Bogor, March 2014

Lutz Fehrmann[1*], Nils Nölke[1], I Nengah Surati Jaya[2], Tatang Tiryana[2], Dominik Seidel[1], Christoph Kleinn[1]

[1] Chair of Forest Inventory and Remote Sensing, Faculty of Forest Sciences and Forest Ecology, Universität Göttingen, Germany
[2] Division of Forestry Planning, Department of Forest Management, Faculty of Forestry, Bogor Agricultural University, Indonesia

On the geometry and allometry of big buttress trees

New insights from 3D modeling with terrestrial laser scanning

DAAD Workshop, Bogor & Jakarta, 19. March 2014

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

DAAD

AWF-wiki

EFForTS

AWF

LIPI

Background

For the implementation of recent climate policy (e.g. REDD+) forest carbon stocks and their changes need to be estimated,

In particular in humid tropical forests, a small number of very large trees contribute considerably to stand basal area and biomass,

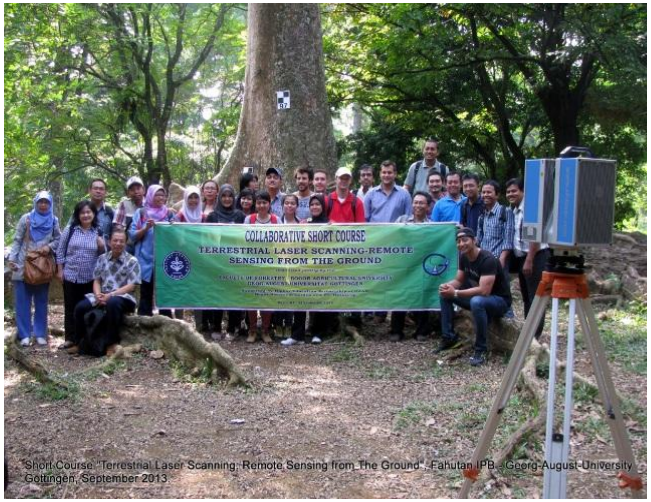
Many of these emergent trees have distinct buttresses and show very irregular non-convex shapes,

- the methods used to measure or determine a diameter for buttress trees have a large impact on the determination of volume and biomass,
- General allometric models do not consider these irregularities!

In September 2013 a training course on Terrestrial Laser Scanning (TLS) was held at IPB and in the Bogor Botanical Garden (collaboration between Universität Göttingen, Lipi and IPB),

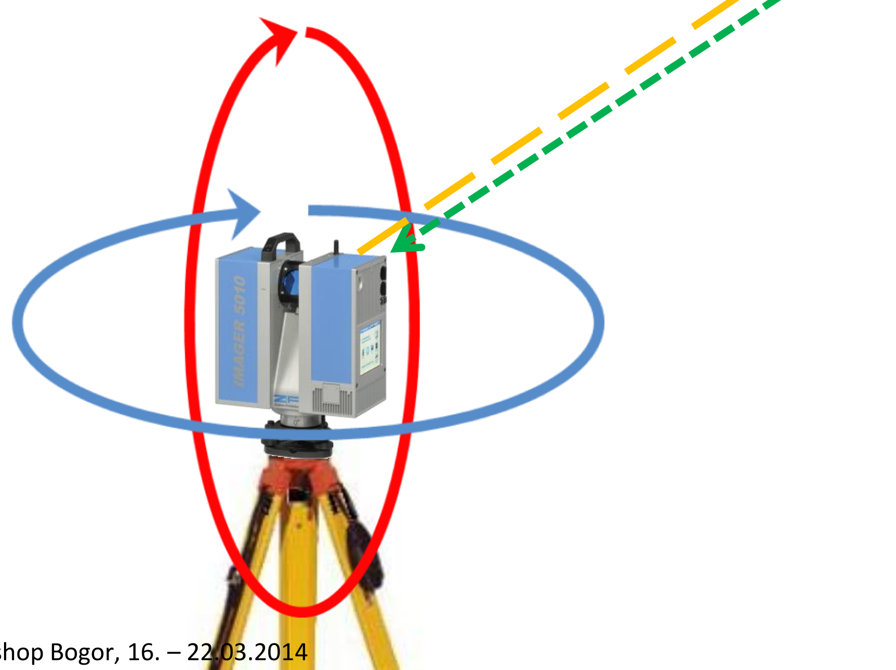
Main focus was to test TLS for the investigation of buttress geometry and the development of buttress volume and cross-sectional geometries over tree height.

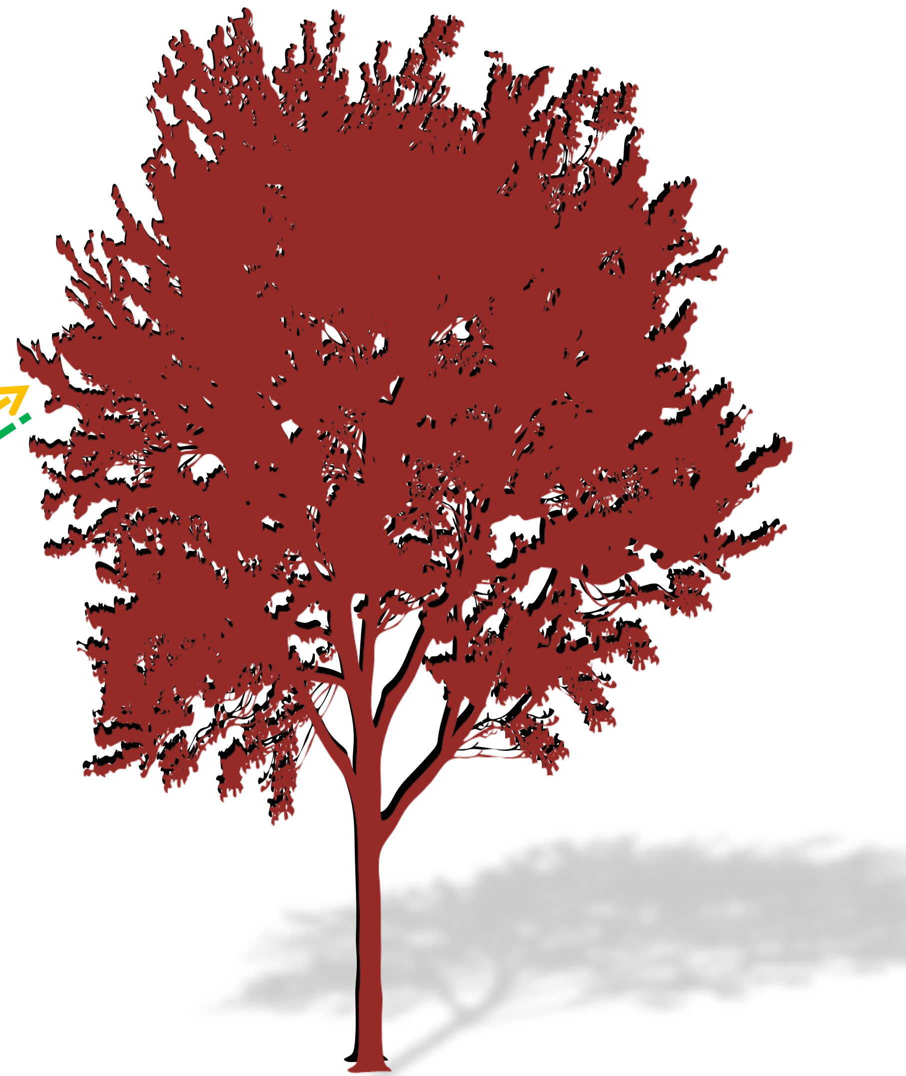
Photos taken by Hartanto Sanjaya (BPPT)



Terrestrial Laser Scanning (TLS)

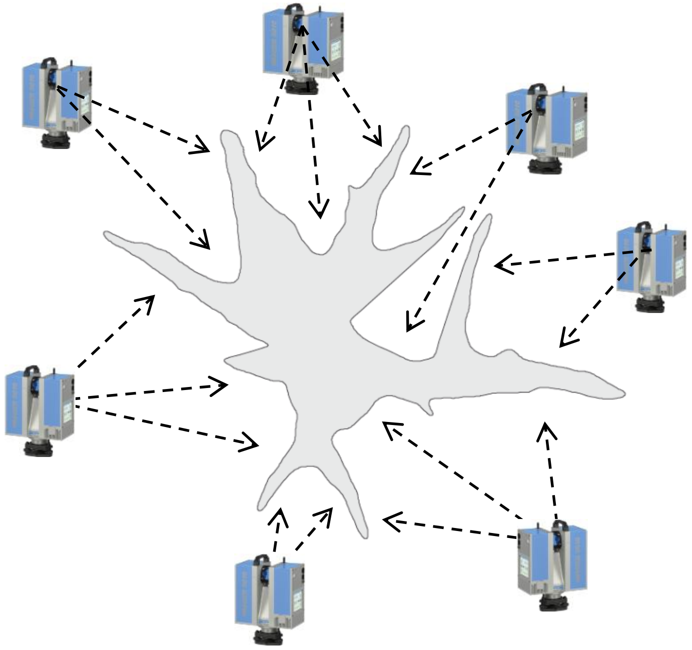
- A 3D laser scanner consists of: (1) laser unit (2) rotating mirror (3) detector
- Distance (d) is measured by the phase difference between the transmitted signal and received signal
- Polar coordinates are stored: (1) distance (2) vertical angle (3) horizontal angle
- Output is a 3D digital point cloud (xyz)

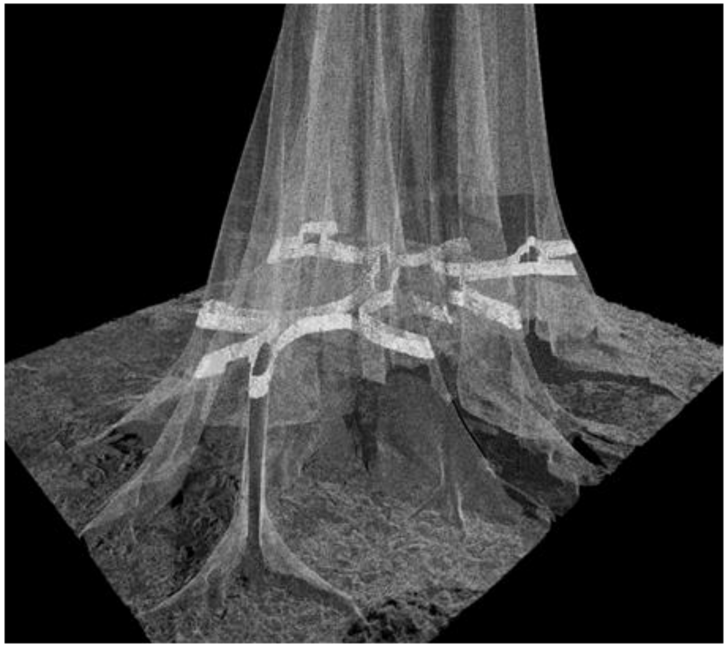




Terrestrial Laser Scanning (TLS)

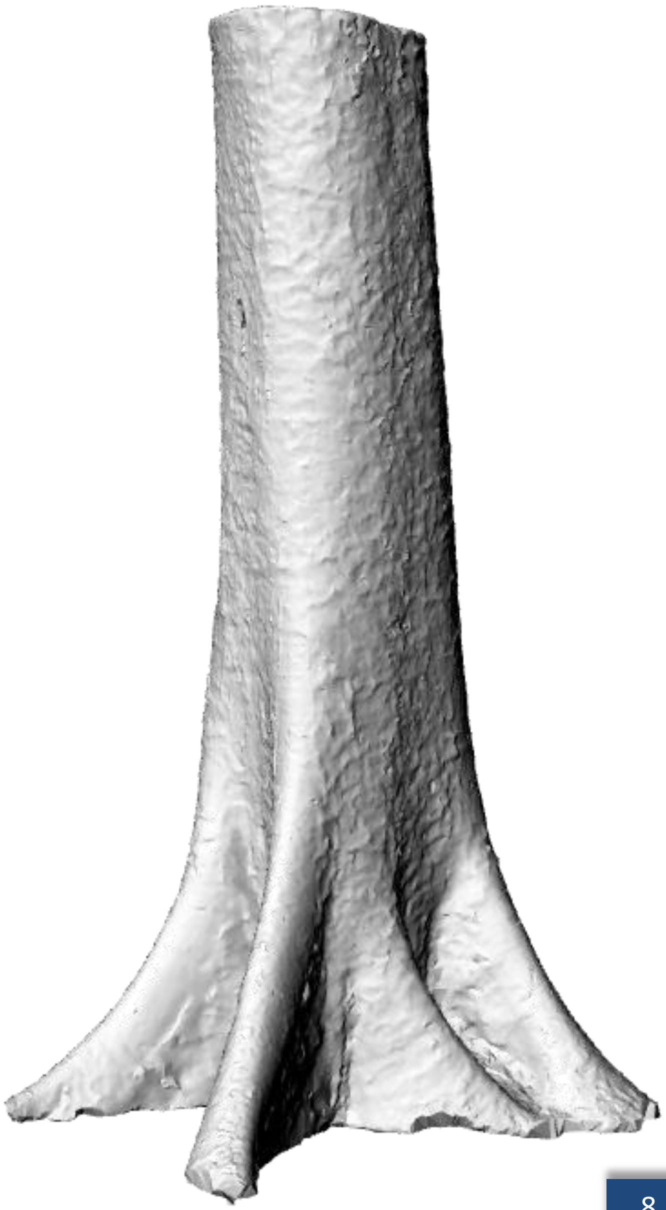
- A multiscan approach (up to eight positions per tree) was necessary to eliminate all scan shadows between the lateral roots,
- The single scans were co-registered by placing artificial targets and combined to one point cloud.





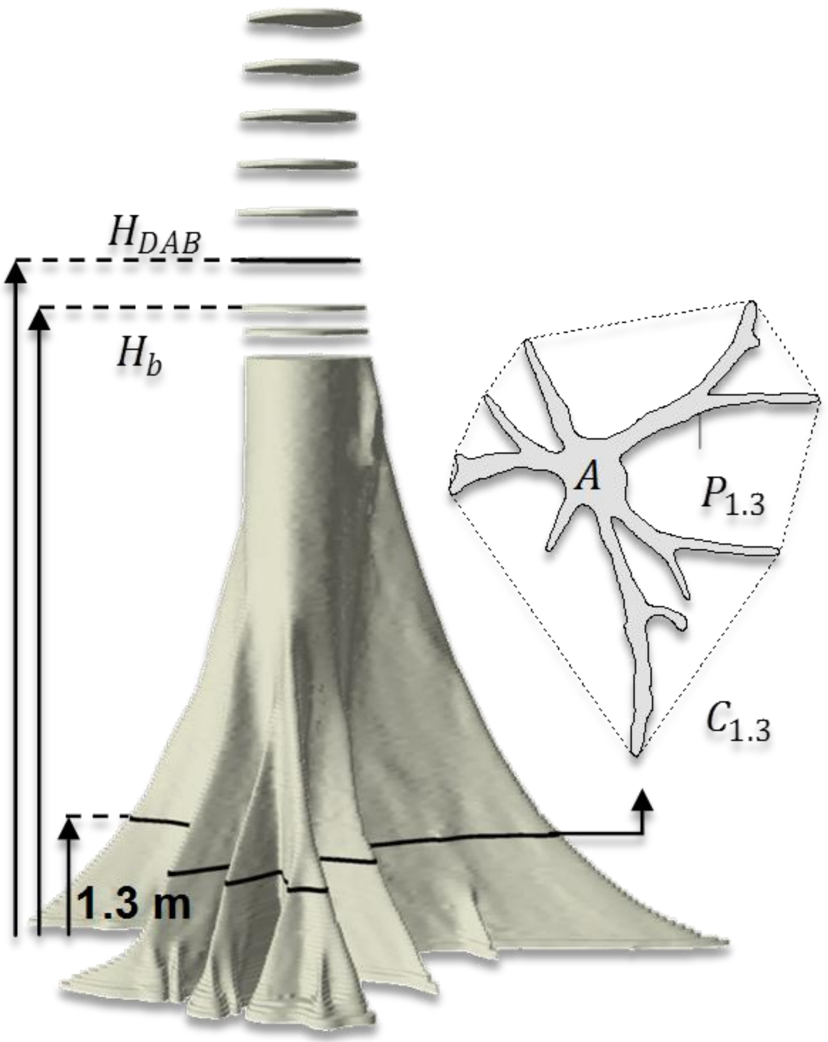
3D modelling

- Automated 3D surface reconstruction was only possible for very simple buttress geometries,
- Problem: the size of remaining scan shadows is often larger than the thickness of buttresses, available meshing algorithms are not appropiate,
- A manual deliniation of all cross sections in thin layers of 5 cm height intervals was used as approximation.



Some of the variables derived for each tree:

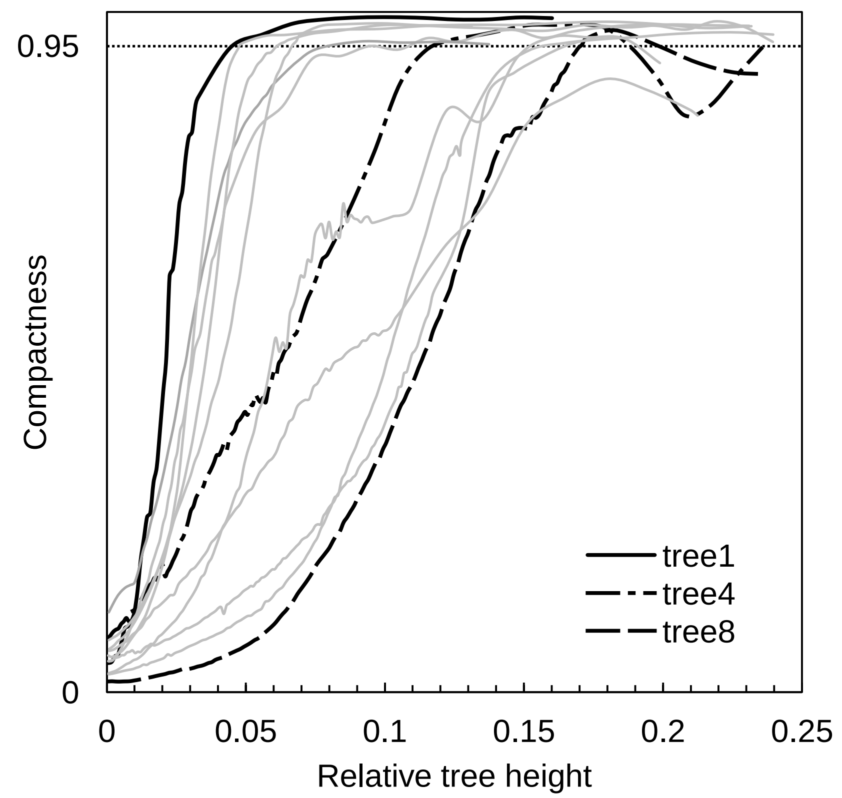
- H_b is the maximum height of buttresses,
- H_{DAB} is the height of the diameter above buttresses (H_{DAB}+50cm),
- A is the actual cross sectional area (here at breast height),
- $P_{1.3}$ is the actual non-convex perimeter of the cross section at breast height and
- $C_{1.3}$ is the perimeter of the convex hull (dashed line),
- Area, perimeter and a compactness index were derived in 5 cm steps up to the end of buttresses,
- Volume was calculated for each height interval.



Geometric complexity

The isoperimetric quotient Q is a measure of compactness and describes the ratio of the actual cross sectional area A and that of the circle of same perimeter P

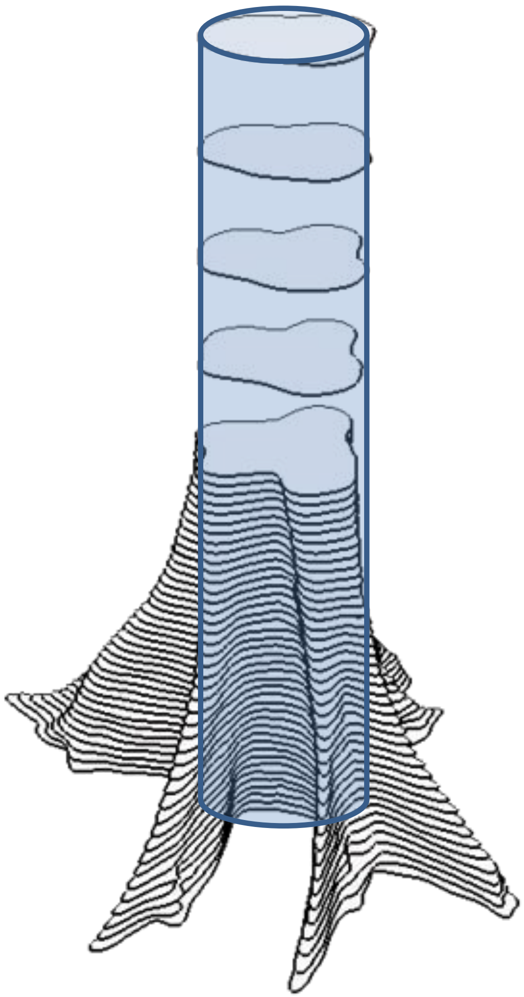
The end of buttresses refers to the height at which $Q \geq 0.95$, indicating that the shape of the cross section is close to a circle



Buttress form factor

Based on the *DAB* and its height we derived a buttress form factor f_b that describes the relation between the actual buttress volume (V_b) and the volume of a cylinder with diameter equal to *DAB* and length equal to the *DAB* measurement height H_{DAB} as:

$$f_b = \frac{V_b}{\pi/4\ DAB^2 H_{DAB}}$$

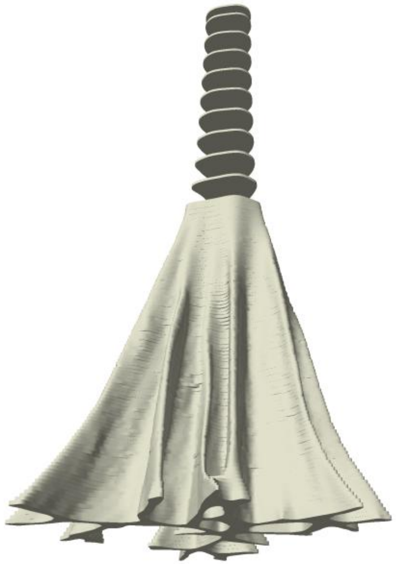


- We scanned 12 trees of different botanical families that show very different buttress morphology and tree dimensions:

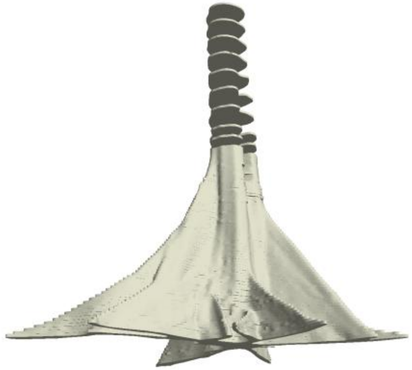
Tree	Species	Family	Height (m)
1	*Koompassia excelsa*	Fabaceae	43.3
2	*Ficus robusta*	Moraceae	39.9
3	*Celtis rigescens*	Cannabaceae	48.3
4	*Ficus albipila*	Moraceae	53.7
5	*Shorea leprosula*	Dipterocarpaceae	51.7
6	*Sterculia urceolata*	Sterculiaceae	34.0
7	*Sterculia urceolata*	Sterculiaceae	39.1
8	*Sterculia foetida*	Sterculiaceae	39.1
9	*Ceiba pentandra*	Bombacaceae	32.6
10	*Bombax ceiba*	Bombacaceae	34.1
11	*Bombax valetonii*	Bombacaceae	30.3
12	*Bombax valetonii*	Bombacaceae	30.1

Buttress morphology

- For visual representation the single cross sectional areas were extruded to their original height (5 cm),
- Above the buttresses the height interval of deliniated cross sections was increased to 50 cm.
- The selcted sample trees show very different buttress morphologies:

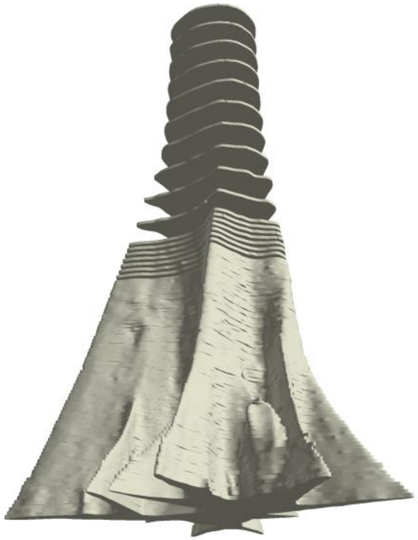


Ficus robusta (tree 2), DAB: 89cm, BA: 1.49m²



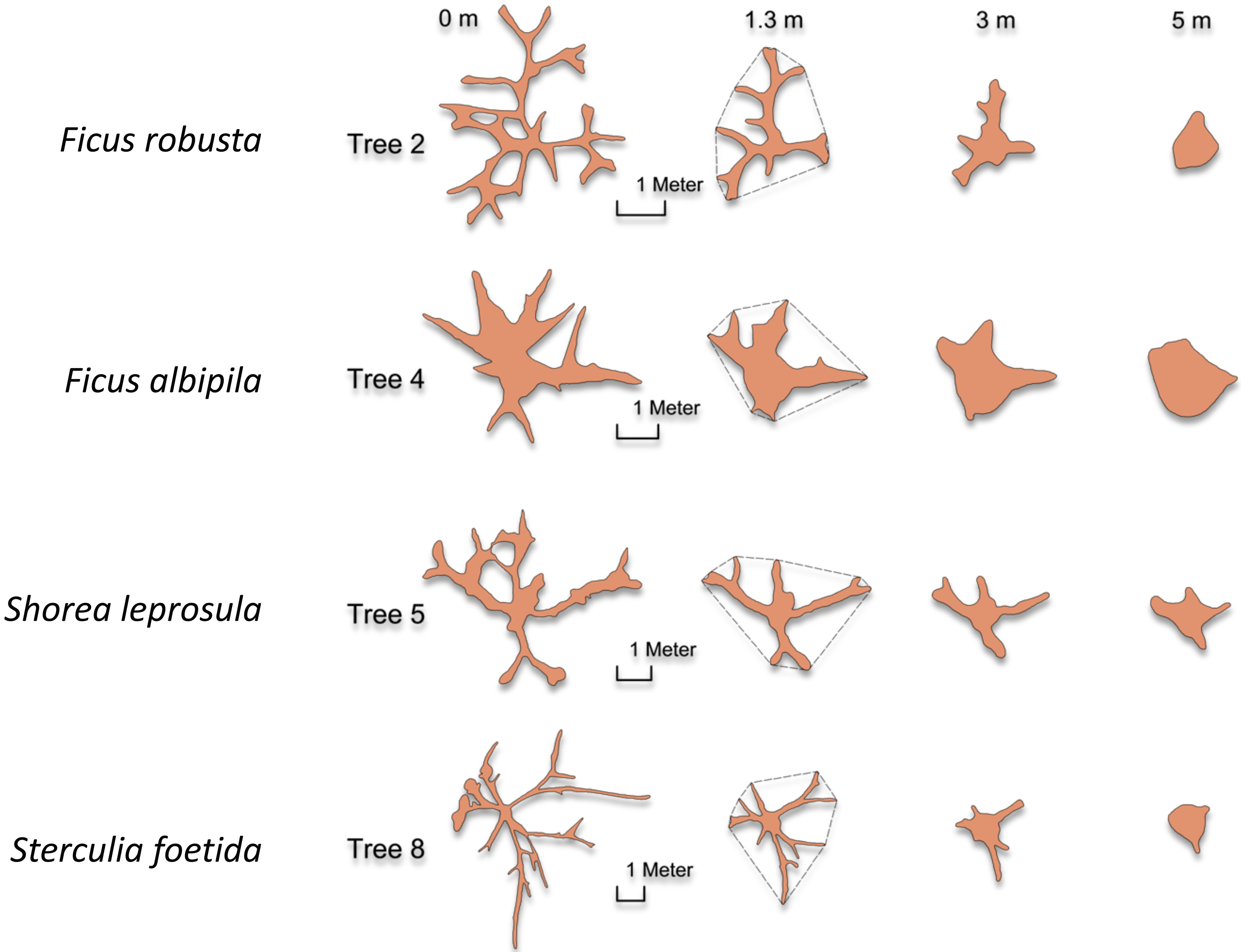
Sterculia urveolata (tree 7), DAB: 93cm, BA: 1.27m²

Shorea leprosula (tree 5), DAB: 119cm, BA: 2.73m²



Ficus albipila (tree 4), DAB: 172cm, BA: 3.15m²

Cross sectional area



Results

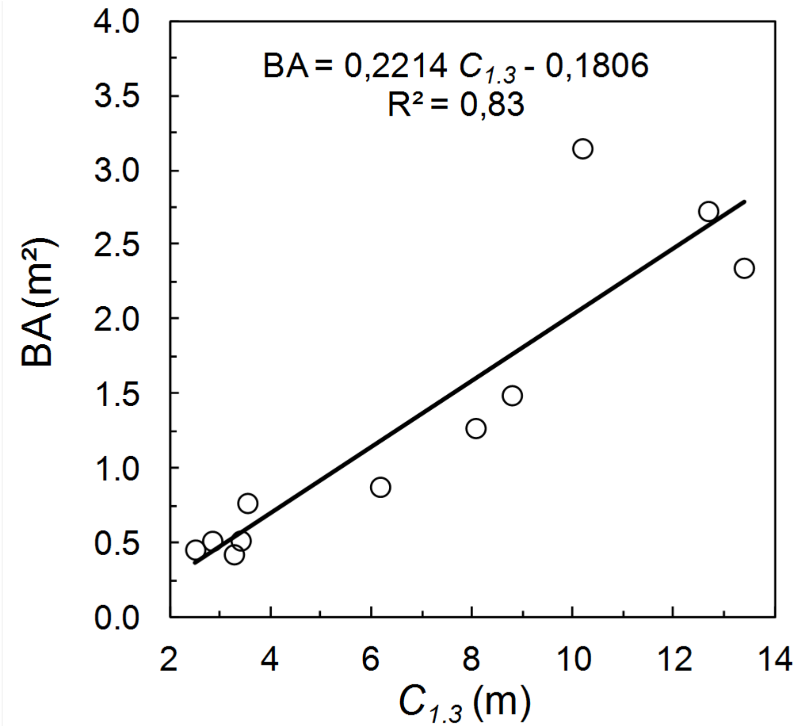
- Buttress heights of up to 8m,
- Buttress volume of up to 19m³,
- Basal area of up to 3.1m per tree!
- The mean form factor f_b is 1.55 (with standard deviation of ± 0.20)

Tree	BA (m²)	$C_{1.3}$(m)	H_b (m)	DAB (cm)	V_b (m³)	f_b
1	2.41	5.84	1.93	1.43	7.45	1.91
2	1.49	8.78	6.08	0.89	7.66	1.85
3	0.52	3.40	4.08	0.72	2.47	1.33
4	3.15	10.18	6.18	1.72	19.35	1.25
5	2.73	12.68	8.08	1.19	16.86	1.78
6	0.88	6.17	6.73	0.76	5.10	1.56
7	1.27	8.06	5.78	0.93	6.63	1.56
8	2.35	13.38	6.18	1.30	13.21	1.50
9	0.77	3.53	2.48	0.84	2.65	1.60
10	0.43	3.27	1.78	0.67	1.12	1.41
11	0.46	2.50	0.98	0.75	1.12	1.71
12	0.52	2.83	1.38	0.76	1.25	1.47

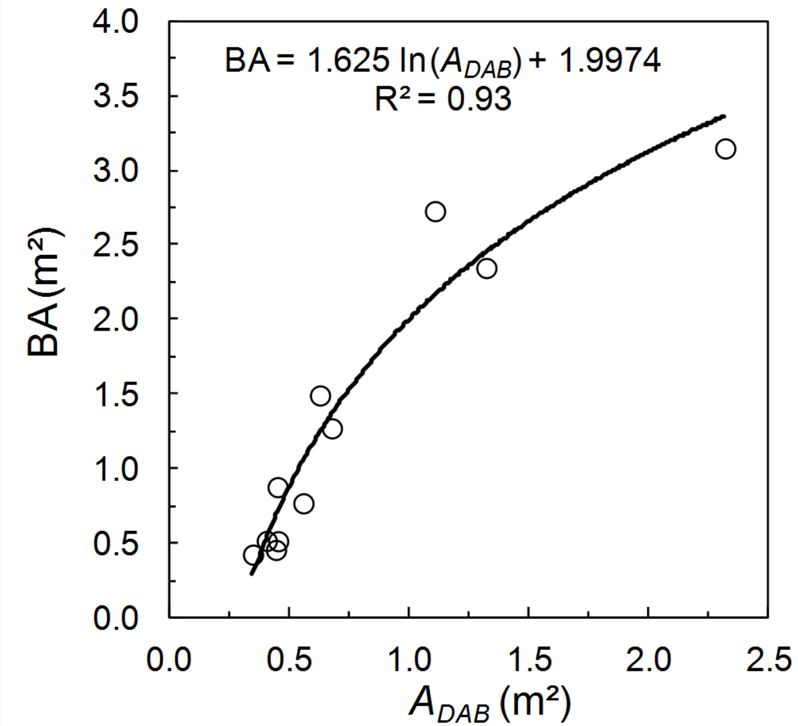
Buttress characteristics extracted for each tree: BA = basal area, $C_{1.3}$ = Girth in 1.3m, H_b= height of buttresses, DAB=diameter above buttress, V_b=buttress volume, f_b=buttress form factor.

Buttress allometry

- The relation between tree basal area and $C_{1.3}$ or cross section in DAB height A_{DAB} :



Relation between the perimeter of the convex hull in 1.3m height $C_{1.3}$ and tree basal area.



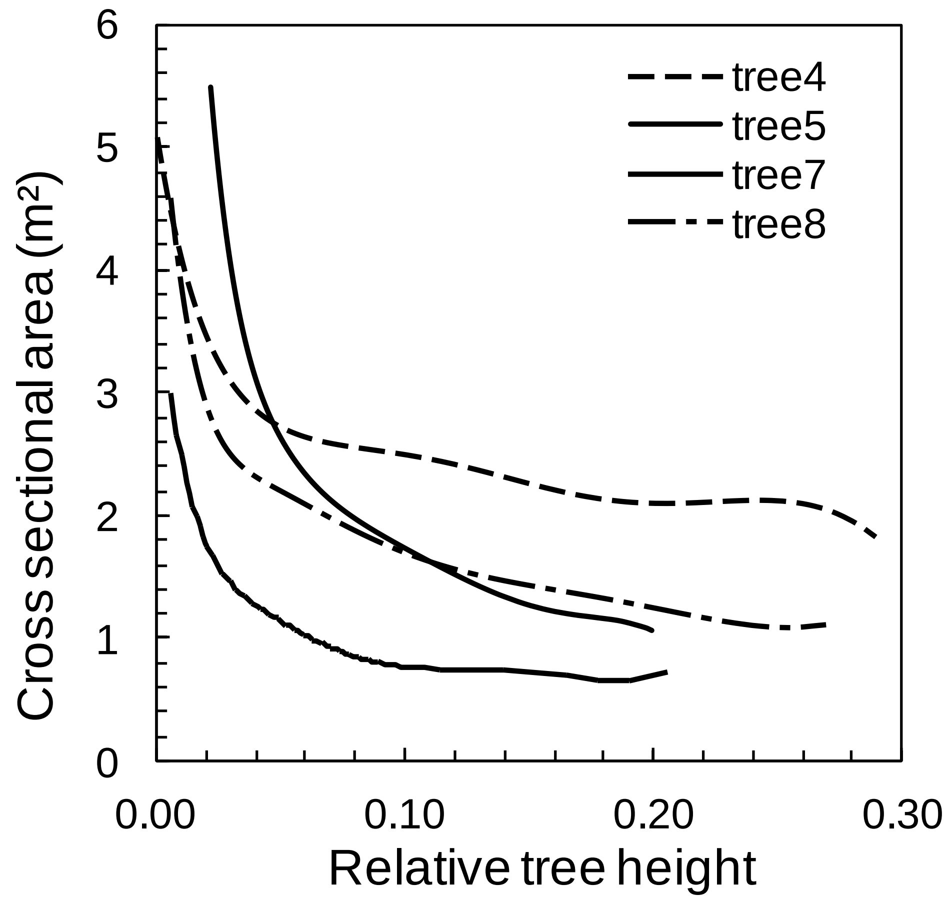
Relation between the cross sectional area in DAB height A_{DAB} and tree basal area in 1.3m height.

Stem taper

In contrast to the different buttress morphology and irregularity of cross sections,

- the development of the stem cross sectional area over tree height is very smooth, and

- very similar to usual taper curves that we know from non-buttress trees.



Development of cross sectional area over relative tree height for four sample trees.

Conclusions

- The relation between tree basal area and $C_{1.3}$ or cross section in DAB height A_{DAB} may be relatively strong (R^2=0.93, N=12!) for a range of different buttress morphologies and tree dimensions!

- The form factor shows that buttress biomass is under-estimated by the factor of ~1.55 if the DAB is used instead of actual basal area,

  – This might have relevant implications for the estimation of carbon stocks in tropical forests,

- The methodological approach is very appropriate and may help to improve volume and biomass models in future.

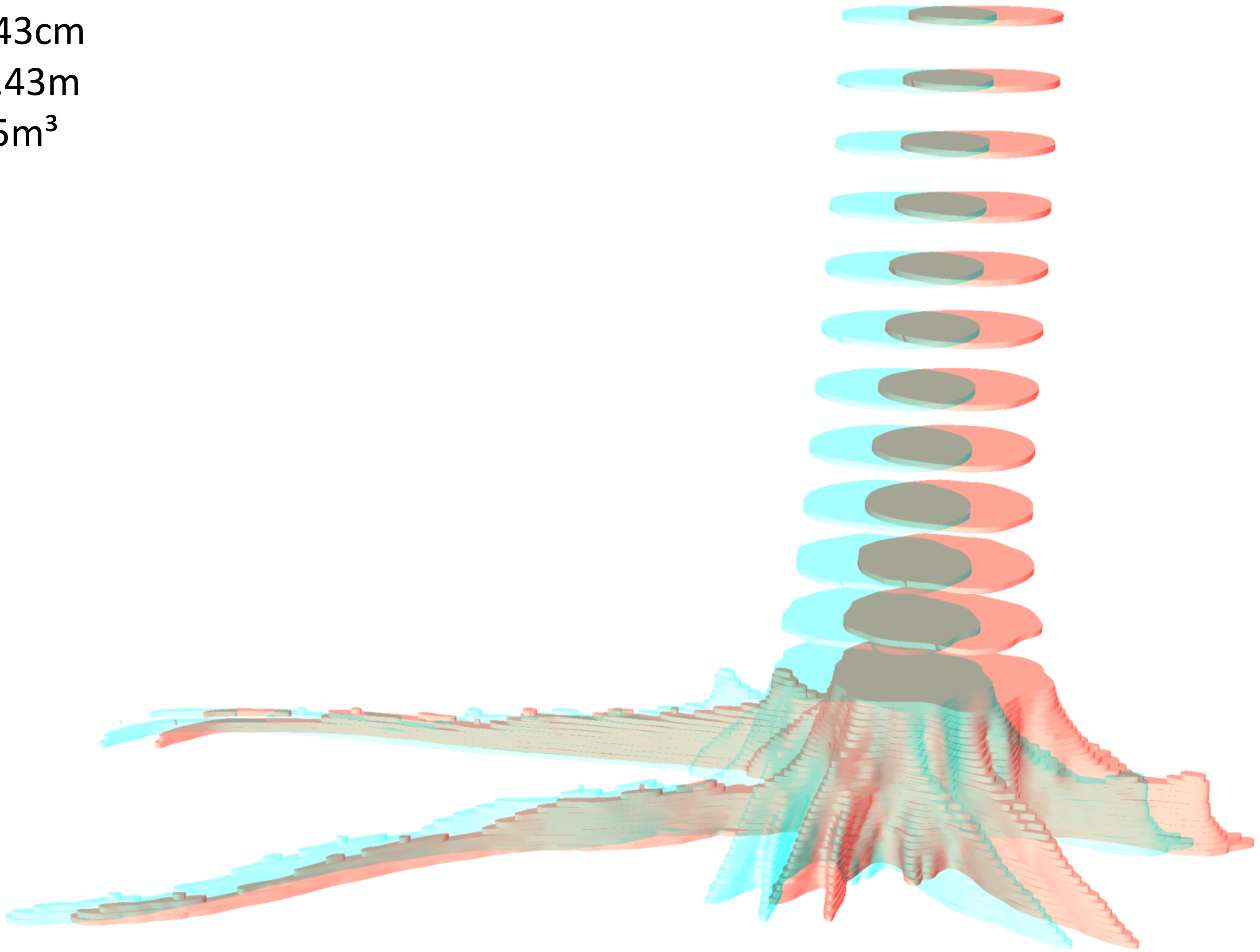
Wear the glasses with the blue filter on the left eye!

Kompassia excelsa

DAB: 143cm

H_{DAB}: 2.43m

V_b: 7.45m³

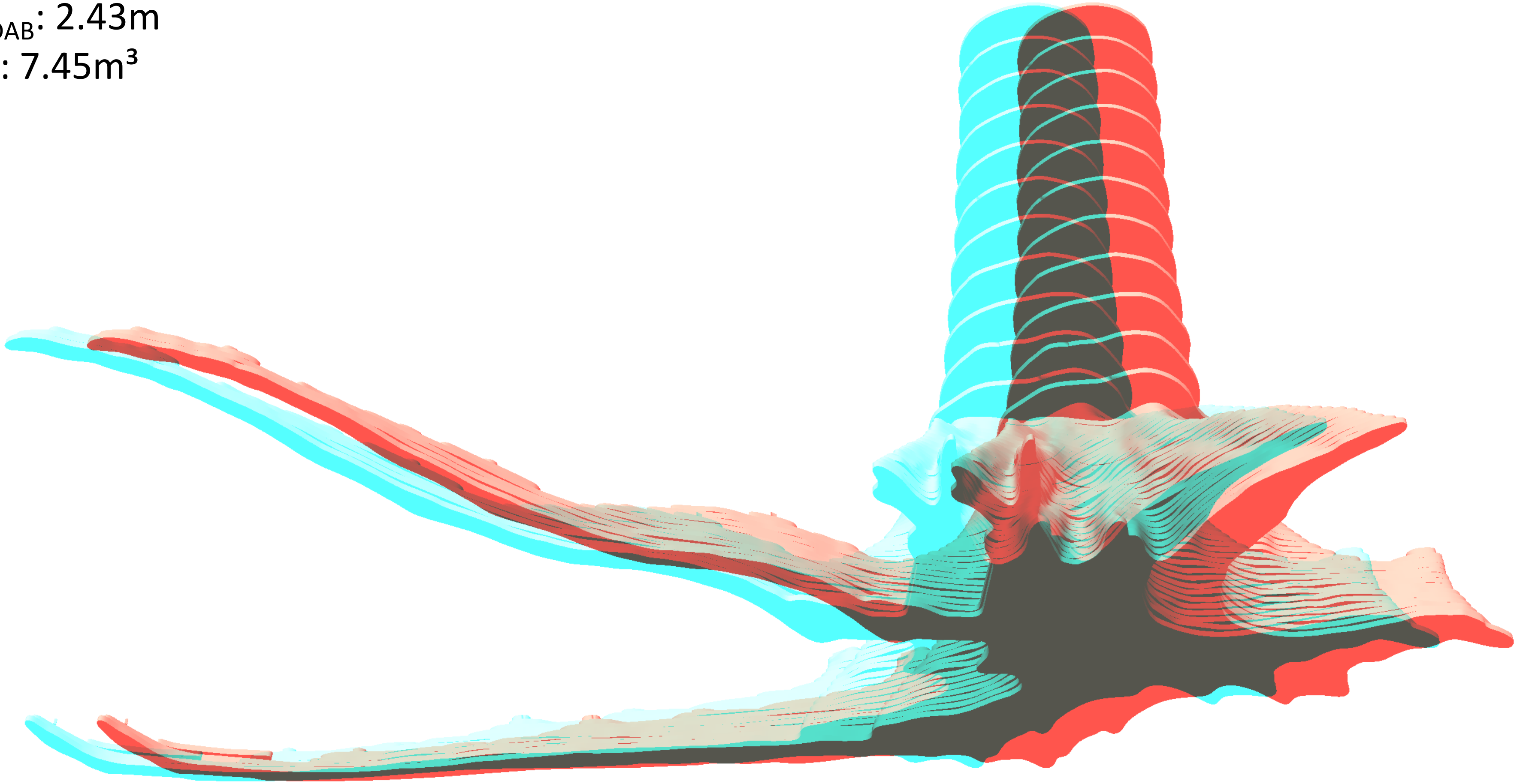


Kompassia excelsa

DAB: 143cm

H_{DAB}: 2.43m

V_b: 7.45m³



Ficus robusta

DAB: 89cm

H_{DAB}: 6.58m

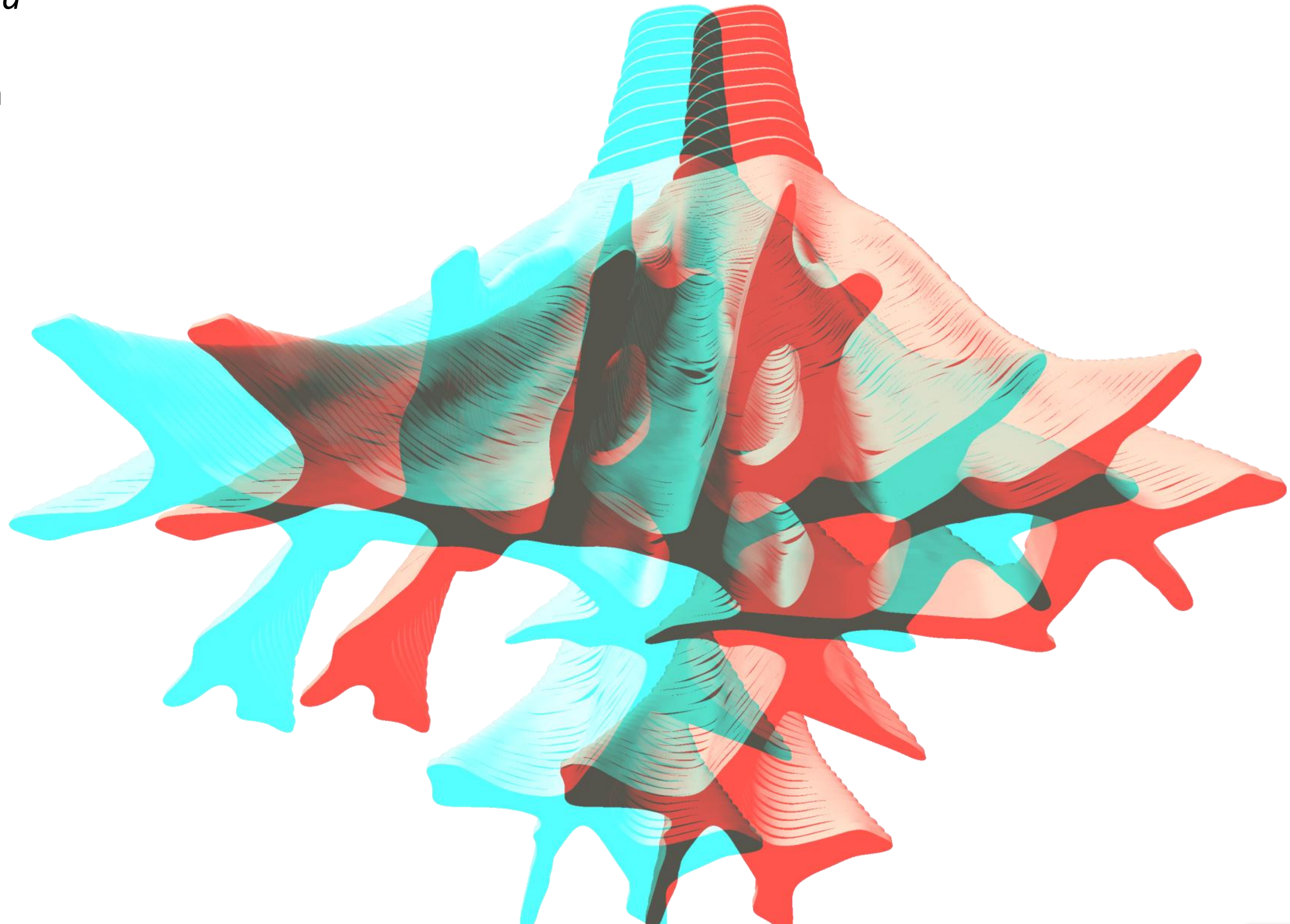
V_b: 7.66m³

Ficus robusta

DAB: 89cm

H_{DAB}: 6.58m

V_b: 7.66m³

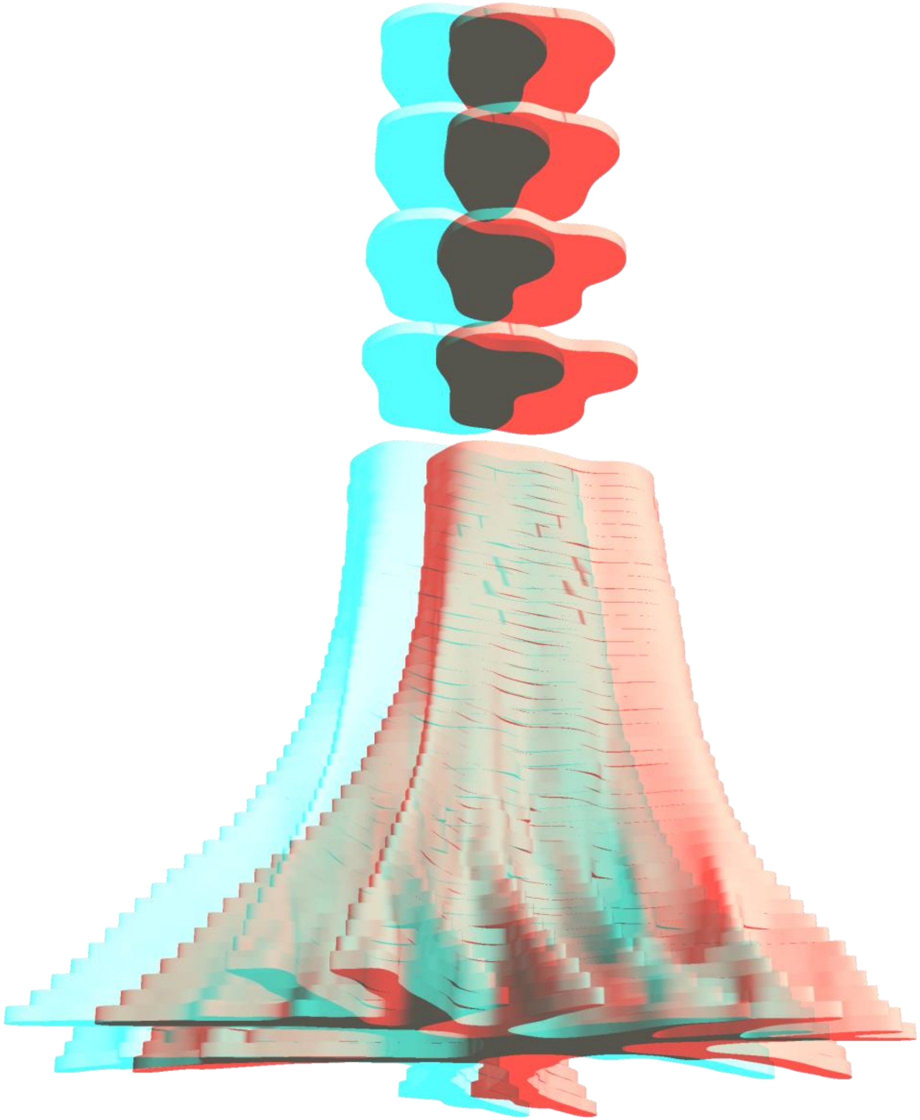


Celtis rigescens

DAB: 72cm

H_{DAB}: 4.58m

V_b: 2.47m³

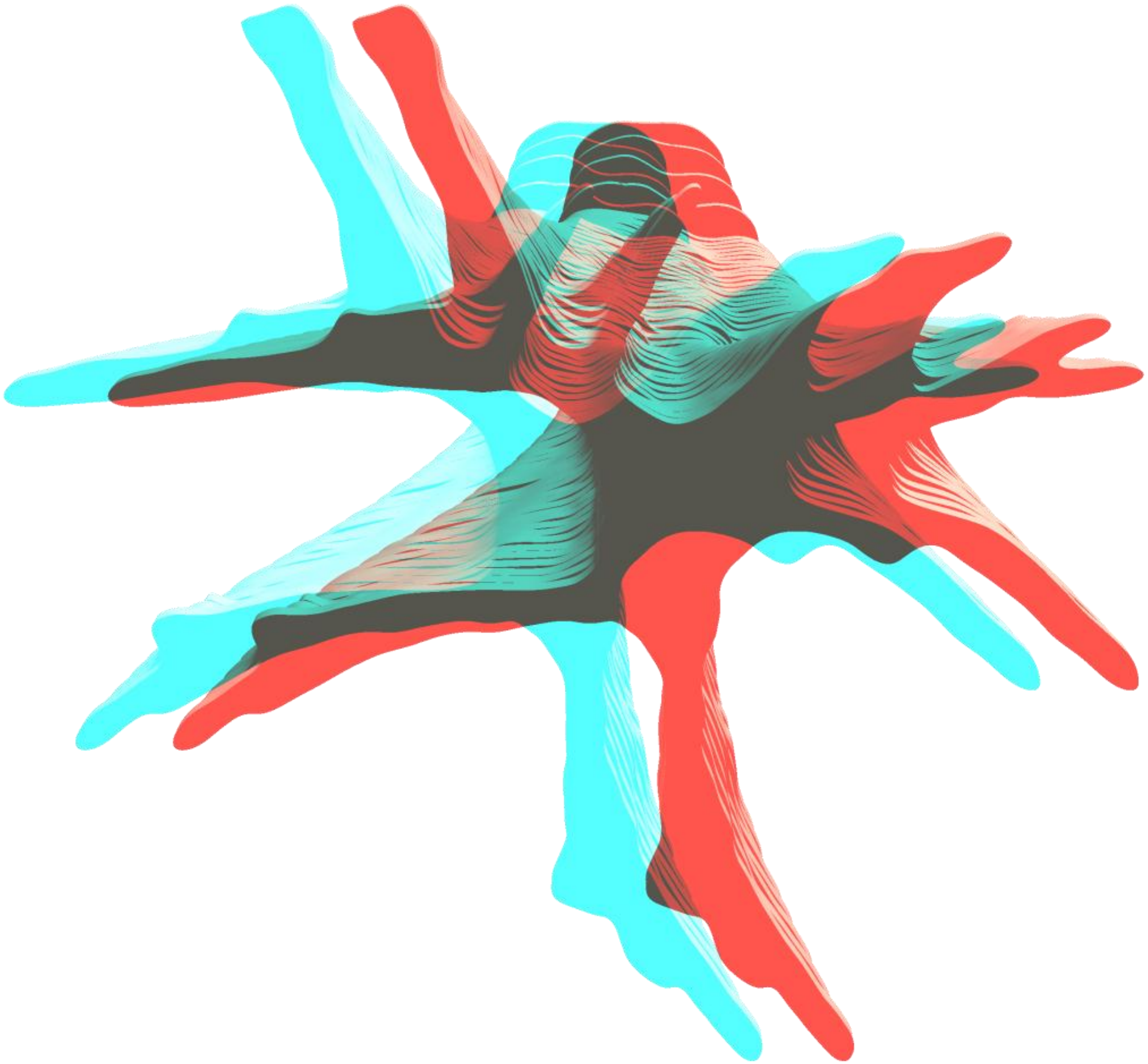


Celtis rigescens

DAB: 72cm

H_{DAB}: 4.58m

V_b: 2.47m³

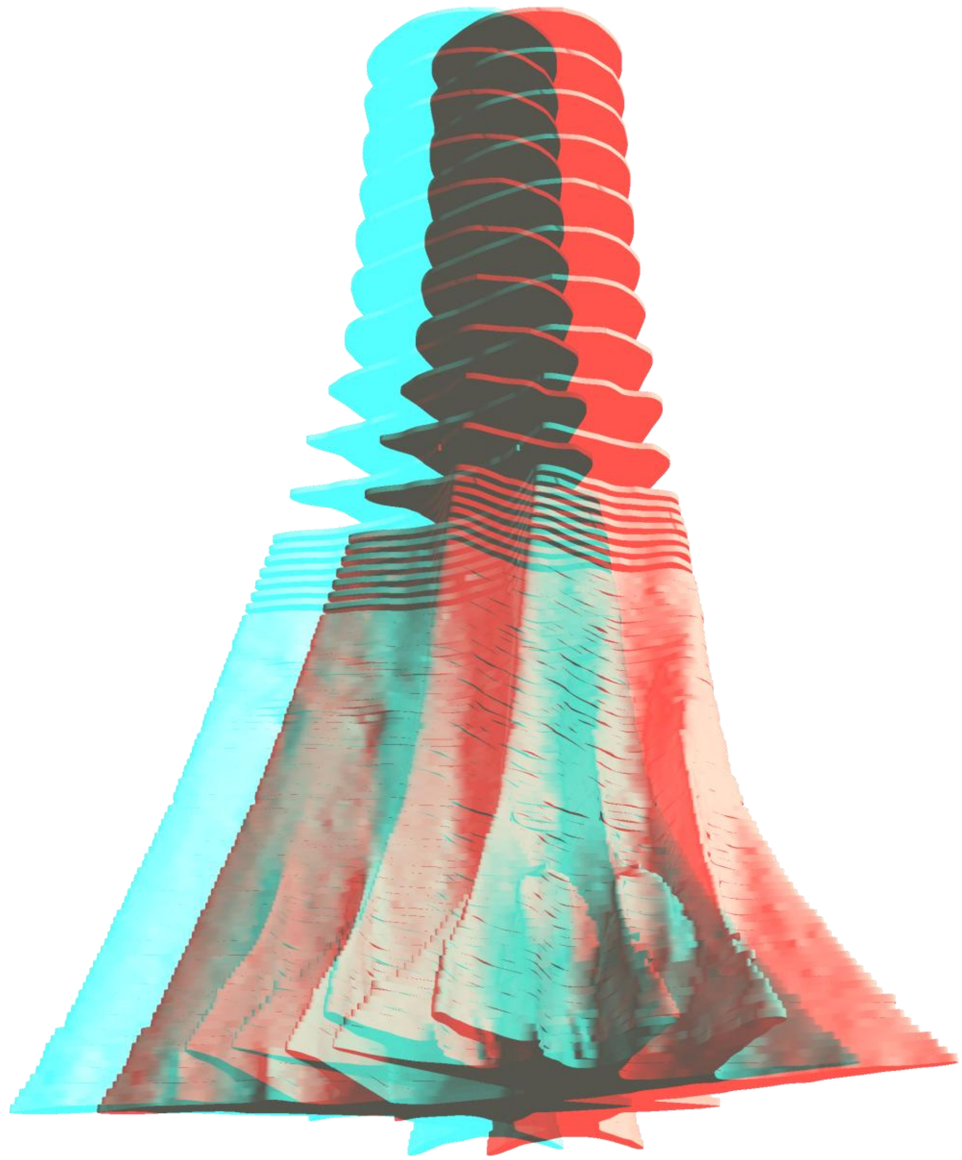


Ficus albipila

DAB: 172cm

H_{DAB}: 6.68m

V_b: 19.35m³

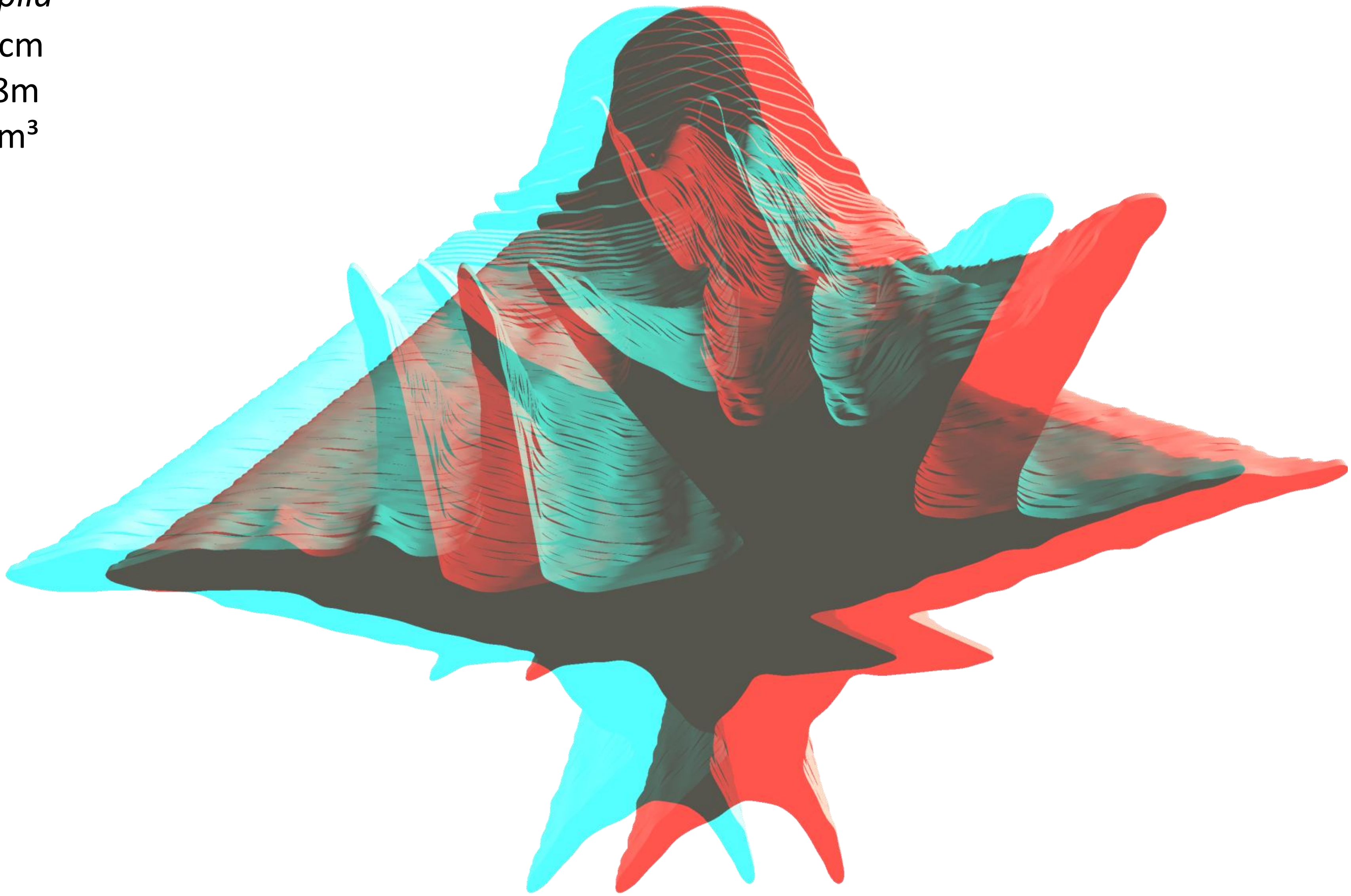


Ficus albipila

DAB: 172cm

H_{DAB}: 6.68m

V_b: 19.35m³

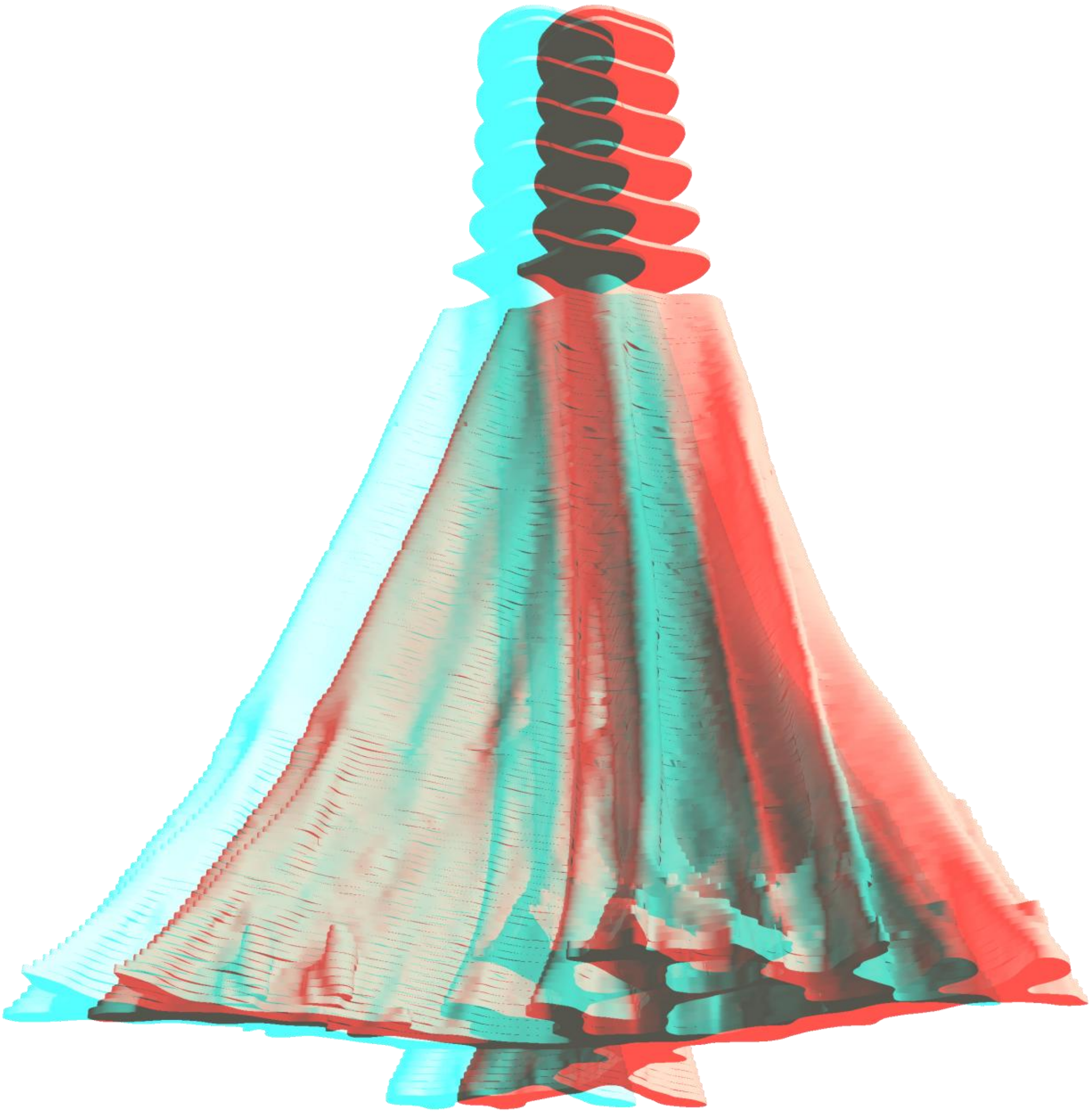


Shorea leprosula

DAB: 119cm

H_{DAB}: 8.58m

V_b: 16.86m³

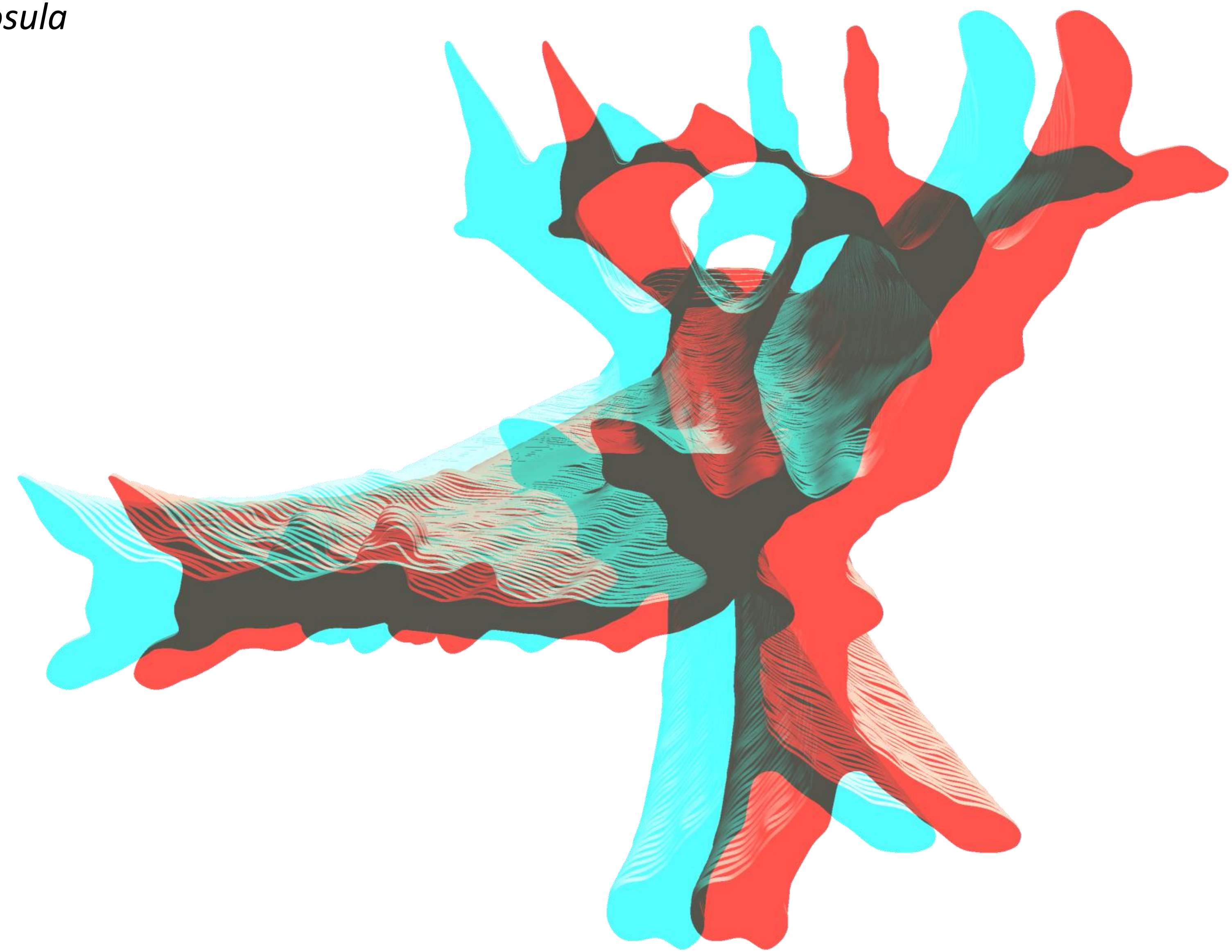


Shorea leprosula

DAB: 119cm

H_{DAB}: 8.58m

V_b: 16.86m³

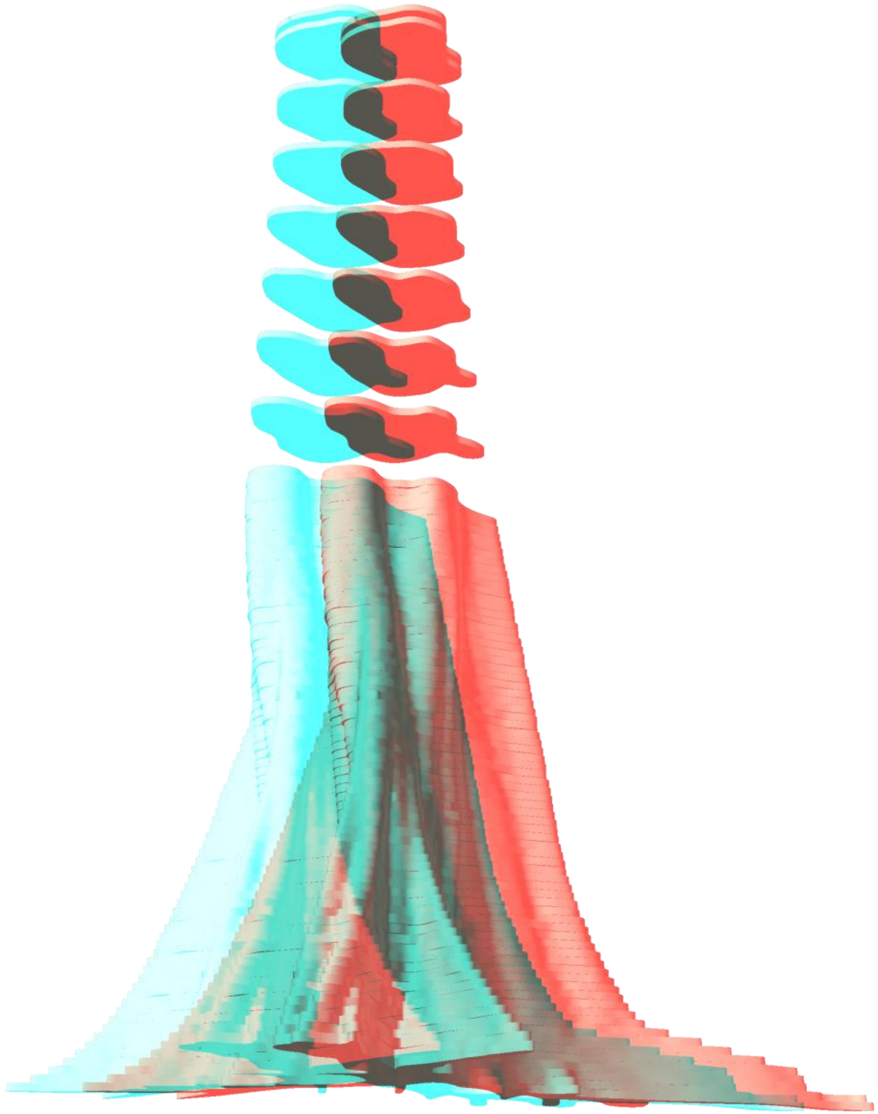


Sterculia urceolata

DAB: 76cm

H_{DAB}: 7.23m

V_b: 5.10m³

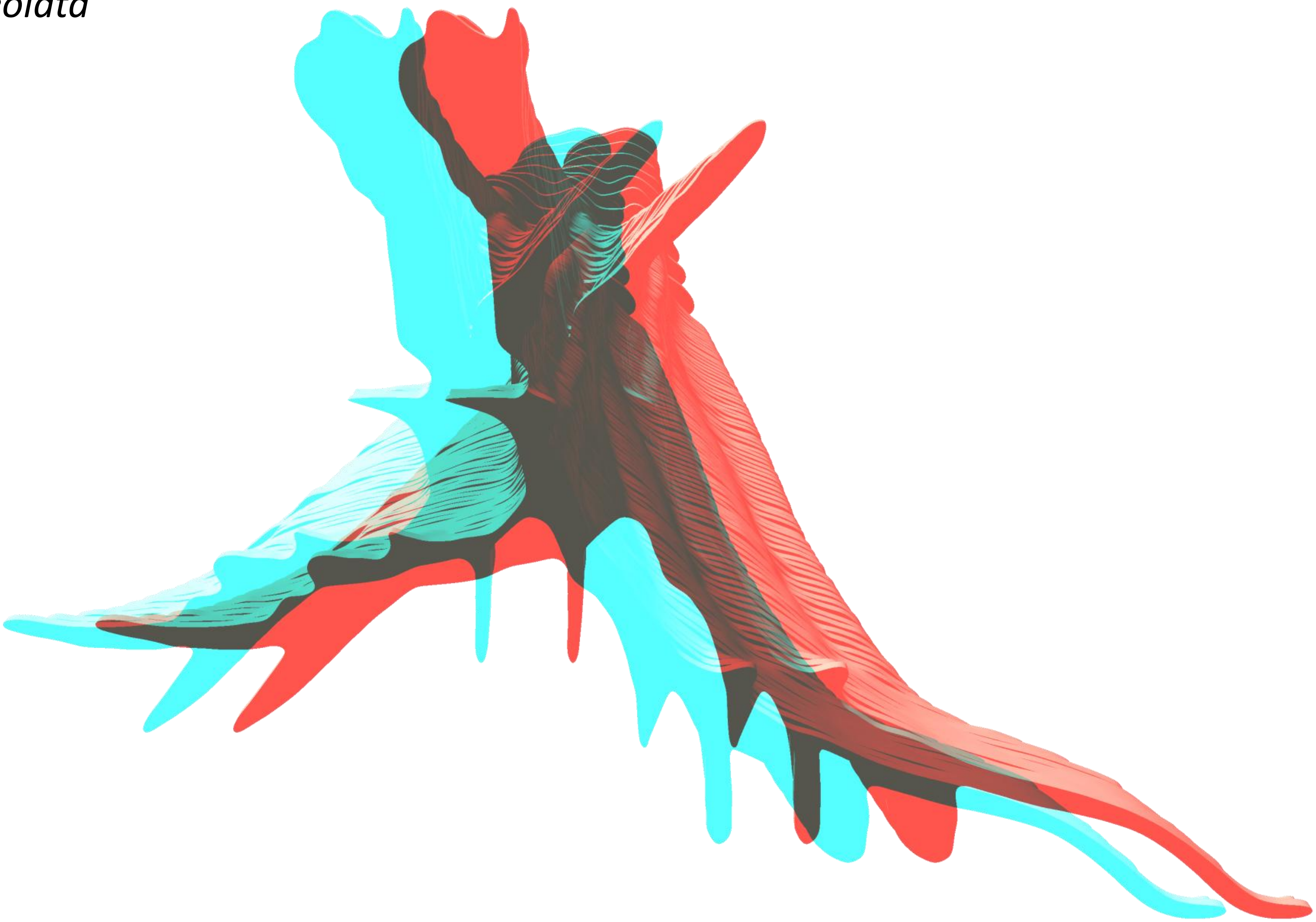


Sterculia urceolata

DAB: 76cm

H_{DAB}: 7.23m

V_b: 5.10m³

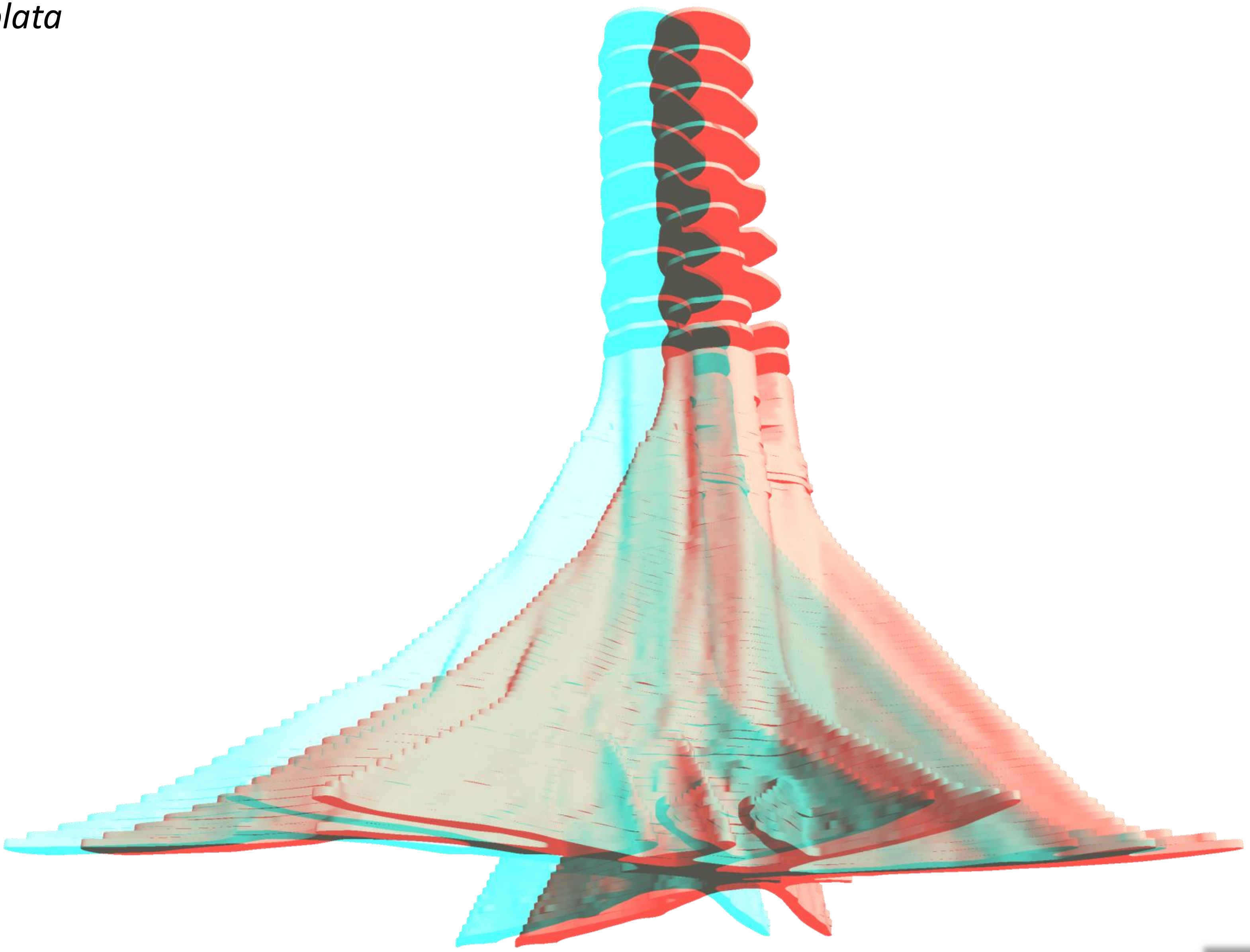


Sterculia urceolata

DAB: 93cm

H_{DAB}: 6.28m

V_b: 6.63m³

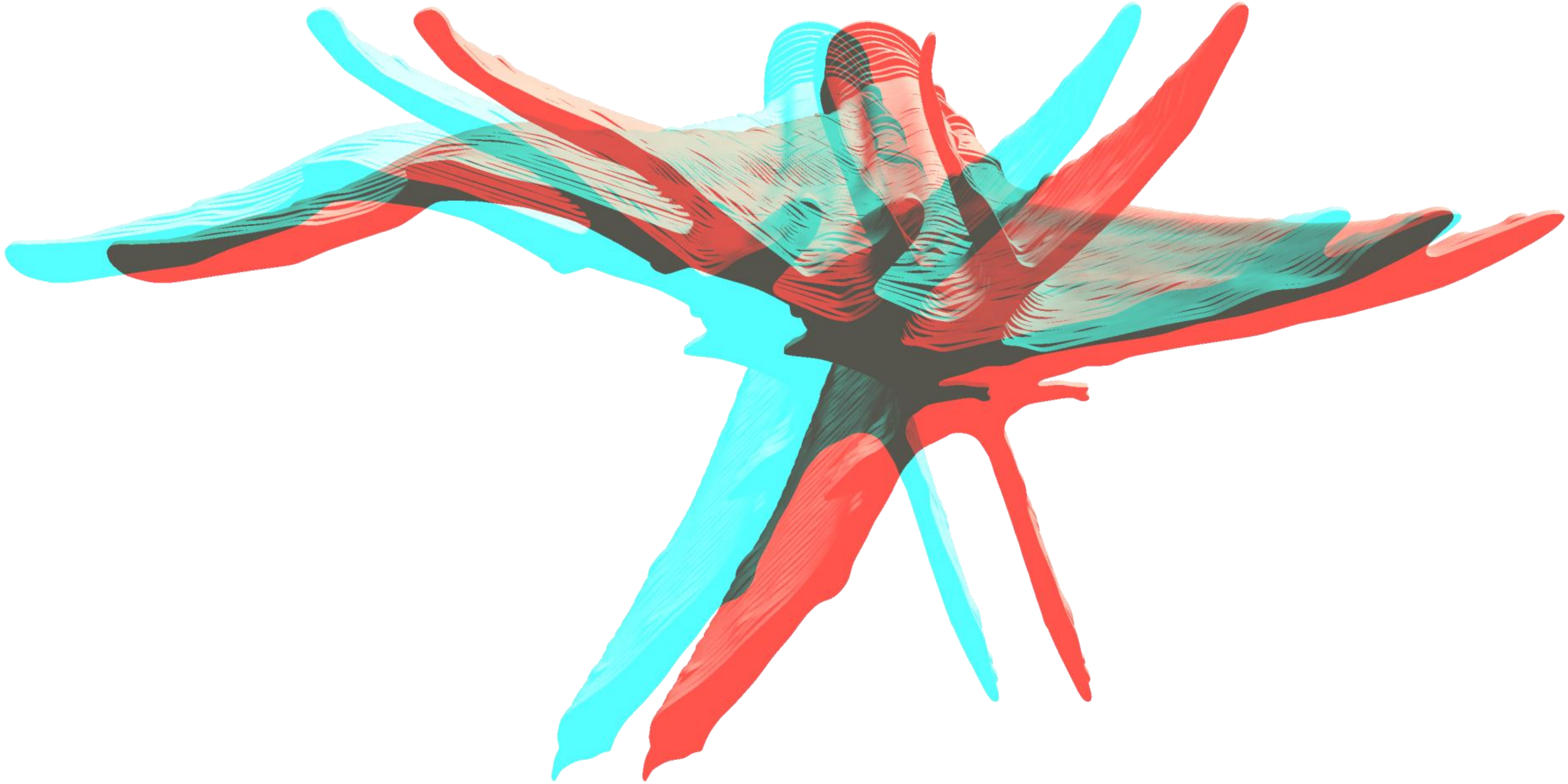


Sterculia urceolata

DAB: 93cm

H_{DAB}: 6.28m

V_b: 6.63m³

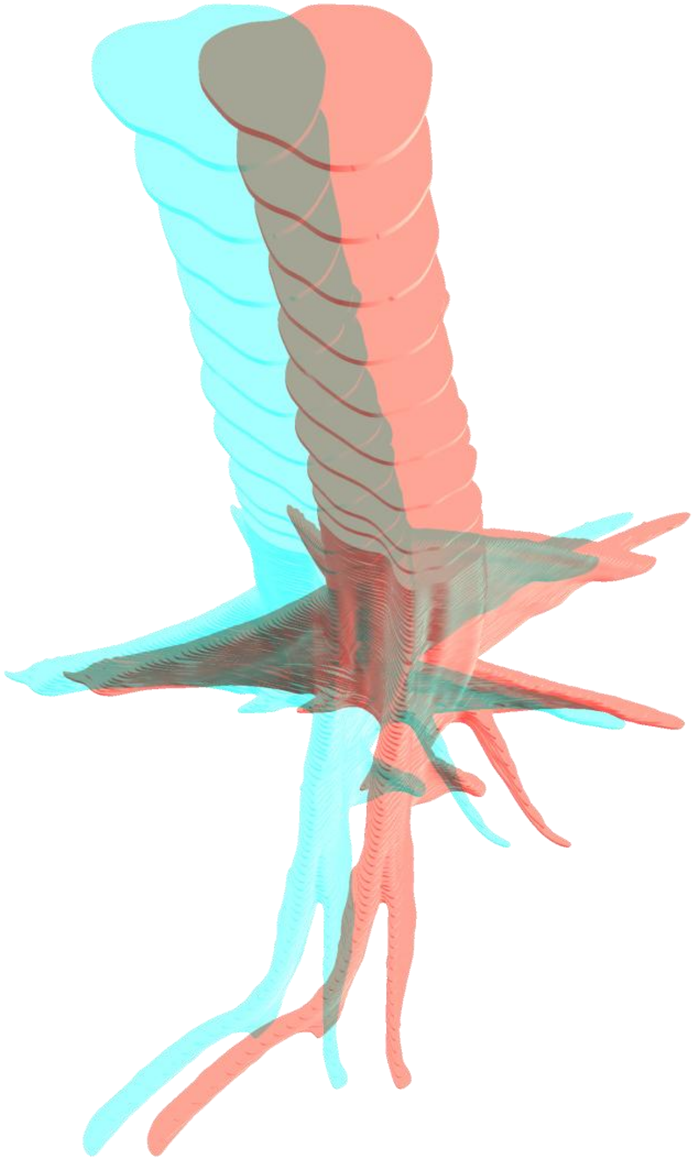


Sterculia urceolata

DAB: 93cm

H_{DAB}: 6.28m

V_b: 6.63m³

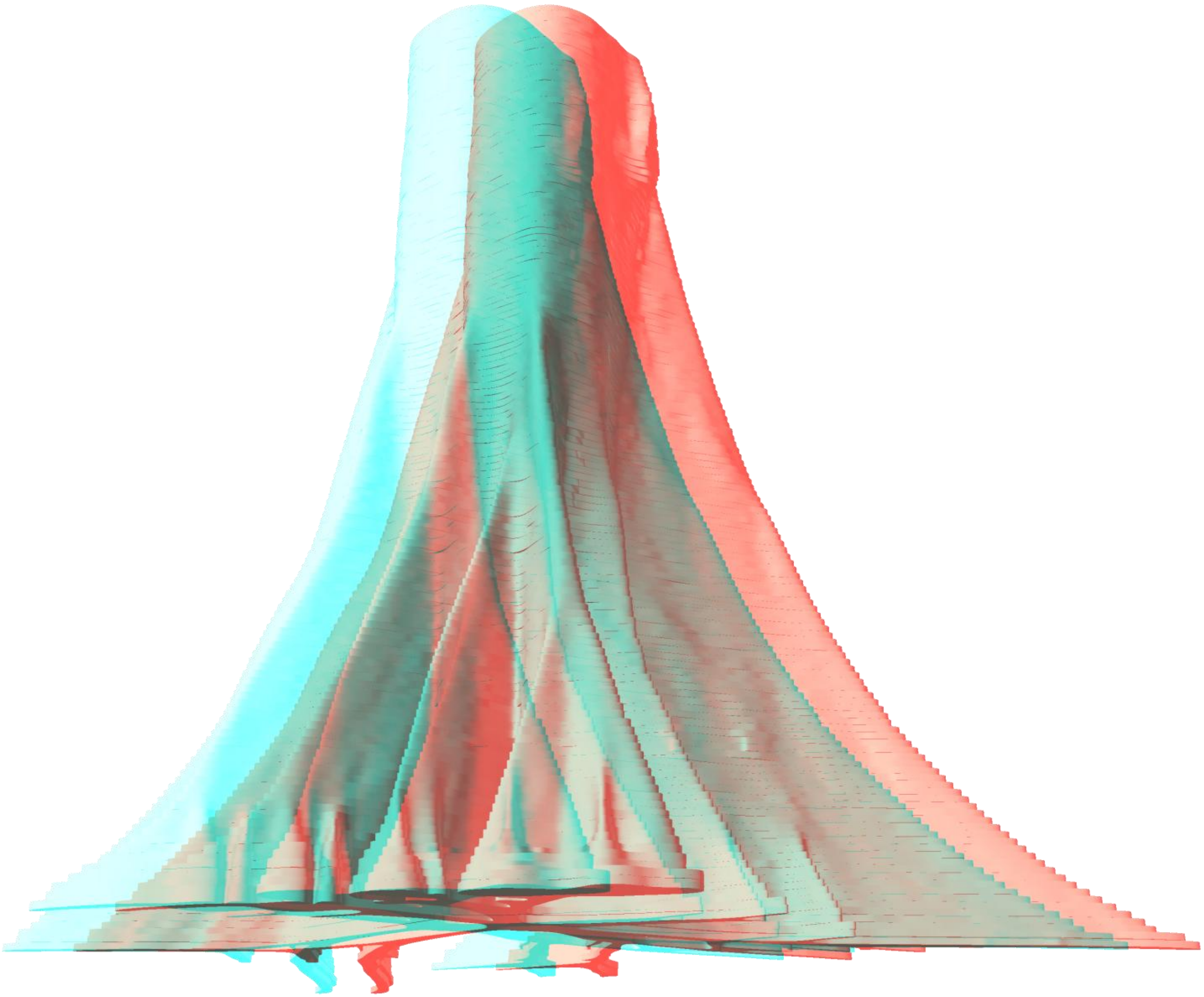


Sterculia foetida

DAB: 130cm

H_{DAB}: 6.68m

V_b: 13.21m³

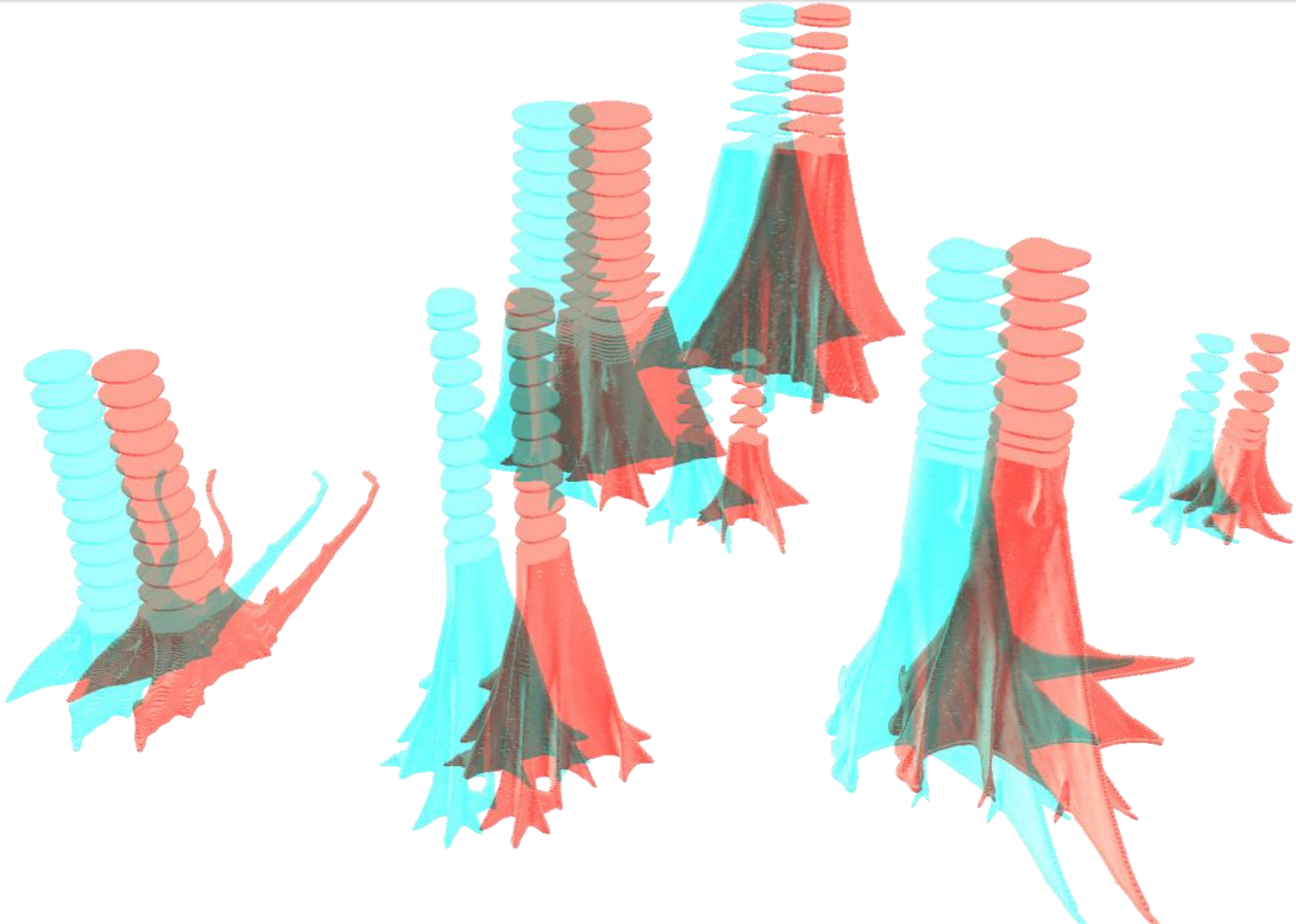


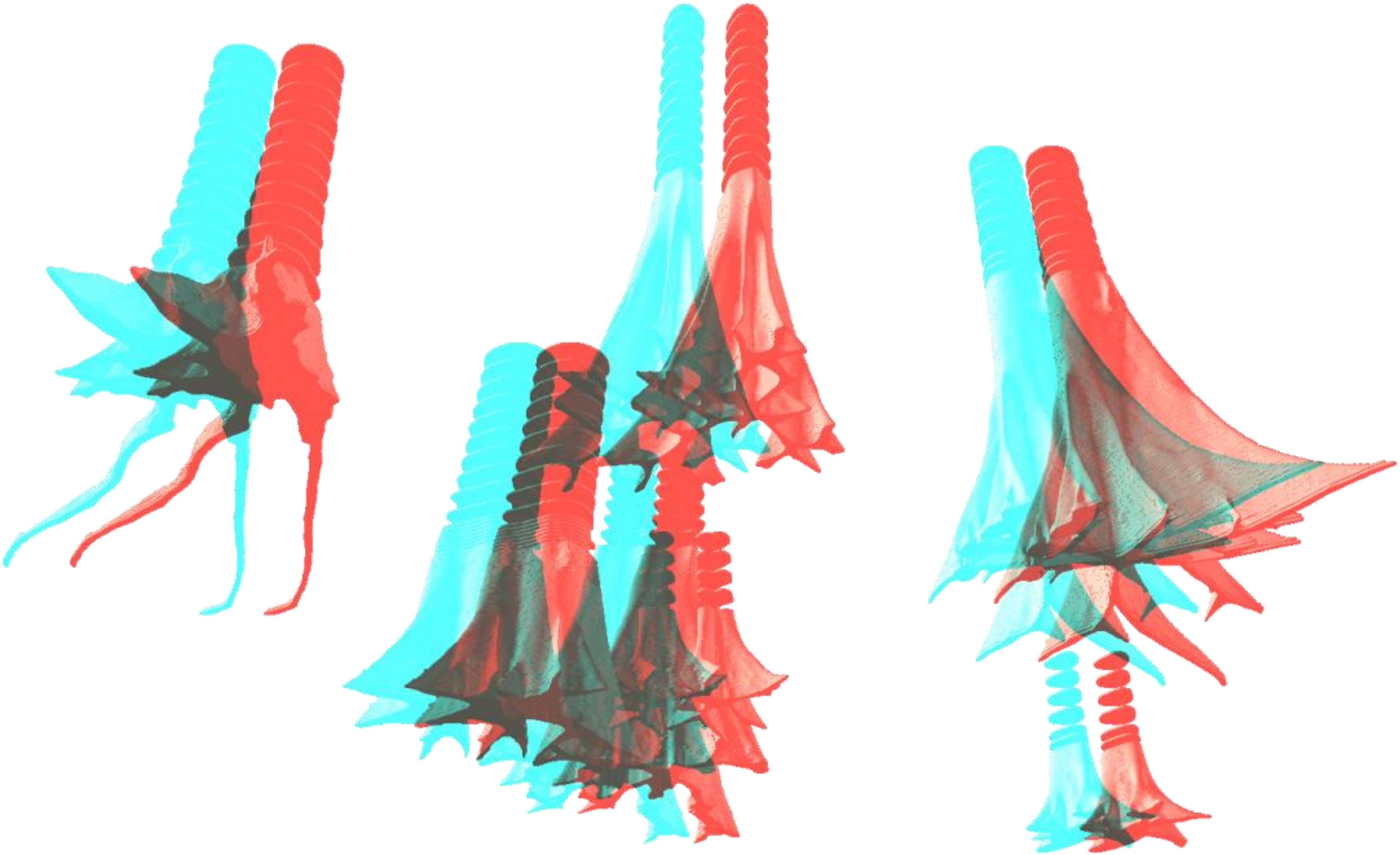
Sterculia foetida

DAB: 130cm

H_{DAB}: 6.68m

V_b: 13.21m³





Acknowledgements

Terima kasih!

We thank:

- **Dr. Dominik Seidel and Nils Nölke** for conducting the TLS course,
- Our Bachelor students **Mr. Michael Weber and Mr. Markus Klingemann** for help in data collection and preparation,
- the Faculty of Forest Sciences and Forest Ecology in Göttingen for granting financial support.
- PT. Datascrip and Zoller + Froehlich GmbH in Jakarta for making available the laser scanner for our project.
- **Dr. Didik Widyatmoko, director of LIPI and the staff of Bogor Botanical Gardens for granting the permission to implement our study.**

References

Basuki TM, van Laake PE, Skidmore AK, Hussin YA (2009) Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. For. Ecol. Man. 257:1684-1694.

Clark DA (2002) Are tropical forests an important carbon sink? Reanalysis of the long-term plot data. Ecological Applications 12:3-7.

Crook MJ, Ennos, AR, Banks JR (1997) The function of buttress roots: a comparative study of the anchorage systems of buttressed (Aglaia and Nephelium ramboutan species) and non-buttressed (Mallotus wrayi) tropical trees. Journal of Experimental Botany 48:1703-1716.

Ennos AR (1993) The scaling of root anchorage. Journal of Theoretical Biology 161:61-75.

Metcalf CJE, Clark JS, Clark DA (2009) Tree growth inference and prediction when the point of measurement changes: modelling around buttresses in tropical forests. Journal of Tropical Ecology 25:1-2.

Newbery DM, Schwan S, Chuyong GB, van der Burgt XM (2009) Buttress form of the central African rain forest tree Microberlinia bisulcata, and its possible role in nutrient acquisition. Trees 23:219-234.

Ngomanda A, Mavouroulou QM, Obiang NLE, Iponga DM, Mavoungou J-F, Lépengué N, Picard N, Mbatchi B (2012) Derivation of diameter measurements for buttressed trees, an example from Gabon. Journal of Tropical Ecology 28:299-302.

Richards PW (1952) The tropical rain forest. Cambridge University Press.