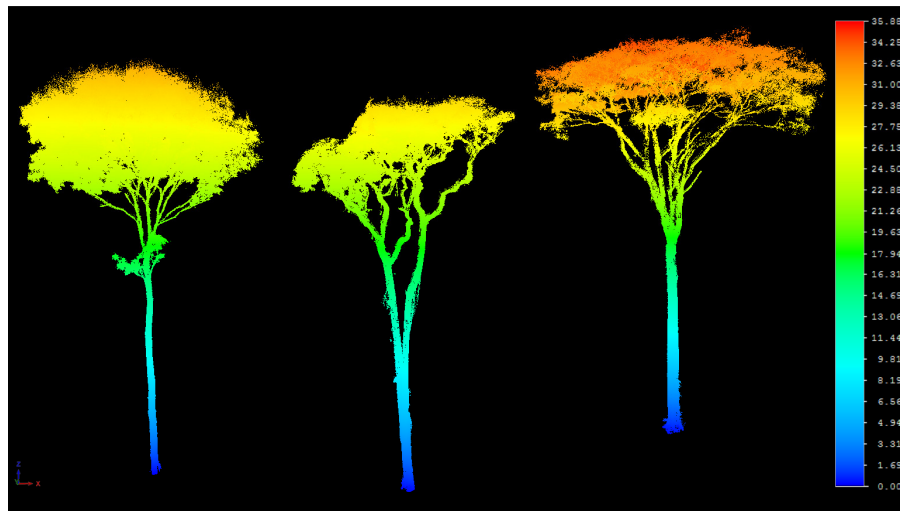


Figure 1: Tree pointcloud of scanned trees (in scale) from GEM plots in Peru; (left) *Tachigali polyphylla*, (centre) *Jacaranda copaia* and (right) *Sclerolobium bracteosum*.

For each tree a quantitative structure model (QSM) [3] was reconstructed using different settings from the tree pointcloud. Visual evaluation of the modelled tree compared to the original pointcloud gave us an insight of the optimal settings in order to determine an accurate evaluation. Then, specific branch parameters, such as branch hierarchy, branch length and radius (lower and upper) were calculated from the QSM. Finally, these parameters were used in the WBE plant-scaling model. This model calculated the following exponents: length ratio scaling, radii ratio scaling and estimated metabolic rate scaling.

Results and Discussion

The theoretical exponent expected from WBE for branch length scaling is 0.3 and for branch radii scaling is 0.5. Across all trees, the calculated branch-level length scaling exponent varied from 0.30 to 0.38 and the calculated branch-level radii scaling exponent ranged from 0.44 to 0.51 (Table 1). The calculated (estimated) metabolic rate scaling exponent was 0.70, 0.78 and 0.81 for tree 01, 02 and 03 respectively (expected to be 0.75 from the WBE model).

Table 1: Scaling exponents for branch length and radii

Tree	Length scaling	Confidence interval	Radii scaling	Confidence interval	Estimated metabolic rate scaling
<i>Tachigali polyphylla</i>	0.38	0.36 – 0.41	0.51	0.49 – 0.54	0.70
<i>Jacaranda copaia</i>	0.38	0.33 – 0.42	0.44	0.40 – 0.49	0.78
<i>Sclerolobium bracteosum</i>	0.30	0.25 – 0.36	0.46	0.40 – 0.52	0.81

Estimations of tree scaling metabolism derived from architecture via TLS scans showed consistent and comparable values to the model predictions for all scaling exponents. Since the scanned trees were different species, these results provide evidence to support the WBE assumption of similarities in branching structure and common set of branching rules across trees. It is possible that these deviations from the WBE predictions were not observed here due to the maturity of the sampled trees. It has been shown that the WBE model predictions apply more closely to trees that are larger and closer to the limits of an infinitely sized network [1].

Bentley et al [2] showed that the scaling of branch radii was less variable than the scaling of branch length. These results support the WBE assumption that energy minimization for water transport leads to minimization of hydrodynamic resistance. This assumption implies that changes in radius lead to bigger changes and more use of energy than changes in length; thus trees would be more able to respond to their environment through changes in branch length compared to branch width. Nevertheless, in the current study we could not find a strong evidence of this variability; length and radii were equally variable. While it might be possible that Bentley's results were driven by the inclusion of a large number of temperate trees, it is more likely that increased variability in length scaling was not observed in our study because the trees studied were large canopy trees. Therefore, these mature, emergent trees did not have high light competition and as such their branching structure could potentially be in close equilibrium with the demands from the surrounding environment. In the future, it would be useful to analyse more trees and their surrounding light environment demands to further explore this variability.

Lastly, these above findings are extremely relevant to field of ecology for the scaling of whole tree carbon and water use. Currently, the only way to extract these branch-level parameters from trees is to painstakingly

measure each branch part by hand. This procedure can take hours and only extracts parameters from part of the tree. Here, by coupling T-LiDAR with pointcloud processing codes we are able to extract branch-level parameters from a much larger percentage of the whole tree (and even in some cases from the whole tree). Thus, this fast and relatively easy way to calculate branch-level scaling exponents has the potential to revolutionize the ability to calculate the scaling of whole tree carbon and water use. That the branching laws follow a theoretically predictable function based on metabolic considerations provides a theory-based validation for this approach. Not only will researchers be able to calculate exponents for trees of much greater sizes than possible by hand, it will be possible to process a greater number of trees in much less time.

Conclusion

Tree scaling metabolism derived from TLS evidenced that (1) length ratio exponent, radii ratio exponent and architecture estimated metabolic rate converge between the tropical trees analysed, (2) there is no strong evidence to support that tropical trees are able to respond to environment through changes in branch length more so than branch width, and (3) length ratio exponent, radii ratio exponent and estimated metabolic rate from the analysed samples are comparable with the predicted values.

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