The stem and branch metrics were derived based on the construction of 3D tree model. Tables S1–S4 list the detail definition and format of stem, branch, entire tree and crown metrics. The DBH was calculated as the diameter of the circle fitted to stem points at the tree height (TH) between 1.3m and 1.4 m using the least square algorithm (Figure S1). Tree height was the height difference between the highest and lowest points of individual trees. The minimum stem radius was the radius of fitted circle at the crown start height using the same fitting method of DBH. Tree volume was calculated using the alpha shape algorithm (Colaço et al., 2017; Di Gennaro and Matese, 2020). Stem radial irregularity S5 was the standard deviation of the distance Δs between points and projected circle. Stem taper S6 was the taper of stem from crown start height and tree root.

The branch metrics were derived based on the construction of a 3D tree model TreeQSM generated by fitting cylinders to branch points. Branch length, radius, and volume were extracted from 3D cylinders. The angle between branch and stem or between different order branches was calculated through the centreline of 3D cylinder models. The distance between branches was calculated as the vertical distance between the start points of branches.

Some entire tree metrics were derived based on griding tree point cloud with edge length of 0.1 m referring to the work of Lin and Hyyppä (2016). The grid height was the height of grid center. To T4, the coverage area was calculated as the project area that projecting tree points on the x-y plane. The volume of point clouds was calculated by the convex hull algorithm (Cupec et al, 2020). The convex hull of a point cloud is the smallest convex set that contains it. The volume of the smallest convex set was used as the volume of the corresponding point cloud. Total surface area in T13 was computed through the alpha shape algorithm (Colaço et al., 2017; Di Gennaro and Matese, 2020).

Table S1. Detailed definition and format of stem structural metrics.

Attribute	No.	Definition	Format
Stem diameter	S1	S1=DBH;	$S1 = DBH$
	S2	S2=DBH/TH;	$S2 = DBH/TH$
	S3	S3=DBH/tree volume;	$S3 = DBH/TV$
	S4	S4=DBH/minimum stem radius	$S4 = DBH/R_{st}$
Stem shape	S5	Stem radial irregularity	$S5 = \sqrt{\sum_{i=1}^{p_{sri}} (\Delta s_i - \overline{\Delta s})^2 \Big/ p_{sri}}$
	S6	Stem taper	$S6 = (R_{sb} - R_{st})/S7$
Stem length	S7	Stem length	S7 = SL
	S8	Stem length / tree height	$S8 = S7/TH$
Stem angle	S9	Angle between stem direction vector and axis x	S9=A_x
	S10	Angle between stem direction vector and axis y	S10=A_y
	S11	Angle between stem direction vector and axis z.	S11=A_z
Stem volume	S12	Stem volume	S12=$\sum_{i=1}^{s} SV_i$

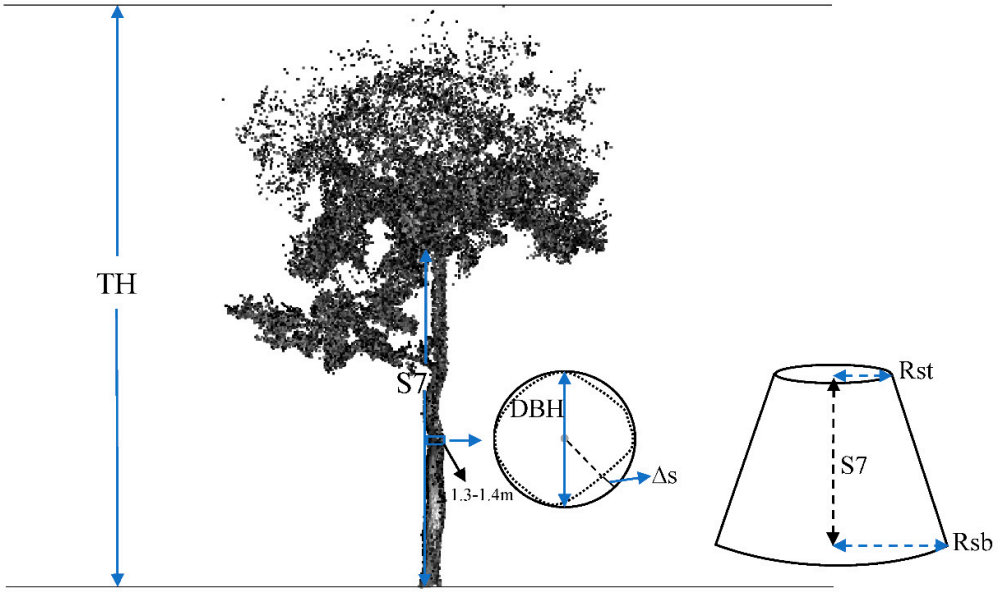

Figure S1. Illustration of stem metric derivation.

Table S2. Detailed definition and format of branch structural metrics.

Attribute	No.	Structural metrics	Format
Branch angle	B1	Average count of 1st branches in 8 azimuths	$B1=\sum_{i=1}^{8} Nb1_i/8$
	B2	Median of 1st branch angle	$B2=\begin{cases}\frac{\left(A_{\frac{n}{2}}+A_{\frac{n+1}{2}}\right)}{2}, n\ is\ even\\ A_{\frac{n+1}{2}}, n\ is\ odd\end{cases}$
	B3	Sum of 1st branch angle	$B3=\sum_{i=1}^{n} A_i$
	B4	Average of 1st branch angle	$B4=\frac{B3}{n}$
	B5	Median 1st branch angle/median 2nd branch angle	$B5=f(A_i, n)/f(A_{2i,} n_2)$
	B6	Standard deviation of 1st branch angle	$B6=\sqrt{\frac{\sum_{i=1}^{n}(A_i-\bar{A})^2}{n-1}}$
Branch length	B7	Sum of 1st branch length	$B7=\sum_{i=1}^{n} B1_{li}$
	B8	Average of 1st branch length	$B8=\frac{B7}{n}$
	B9	Ratio of average of 1st branch length to tree height	$B9=\frac{B8}{TH}$
	B10	Ratio of average of 1st branch length to DBH	$B10=\frac{B8}{DBH}$
	B11	Overall branch length / overall branch volume	$B11=\frac{BL}{BV}$
	B12	Average length of top 10 longest branches	$B12=\frac{\sum_{i=1}^{10} B1_{li}}{n}$
Branch radius	B13	Average of 1st branch radius	$B13=\sum_{i=1}^{n} Rb1_i/n$
	B14	B13/tree height	$B14=B13/TH$
	B15	Average radius of top 10 largest branches	$B15=\sum_{i=1}^{10} Rb1_i/10$
Branch cluster	B16	Average vertical distance between 1st branches	$B16=\sum_{i=1,j=1}^{n-1} d_{bi\_bj}/n-1$
	B17	B16/DBH	$B17=B16/DBH$
	B18	Branch volume below 55% of the tree	$B18=BV_{0-55}$
	B19	Average number of 1st branch with the 40cm height interval	$B19=\frac{1}{hl}\sum_{i=1}^{hl} B_{1\_hl_i}$

Where Nb1 is the number of 1st branch in an azimuth,A_i is the angle between 1st branch and trunk, $\bar{A}$ is the average of all A_i, n is the number of 1st branches, n_2 is the number of 2nd branches, A_{2i} is the angle between the 1st and 2nd branches, $B1_l$ is the length of 1st branch, BL is the overall branch length, BV is overall branch volume, Rb1 is 1st branch radius, TH is tree height, d_{bi_bj} is the vertical distance between 1st branch bi and bj, BV_{0-55} is the branch volume below 55% of the tree, hl is the number of layers with height of 0.4m, $B_{1\_hl_i}$ is the number of 1st branches in the height layer i. The median value in B2 and B5 was calculated by $f(A, n)$, Before input into the function, A values were sorted from smallest to largest, n is the number of variables in A. When n is even, the output of $f(A, n)$ is the average

of $\frac{n}{2}$th and $\frac{n+1}{2}th$ A values. When n is odd, the output of $f(\mathrm{A}, n)$ is the $\frac{n+1}{2}$th A value.

$$f(A_i, n) = \begin{cases} \dfrac{(A_{\frac{n}{2}} + A_{\frac{n+1}{2}})}{2}, n\ is\ even \\ A_{\frac{n+1}{2}}, n\ is\ odd \end{cases}$$

Table S3. Detailed definition and format of entire tree structural metrics.

Attribute	No.	Definition	Format
Height metrics	T1	Tree height	$\mathrm{T1} = \mathrm{H_t} - \mathrm{H_e}$
	T2	Mean height of all G0.1 / tree height	$\mathrm{T2} = (\frac{1}{\mathrm{g}}\sum_{\mathrm{i=1}}^{\mathrm{g}} \mathrm{H_{gi}})/\mathrm{TH}$
	T3	Mean height of all G0.1	$\mathrm{T3} = \frac{1}{\mathrm{g}}\sum_{\mathrm{i=1}}^{\mathrm{g}} \mathrm{H_{gi}}$
Cover metrics	T4	Coverage area within 30% of tree height / crown coverage area	$\mathrm{T4} = \mathrm{C_{30\%}}/\mathrm{C_{crown}}$
Volume distribution	T5	Number of stem G0.1 / all G0.1	$\mathrm{T5} = \mathrm{g_s}/\mathrm{g}$
	T6	Tree volume	$\mathrm{T6} = \mathrm{cov(p)}$
	T7	Tree volume within 80-90% of the tree height / tree volume within 10% of the tree height	$\mathrm{T7} = \mathrm{cov(p)_{80-90}}/\mathrm{cov(p)_{0-10}}$
	T8	Relative cylinder volume below 55% of tree height;	$\mathrm{T8}=\mathrm{cov(p)_{0-55}}$
	T9	Total length of all cylinders / total tree volume.	$\mathrm{T9} = \mathrm{L_{cyl}}/\mathrm{cov(p)}$
	T10	Tree volume / crown cover area;	$\mathrm{T10} = \mathrm{cov(p)}/\mathrm{C_{crown}}$
	T11	Tree volume / tree height;	$\mathrm{T11} = \mathrm{cov(p)}/\mathrm{TH}$
	T12	Tree volume / crown diameter	$\mathrm{T12} = \mathrm{cov(p)}/\mathrm{d_{crown}}$
Surface	T13	Total surface area of entire tree	$\mathrm{T13} = \alpha(\mathrm{p})$

Where $\mathrm{H_t}$ is the highest height of a tree, $\mathrm{H_e}$ is the lowest height of a tree, g is number of grids, $\mathrm{H_{gi}}$ is height of the center of grid i, $\mathrm{C_{30\%}}$ is the coverage area with 30% of tree height, $\mathrm{C_{crown}}$ is crown coverage area, $\mathrm{g_s}$ is the number of stem grid, cov is the alpha algorithm used for volume calculation, p is tree points. $\mathrm{cov(p)_{80-90}}$ means tree volume within 80-90% of the tree height, $\mathrm{cov(p)_{0-10}}$ means tree volume within 10% of the tree height, $\mathrm{d_{crown}}$ is crown diameter, α is the convex hull algorithm for surface calculation, G0.1 means grid representing a tree with edge length of 0.1m.

The crown bottom was defined as the lower third of the crown. The highest crown bottom and lowest crown bottom were the highest height and lowest height of crown bottom points

respectively as shown in Figure S2. Along the stem, the height that leaves appeared or the branch appeared was defined as crown start height. Height of max crown spread (H_{maxc}) was the height that crown have maximum spread. The largest crown length and the smallest crown length were the vertical distance from treetop to the lowest crown bottom and the highest crown bottom respectively. CD_{xy} was the maximum distance between projected crown points (project crown points on the x-y plane). CD_{yz} and CD_{xz} were the maximum distance between crown points that projected on the y-z and the x-z plane respectively. CCD was the maximum distance of projected crown points at the opposite direction of crown diameter. Crown radius (Cr) was the half of CD_{xy}. Crown area A_{xy} was calculated by convex hull algorithm. The crown points were firstly projected on the x-y plane, then the projection area was calculated using convex hull algorithm. Crown vertical projecting area A_{vc} was the average of area that projected on the y-z plane and the x-z plane. Crown equivalent diameter (Cer) was the diameter of the equivalent crown whose area equals tree crown as shown in Figure S3. Diameter of the minimum circle of crown (CD_{mincir}) was the diameter of minimum circumcircle of crown. Crown volume (V_c) was calculated through convex hull algorithm. To derive the shape signature index Ss_c, crown surface points were divided into several layers with height interval of 0.1m from crown top to crown bottom. The point number within each layer and layer number can be used to calculate Ss_c.

To evaluate the detailed crown shape, we vertically divided crown into 8 segments as illustrated in Figure S3. In these segments, the ratio between the highest crown top and the lowest crown top was defined as crown top evenness and the ratio between the highest crown bottom and the lowest crown bottom was defined as crown bottom evenness. The points in each segment were projected to the central vertical grided profile with the edge length of 1m referring to Lin and Hyyppä (2016). The difference between profiles were

calculated through diff function in R and the similarity between profiles were calculated through Cor function. Coefficient variation of crown (C_{cv}) demonstrated the height dispersion within a crown scale (Liu and Wu, 2018).

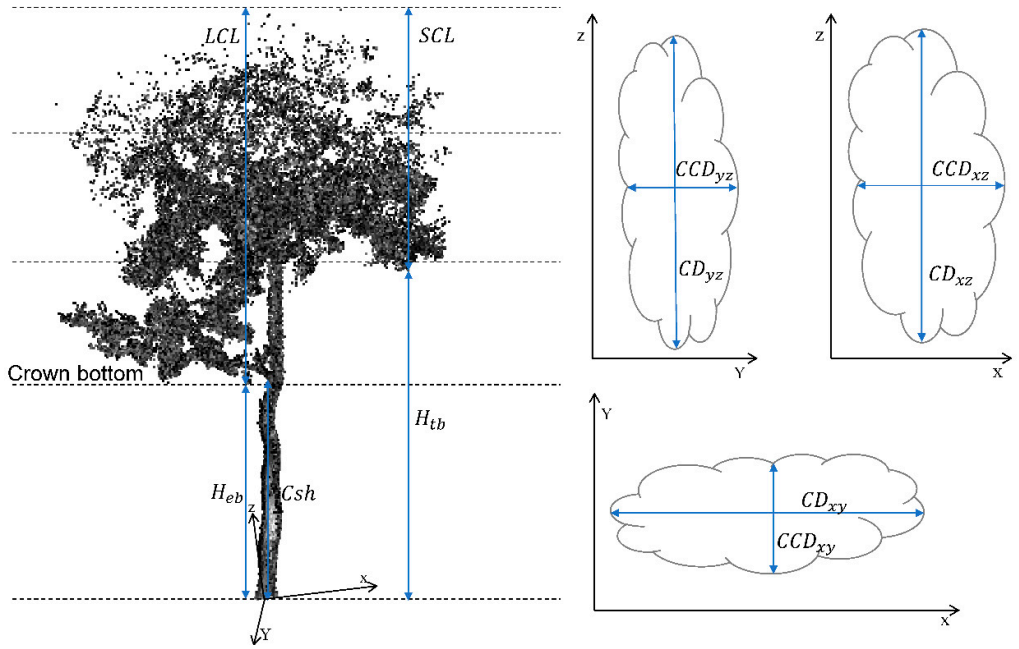

Figure S2**.** Illustration of crown metrics.

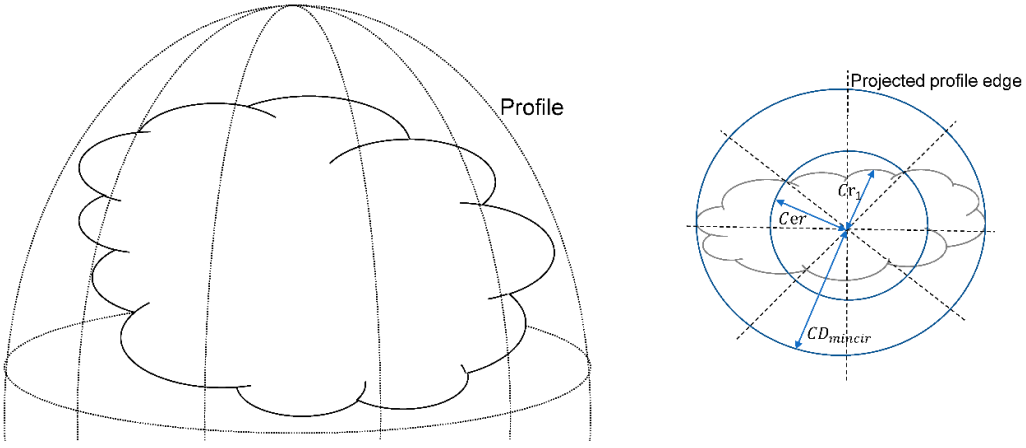

Figure S3. Illustration of crown profile and relevant metrics.

Table S4. Detailed definition and format of crown structural metrics.

Attribute	No.	Definition	Format
Crown height	C1	The highest crown bottom	$C1 = H_{tb}$
	C2	The lowest crown bottom	$C2 = H_{eb}$
	C3	Crown start height	$C3 = Csh$
	C4	Ratio between crown start height and tree height	$C4 = C3/TH$
Crown length	C5	Largest Crown length (LCL)	$C5 = LCL$
	C6	Ratio between longest crown length and smallest crown length (SCL)	$C6 = LCL/SCL$
	C7	Average crown length	$C7 = (LCL + SCL)/2$
	C8	Ratio between LCL and crown diameter that derived from projected crown points on the x-y plane	$C8 = LCL/CD_{xy}$
	C9	Ratio between LCL and tree height	$C9 = LCL/TH$
Crown diameter	C10	Ratio between CD_{xy} and tree height	$C10 = CD_{xy}/TH$
	C11	Ratio between CD_{xy} and SCL	$C11 = CD_{xy}/SCL$
	C12	Ratio between CD_{xy} and crown cross diameter CCD_{xy} that derived from projected crown points on the x-y plane	$C12 = CD_{xy}/CCD_{xy}$
	C13	Crown diameter CD_{xy} that derived from projected crown points on the x-y plane	$C13 = CD_{xy}$
	C14	crown cross diameter CCD_{xy} that derived from projected crown points on the x-y plane	$C14 = CCD_{xy}$
	C15	Ratio between crown diameter and crown cross diameter derived from projected crown points on the y-z plane	$C15 = CD_{yz}/CCD_{yz}$
	C16	Ratio between crown diameter and crown cross diameter derived from projected crown points on the x-z plane	$C16 = CD_{xz}/CCD_{xz}$
	C17	Ratio between the radius of equivalent centers for the grids within the profiles and crown radiu (average for 8 profiles)	$C17 = \sum_{i=1}^{8}(\sum_{j=1}^{n_{cg}} R_{G_j}/n) \Big/ (8 \times Cr)$
	C18	SD of ratio between the radius of equivalent centers for the grids within	$C18 = std((\sum_{j=1}^{n} R_{G_j}/n)/Cr)_i \mid i = 1, \ldots, 8$)

Attribute	No.	Definition	Format
		the profiles and crown radiu	
	C19	Semi-axis lengths of paraboloid fitted to tree crown at axis X.	$C19 = l_x/2$
	C20	Semi-axis lengths of paraboloid fitted to tree crown at axis Y	$C20 = l_y/2$
	C21	Semi-axis lengths of paraboloid fitted to tree crown at axis Z	$C21 = l_z/2$
	C22	Crown equivalent diameter	$C22 = Cer$
	C23	Diameter of the minimum circle of crown	$C23 = CD_{mincir}$
Crown area	C24	Ratio between the height of max crown spread and tree height	$C24 = H_{maxc}/TH$
	C25	Ratio between the height of max crown spread and LCL	$C25 = H_{maxc}/LCL$
	C26	Ratio between crown area A_{xy} and tree height	$C26 = A_{xy}/TH$
	C27	Ratio between crown area and crown vertical projecting area	$C27 = A_{xy}/((A_{xz} + A_{yz})/2)$
Crown height distribution	C28	Ratio between the height of the equivalent centers for the grids within each profile and LCL (average for 8 profiles)	$C28 = \sum_{i=1}^{8}(\sum_{j=1}^{n} H_{G_j}/n)/8 \times LCL$
	C29	Ratio between average height of all crown grids with profiles and LCL	$C29 = (\frac{1}{n}\sum_{i=1}^{n} H_{G_i})/LCL$
	C30	Ratio between C34 and C18	$C30 = C34/C18$
Crown shape	C31	Ratio between overall similarity between two opposite vertical profiles and overall similarity between two adjacent vertical profiles;	$C31 = \frac{\sum_{i=1}^{4} Cor\ (S_i, S_{i+4})}{\sum_{i=1}^{8} Cor\ (S_i, S_{i+1})}$
	C32	Ratio between alpha volume and convex hull volume of crown;	$C32 = V_\alpha/V_{cov}$
	C33	Crown top evenness;	$C33 = H_{tth}/H_{teh}$
	C34	SD of C28 for all of the 8 vertical profiles;	$C34 = std(((\sum_{j=1}^{n} H_{G_j}/n)/LCL)_i \mid i, \ldots$

Attribute	No.	Definition	Format
	C35	Crown bottom evenness	$C35 = H_{bth}/H_{beh}$
Crown volume	C36	Crown volume;	$C36 = V_{\alpha}$
	C37	Ratio between crown volume and crown area	$C37 = V_{\alpha}/A_{xy}$
	C38	Ratio between crown volume and number of points in a crown	$C38 = V_{\alpha}/n_{cp}$
Crown volume distribution	C39	Ratio between convex hull volume of crown grids with maximum point density and corresponding grid volume	$C39 = V_{CG_{maxden}}/V_{G_{maxden}}$
	C40	Standard deviation of the number of the grids filled by laser points for all of the V crown layers	$C40 = std(N_{G_i} \mid i = 1, \ldots, v)$
	C41	Sum of the difference between the 8 adjacent profile/differences between all CG0.1	$C41 = \frac{\sum_{i=1}^{8} diff\ (S_i, S_{i+4})}{\sum diff\ (PG_i, PG_j)}$
Crown irregularity	C42	Coefficient variation of crown;	$C42 = \sqrt{\frac{1}{n_{cp}}\sum_{i=0}^{n_{cp}}(H_i - \frac{1}{n_{cp}}\sum_{i=1}^{n_{cp}} H_i)^2} \Big/ \frac{1}{n_c}$
	C43	Average ratio between the total area of voxel one-side covers and the area of the 2D convex hull of the crown from two perpendicular side views.	$C43 = \frac{1}{2} \times \left(\frac{\sum(n_{G_{XZ}} \times A_G)}{A_{CV}^{XZ}} + \frac{\sum(n_{G_{YZ}} \times A_G)}{A_{CV}^{YZ}}\right)$
	C44	Residual sum of squared errors of gaussian fitting in crown ellipsoid modeling;	$C44 = \delta \mid exp(-\frac{(x-u)^2}{2\delta^2})$
	C45	Shape signature index;	$C45 = \sum_{i=1}^{m}(i \times l_i) \Big/ \sum_{i=1}^{m} l_i$

Where n_{cg} is the number of crown grids, R_{G_j} is the radius of ith grid, l_x, l_y, l_z are the length of axiz x, y, z of fitted paraboloid respectively, H_{maxc} is the height of max crown spread, H_{G_j} is the height of equivalent center of grid j, S is the segment, V_{α} is crown volumn calculated by alpha shape algorithm, V_{cov} is crown volumn calculated by convex hull algorithm, H_{tth} is height of highest crown top, H_{teh} is height of lowest crown top, H_{bth} is height of highest crown bottom, H_{beh} is height of lowest crown bottom, n_{cp} is the number of crown points, $V_{CG_{maxden}}$ is the point volume of grid that have maximum

point density, $V_{G_{maxden}}$ is the volume of grid that have maximum point density, N_{G_i} is the number of grids in layer crown layer i, PG_i is the grid on profile, H_i is the height of point i, A_G is the side area of each crown grid, $n_{G_{XZ}}$, $n_{G_{YZ}}$ are the number of crown grids in the x-z and y-z projection plane, A_{CV}^{XZ}, A_{CV}^{YZ} is the area of crown grids in the x-z and y-z projection plane, m is the number of layers, l_i is the number of points in layer i, CG0.1 means grid representing a tree with edge length of 0.1m.

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