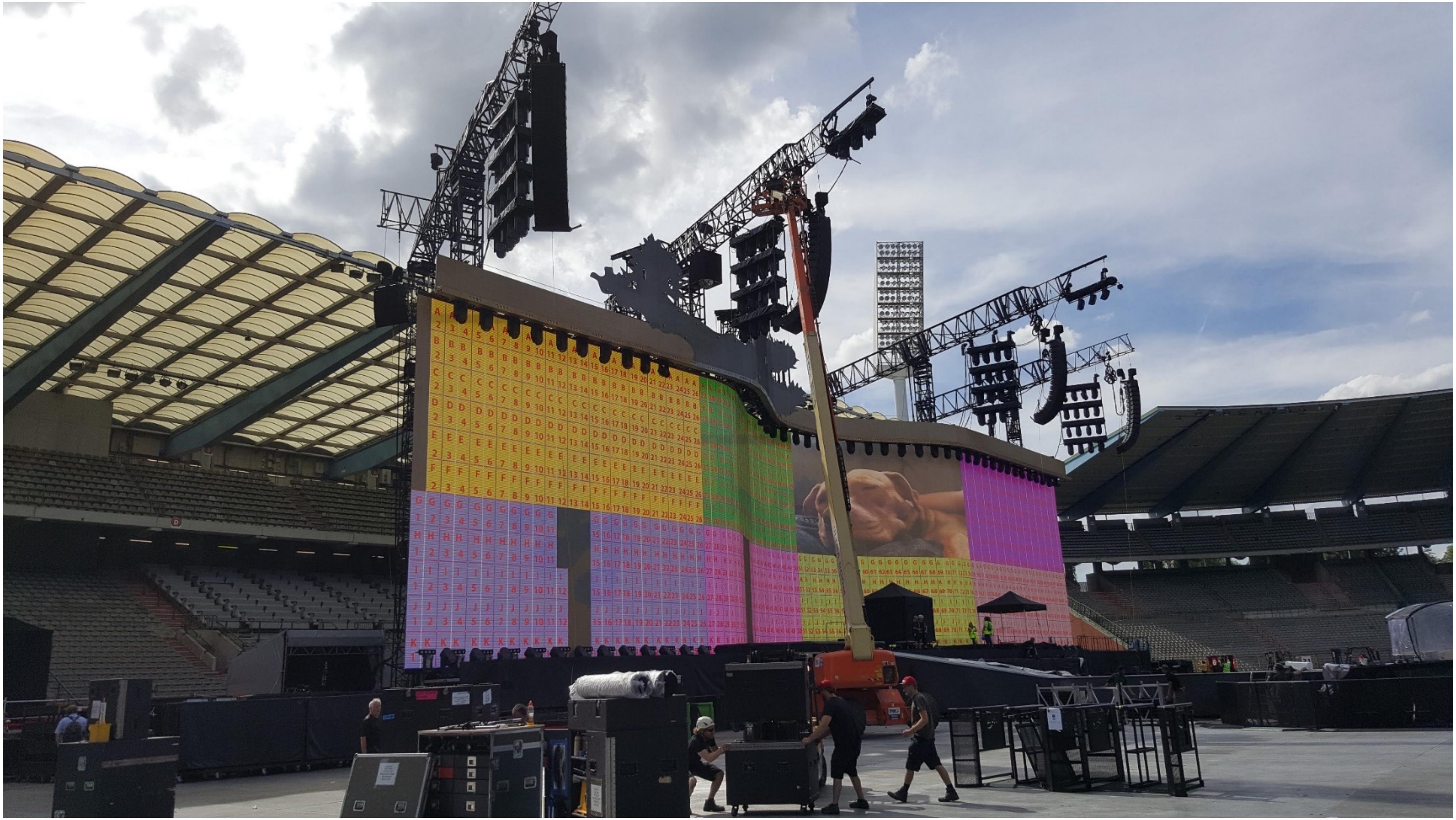
atelier one

TITLE: Building with bamboo - Rotterdam

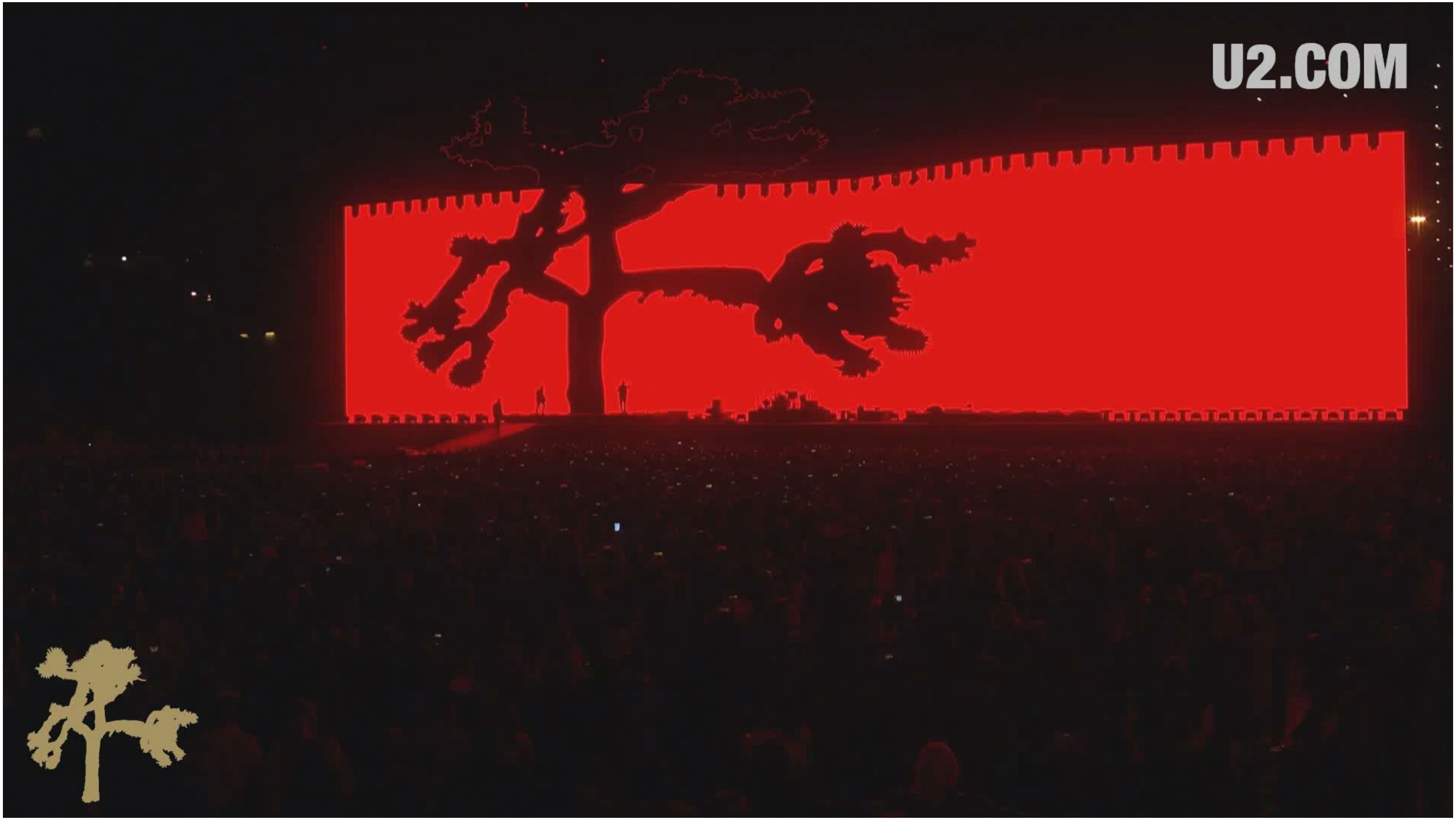
CLIENT:

21 / 06 / 2024



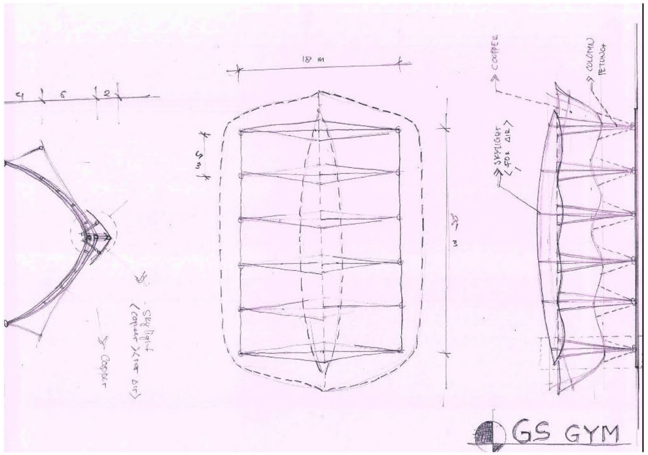

G49
G48
G44

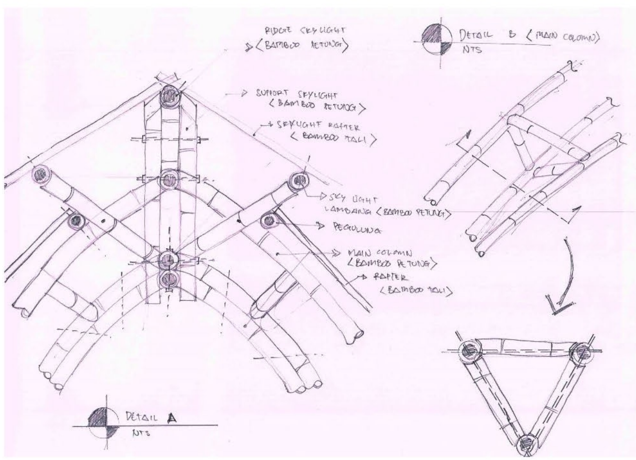

PRG

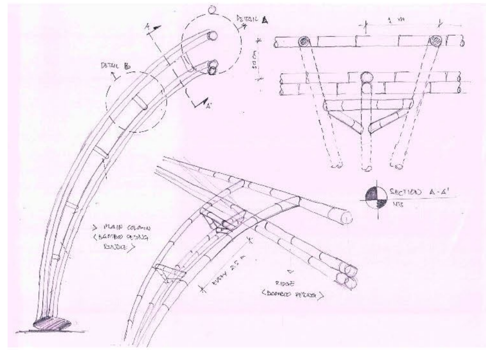

U2.COM

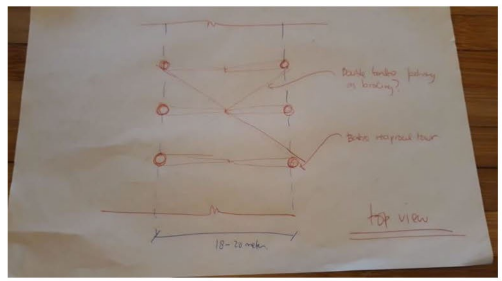

StructuralAwards2018
The Award for Construction Innovation
WINNER
Atelier One Ltd
for
Innovative Touring Frame
U2 'The Joshua Tree' Tour 2017

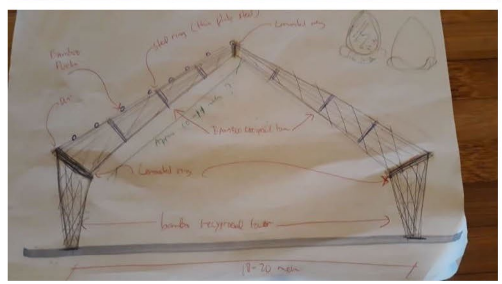
Green School Gym (Arc) by IBUKU, Jorg Stamm and Atelier One

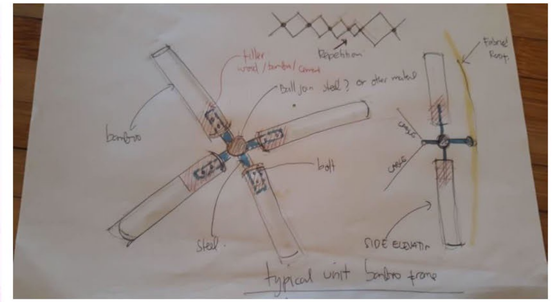

18 m
GS GYM

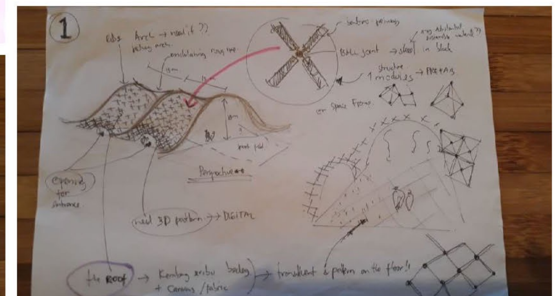

RIDGE SKYLIGHT
<BAMBOO PETUNG>
DETAIL B <MAIN COLUMN>
NTS
SUPPORT SKYLIGHT
<BAMBOO PETUNG>
SKYLIGHT RAFTER
<BAMBOO TALI>
PEGOLINA
MAIN COLUMN
<BAMBOO PETUNG>
RAFTER
<BAMBOO TALI>
DETAIL A
NTS

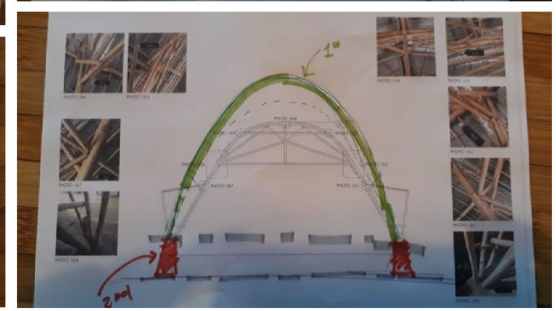

DETAIL A
DETAIL B
SECTION A-A'
NTS


top view
18-20 meter



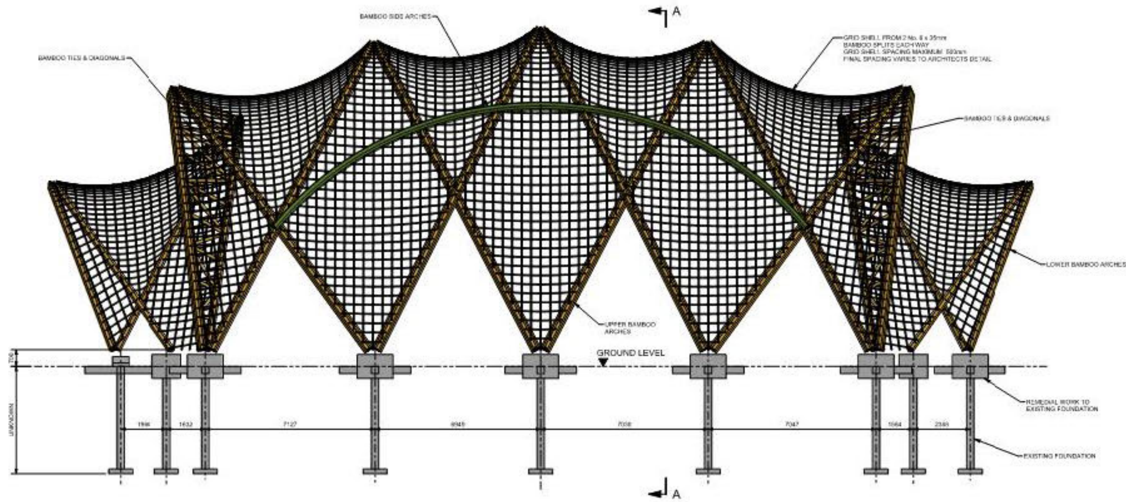

Repetition
bamboo
bolt
Steel
SIDE ELEVATION
typical unit bamboo frame


1
3D pattern → DIGITAL

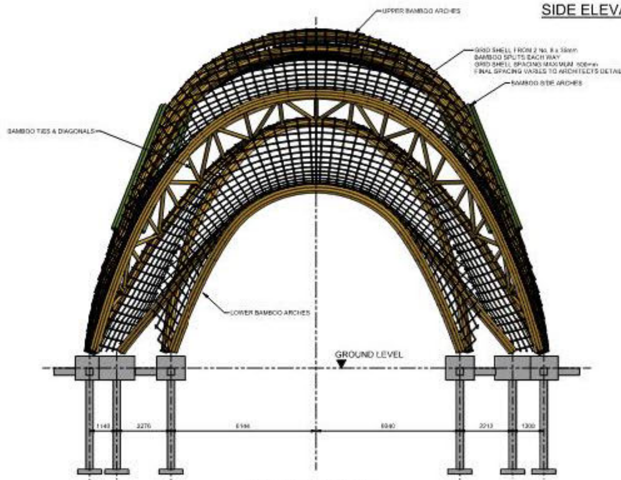

1st
2nd


24.8
7.0
7.1
7.0
7.0
Pathway
SOCCER FIELD

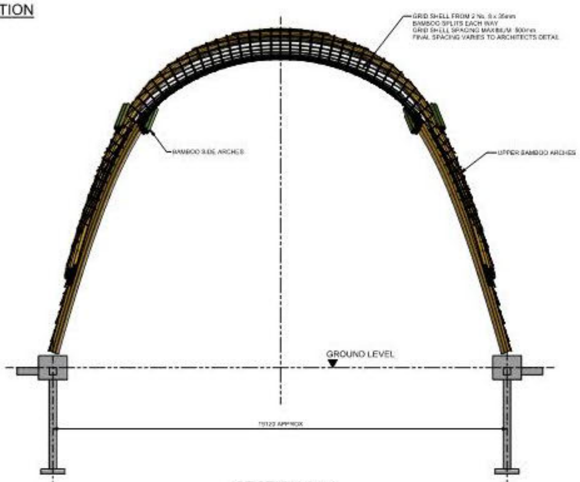

Drainage



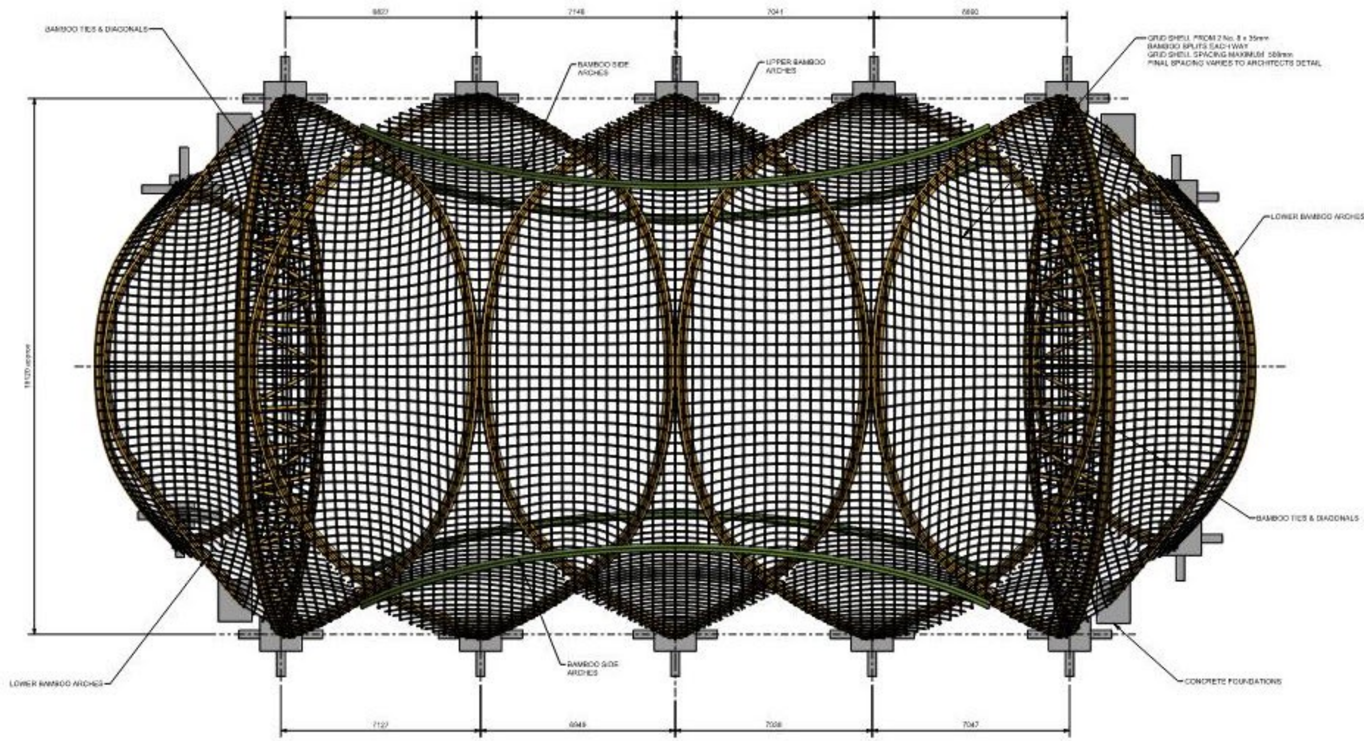
SIDE ELEVATION



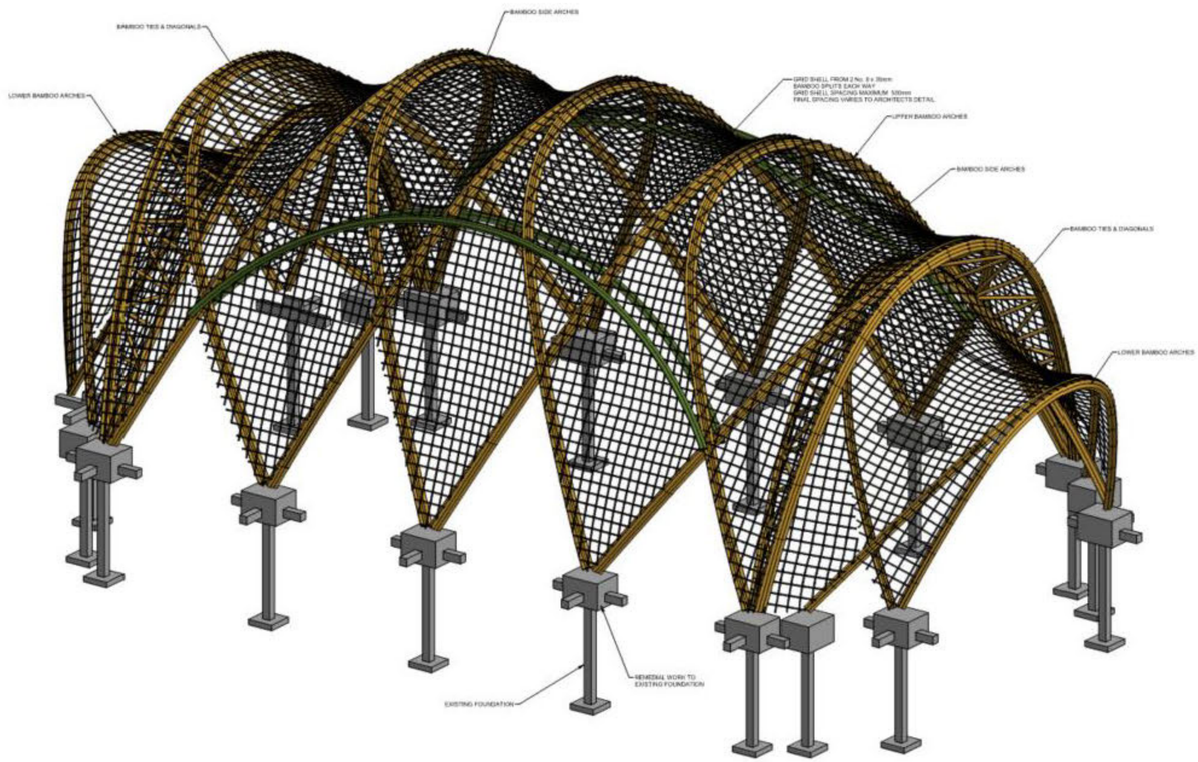
END ELEVATION



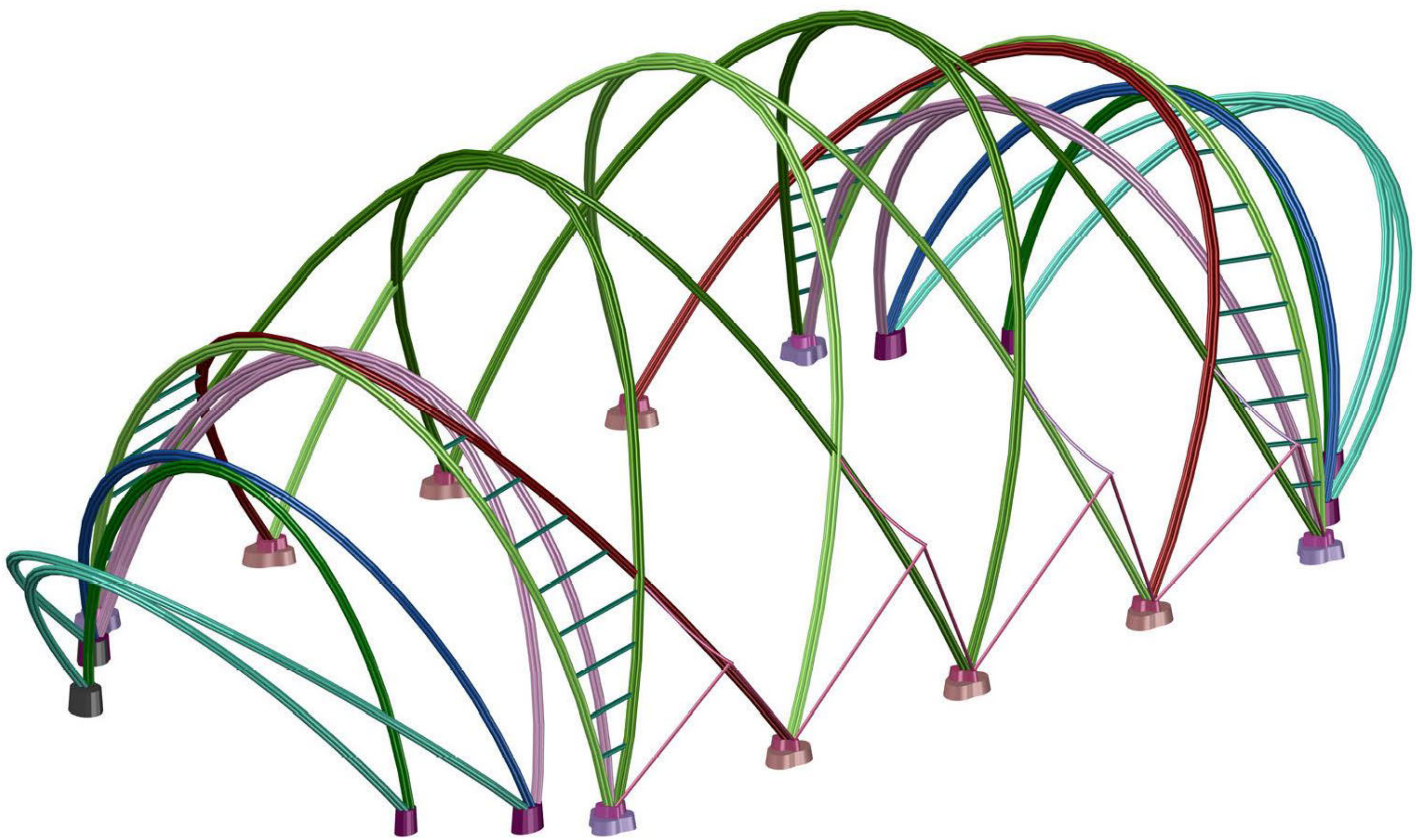
SECTION A - A

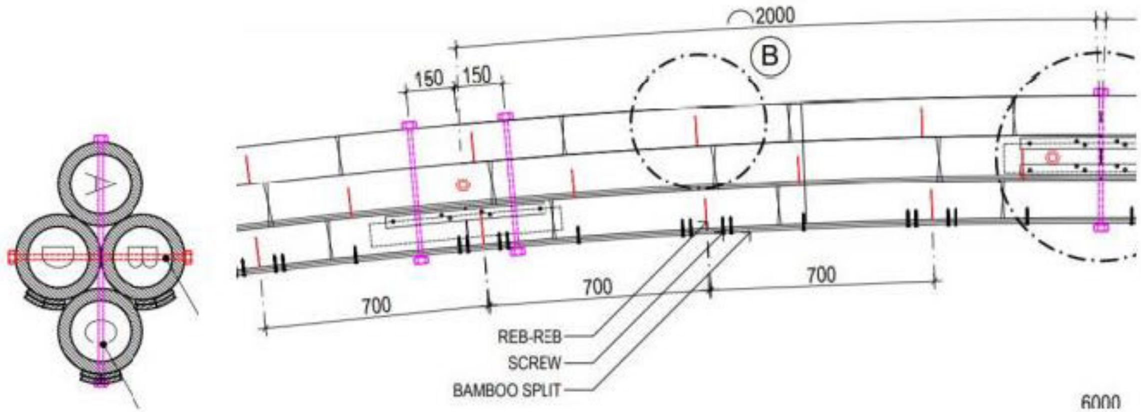


GREEN SCHOOL GYM LAYOUT

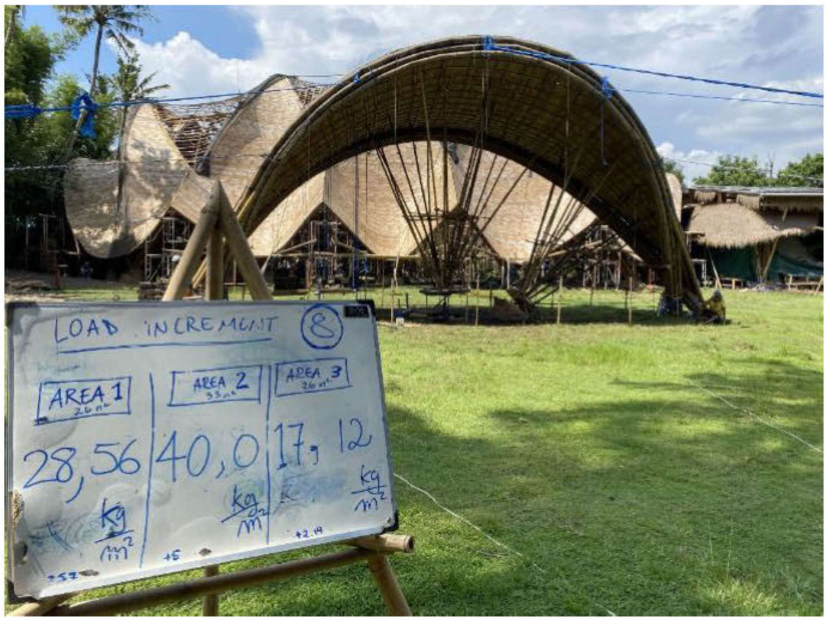


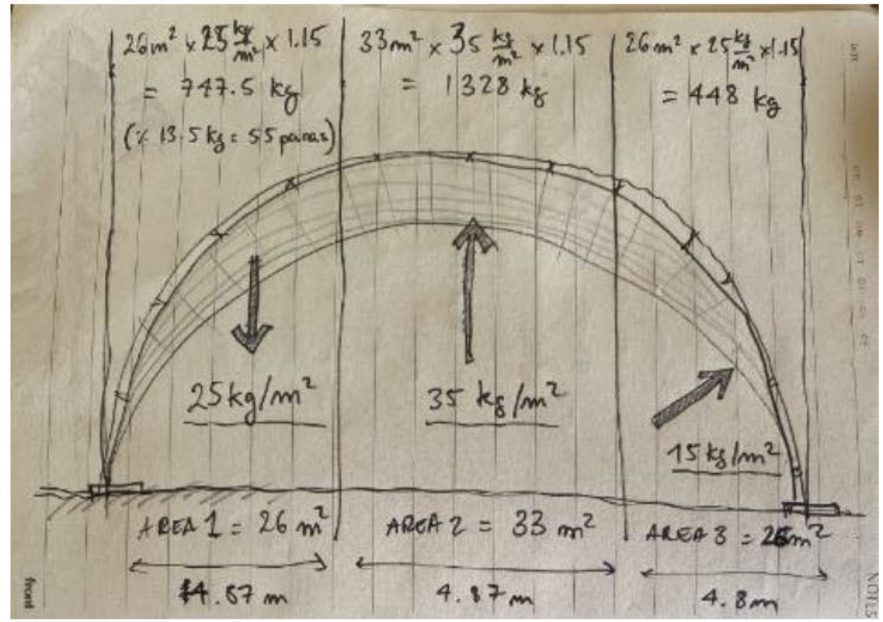
BAMBOO TIES & DIAGONALS
BAMBOO SIDE ARCHES
LOWER BAMBOO ARCHES
GRID SHELL FROM 2 No. 8 x 38mm
BAMBOO SPLITS EACH WAY
GRID SHELL SPACING MAXIMUM 500mm
FINAL SPACING VARIES TO ARCHITECTS DETAIL
UPPER BAMBOO ARCHES
BAMBOO SIDE ARCHES
BAMBOO TIES & DIAGONALS
LOWER BAMBOO ARCHES
REMEDIAL WORK TO
EXISTING FOUNDATION
EXISTING FOUNDATION

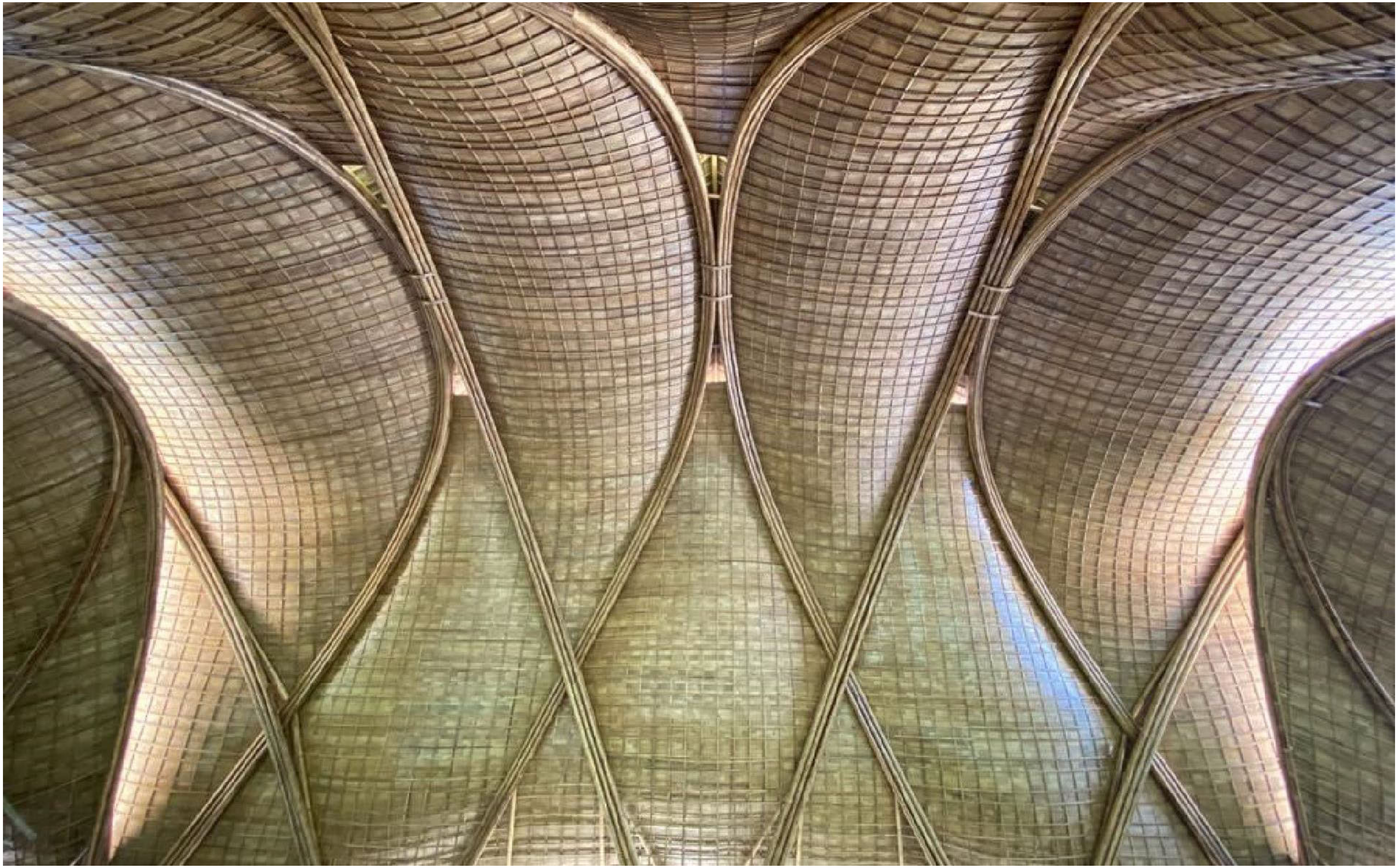




SHORT TERM LOADS	Bundle without Rebreb	Bundle with Rebreb In Tension	Bundle with Rebreb In Comp
MAXIMUM BENDING CAPACITY *(KNm)*	Unfactored: 43.4 Factored: 17.6* (based on 59N/mm² bending strength)	14.71 mean	24.42 mean


LOAD INCREMENT
8
AREA 1
AREA 2
AREA 3
28,56
40,0
17, 12
kg/m²


26m² x 25 kg/m² x 1.15
= 747.5 kg
33m² x 35 kg/m² x 1.15
= 1328 kg
26m² x 25 kg/m² x 1.15
= 448 kg
25kg/m²
35 kg/m²
15 kg/m²
AREA 1 = 26 m²
AREA 2 = 33 m²
AREA 3
4.87 m
4.87 m
4.8m



Structural Awards **2022**

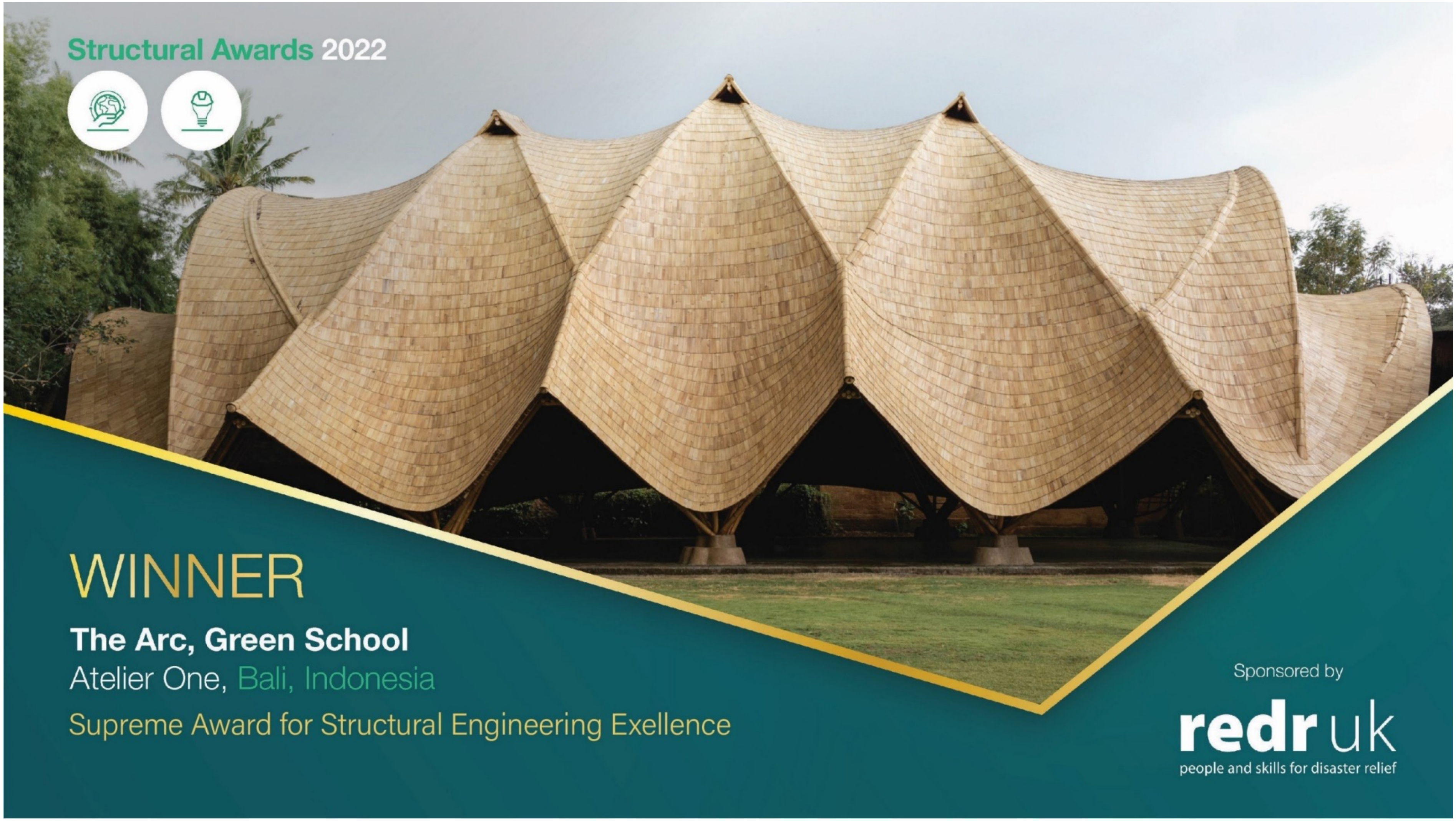
“The project demonstrates the exciting possibility of bamboo as a potential mainstream building material. Architects and engineers alike should be inspired.”

WINNER

The Arc, Green School

Atelier One, Bali, Indonesia

Awarded for advancing the structual application of low carbon materials


Structural Awards 2022
WINNER
The Arc, Green School
Atelier One, Bali, Indonesia
Supreme Award for Structural Engineering Exellence
Sponsored by
redr uk
people and skills for disaster relief

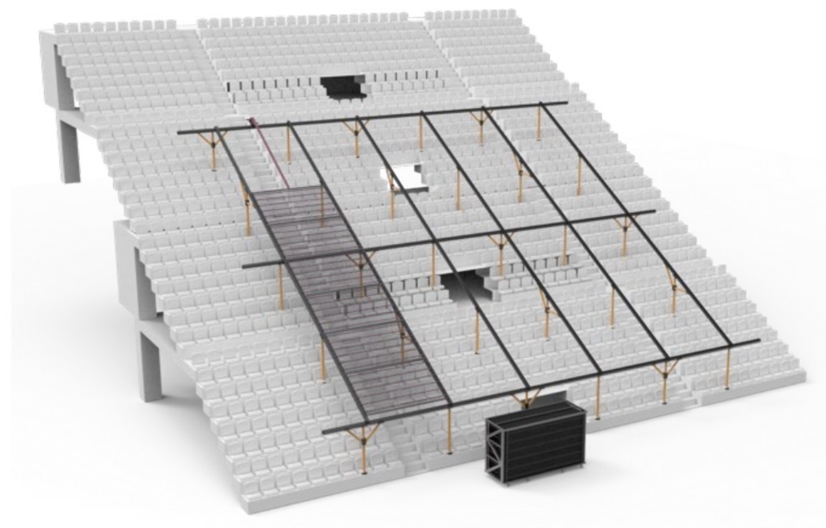

RAYMOND JAMES STADIUM

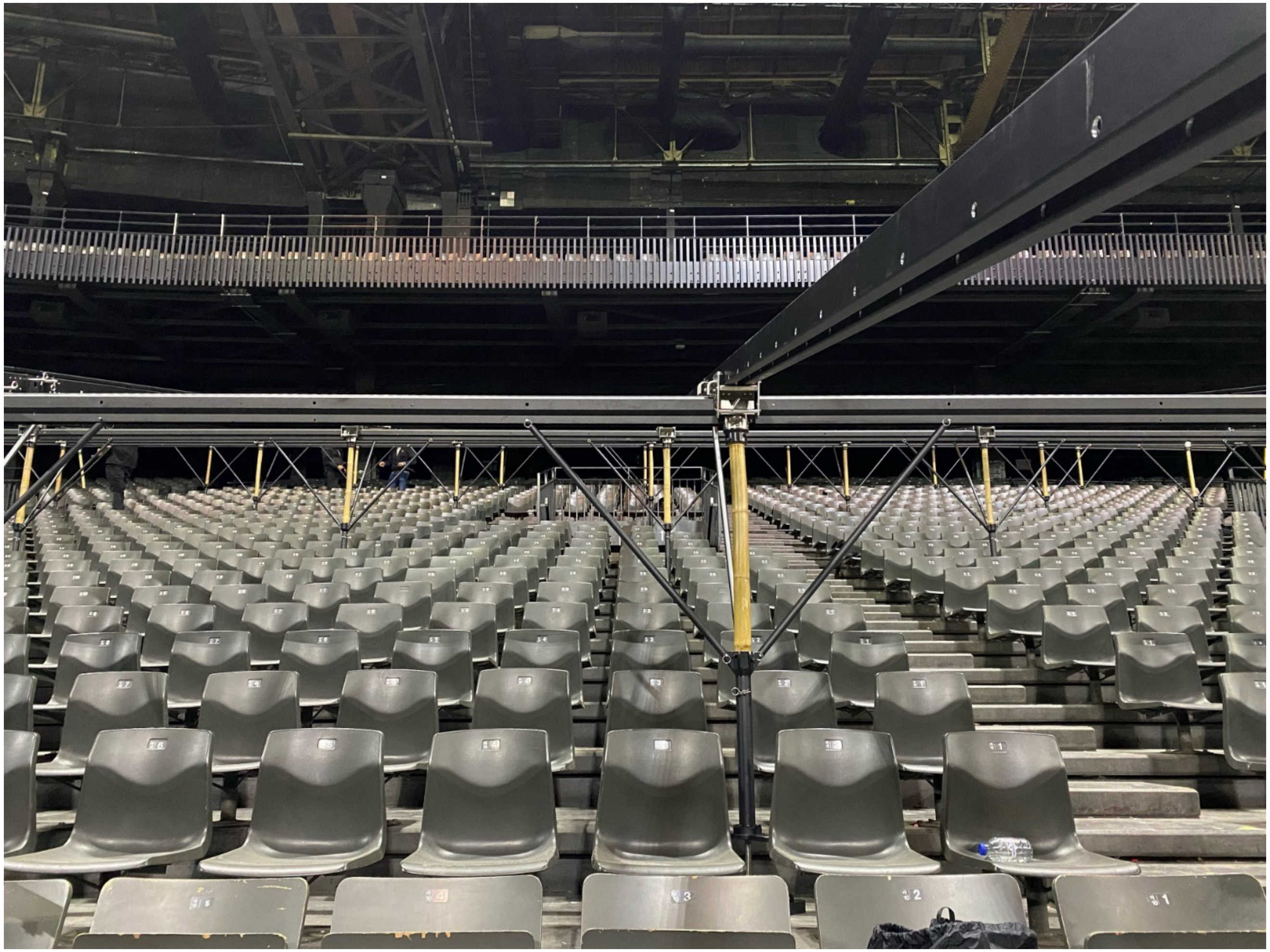
Coldplay to pause touring until concerts are 'environmentally beneficial'

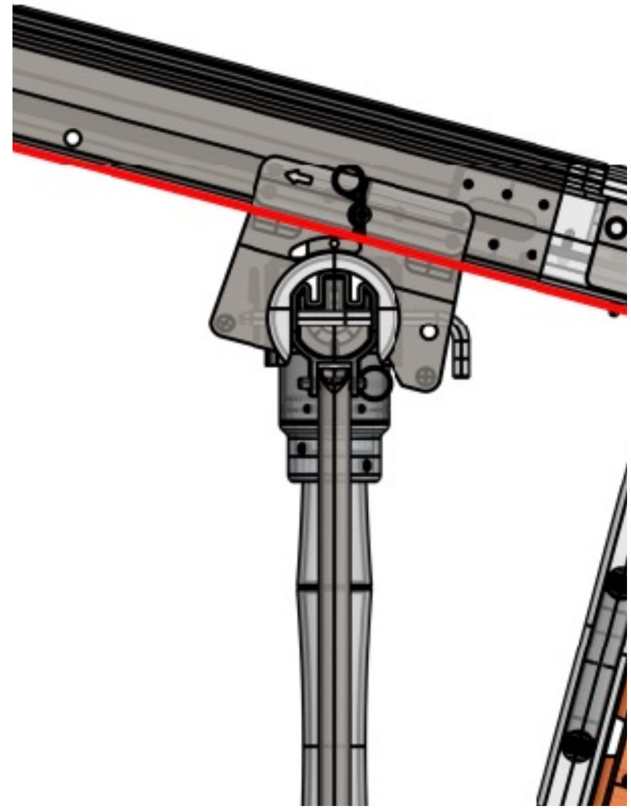
21 November 2019

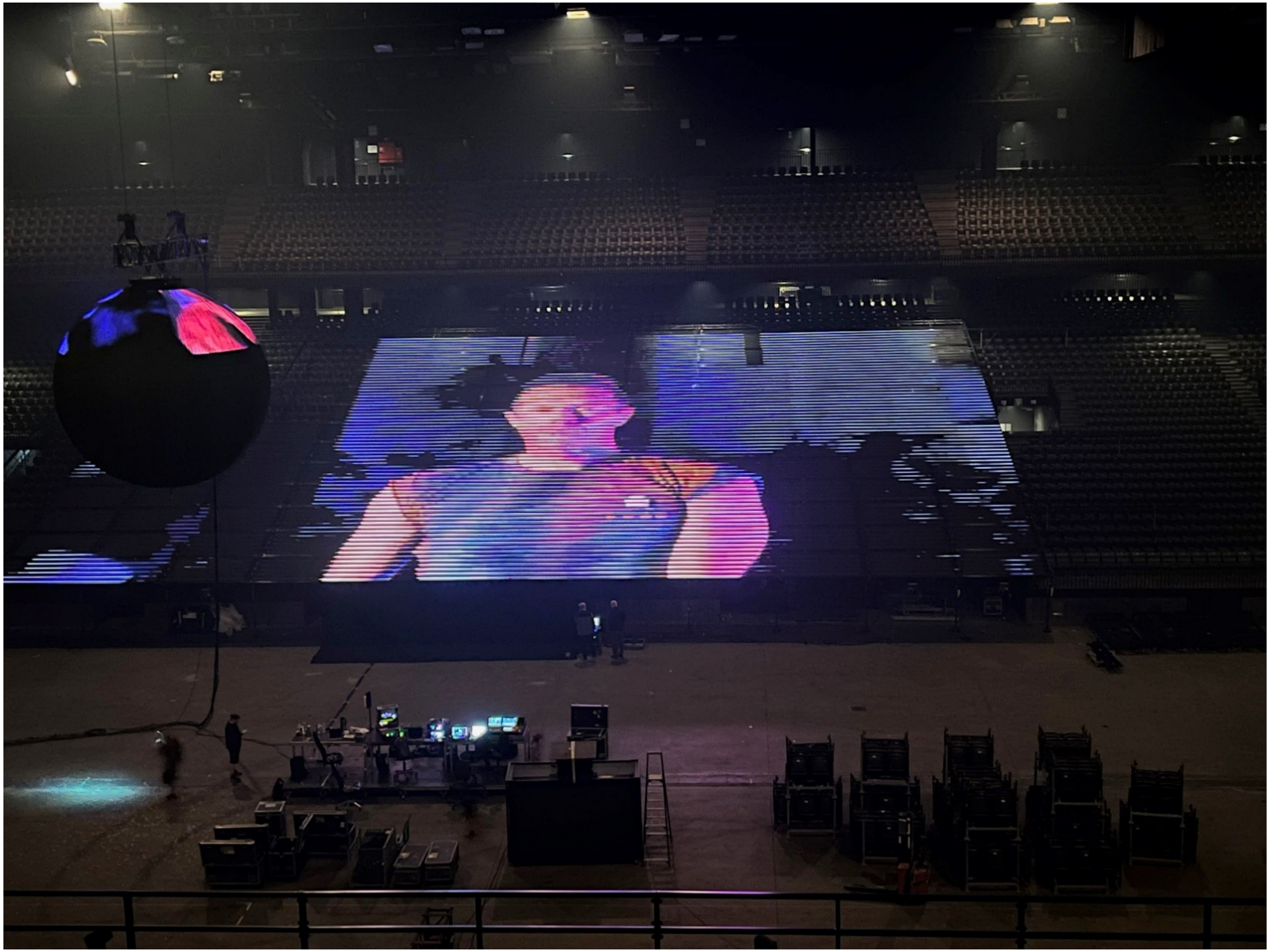
hold for


01:48
and these give an incredible range of dynamic movement.

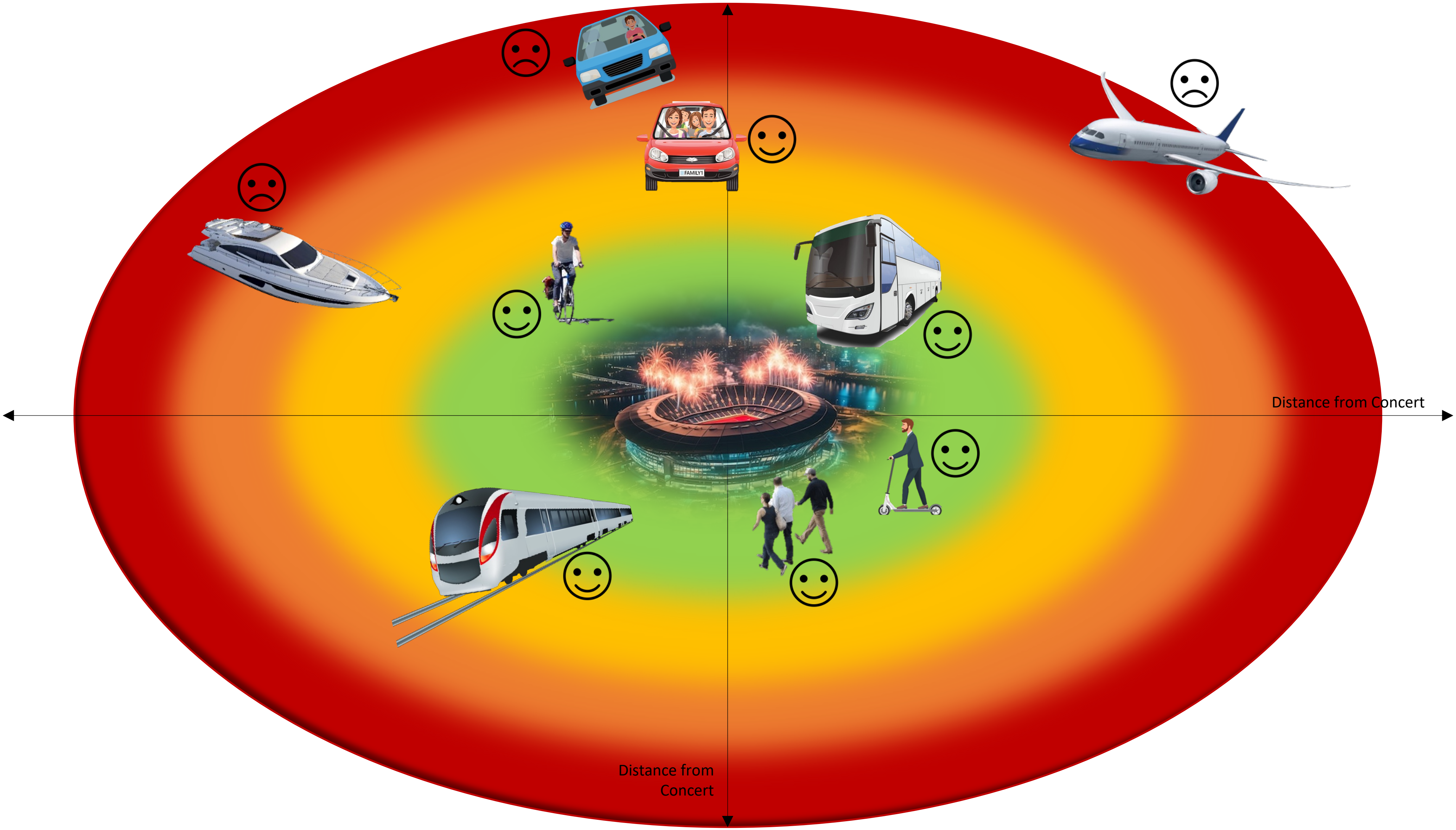




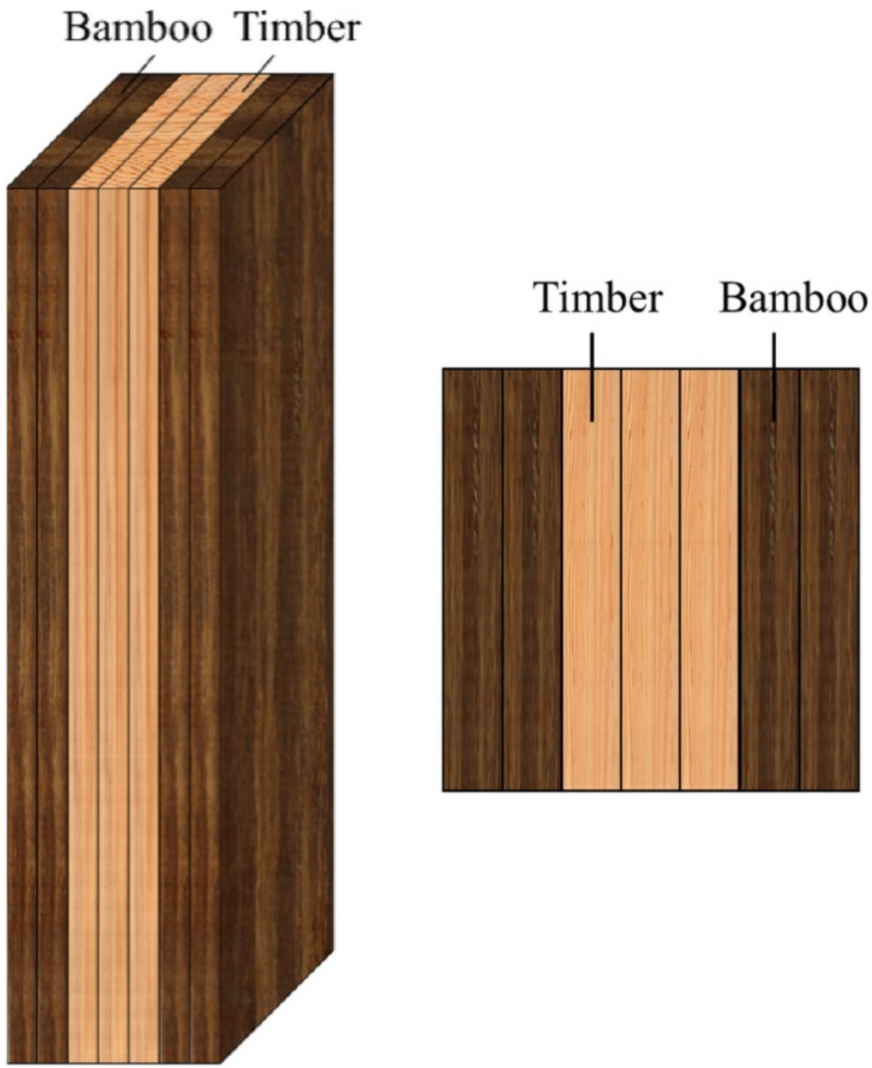





PRISCILLA
Metro Goldwyn Mayer
TRADE MARK



Distance from Concert
Distance from Concert



(a) 3D graph (b) Cross-section

Aureus Earth and the University of Washington Execute Ground-Breaking Carbon Offset Transaction for a Mass Timber Building

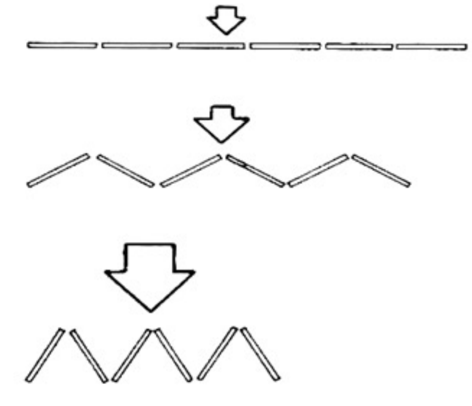
Project to store 1,000 tons of CO2 for decades, keeping carbon out of the atmosphere for the lifetime of the building

Aureus Earth, the world's leading provider of carbon offsetting incentive programs for the construction industry, today announced its first transaction that values the long-term biogenic carbon storage in a mass timber building. The transaction was accomplished in partnership with the University of Washington (UW) Foster School of Business, using the newly completed Founders Hall mass timber building as a proof of concept.

Aureus Earth offers developers financial incentives to utilize carbon-storing and low-carbon materials, turning buildings into carbon sinks and accelerating the decarbonization of the construction industry. The company has developed a carbon offset protocol for sustainably harvested mass timber that quantifies biogenic carbon stored in the building and issues carbon offsets based on carbon dioxide removal (CDR). The resulting carbon offsets can be sold to help reduce the cost of mass timber construction.

THE GEOMETRIC (SHAPE) STIFFNESS

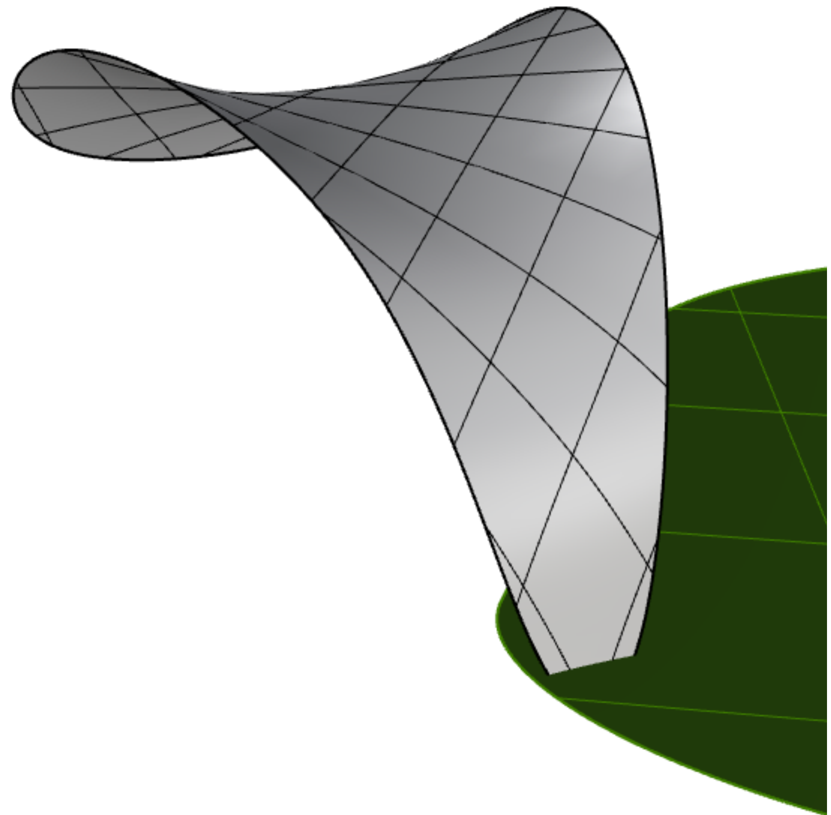
Folded configurations in Palms



Folded plate hut by Ryuichi Ashizawa architects, Osaka

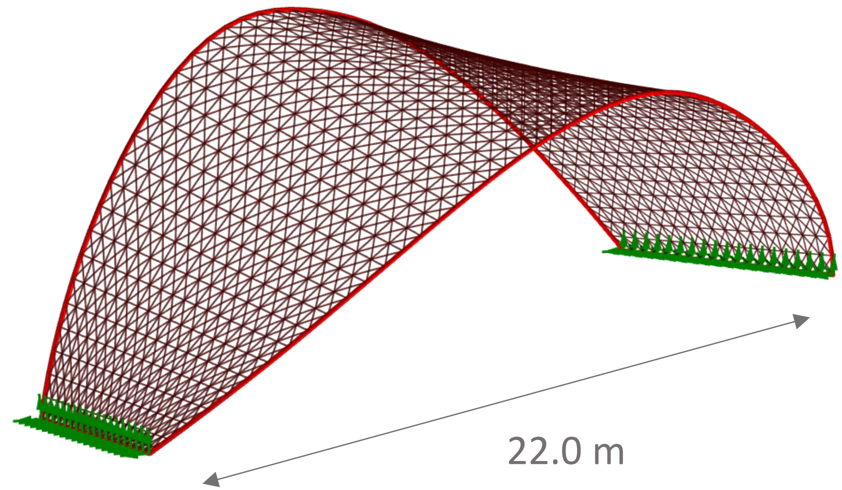
Double curvature in a leaf

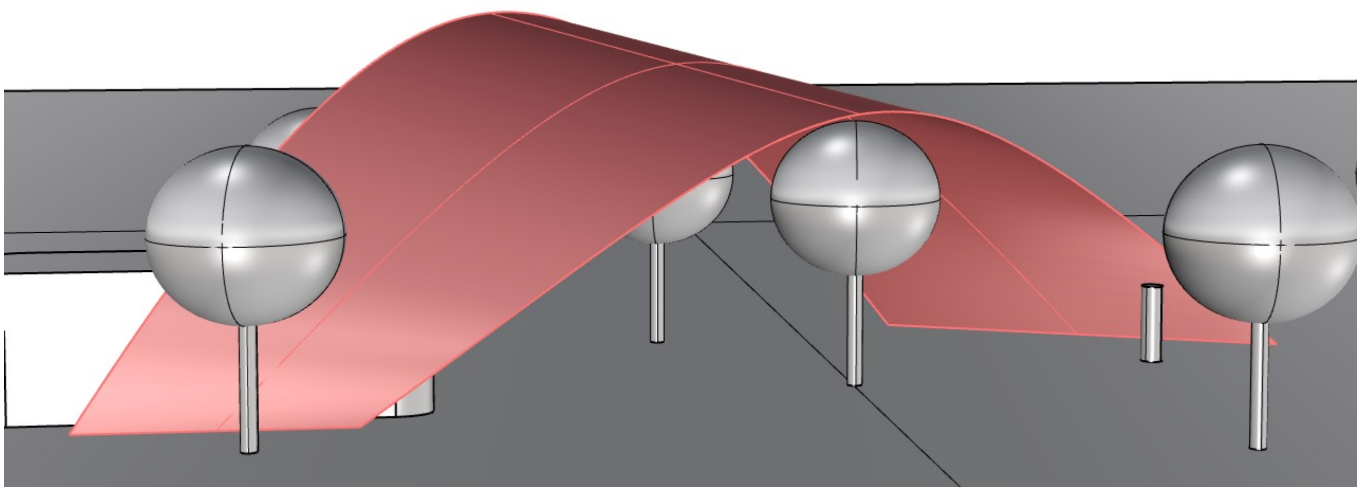
Japanese Knotwood



Canopy structure for Puja house, India

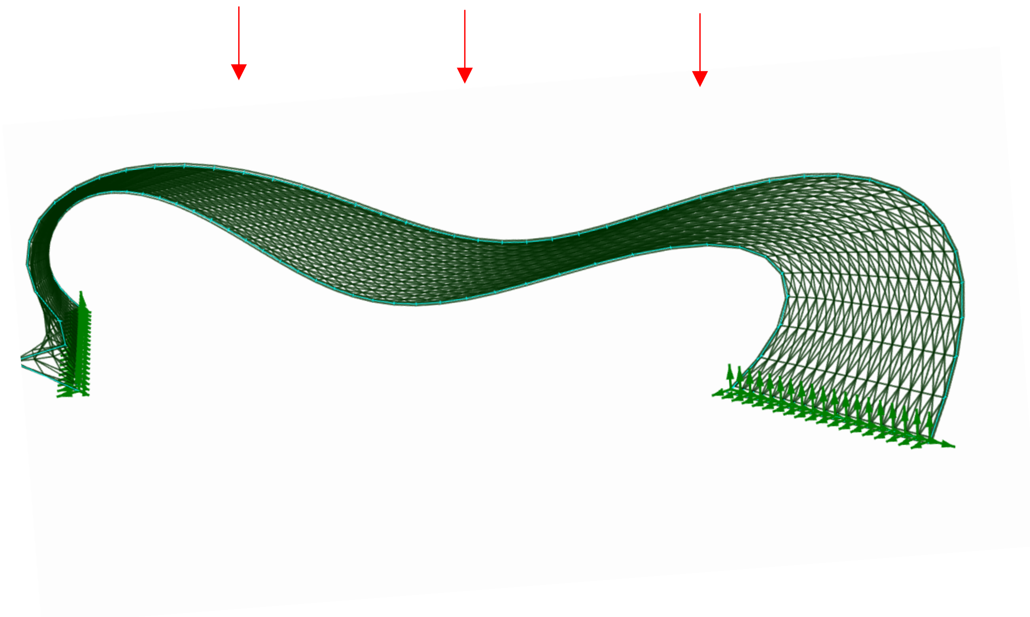
Bamboo shading canopies for a student campus in north Delhi, Ashoka university

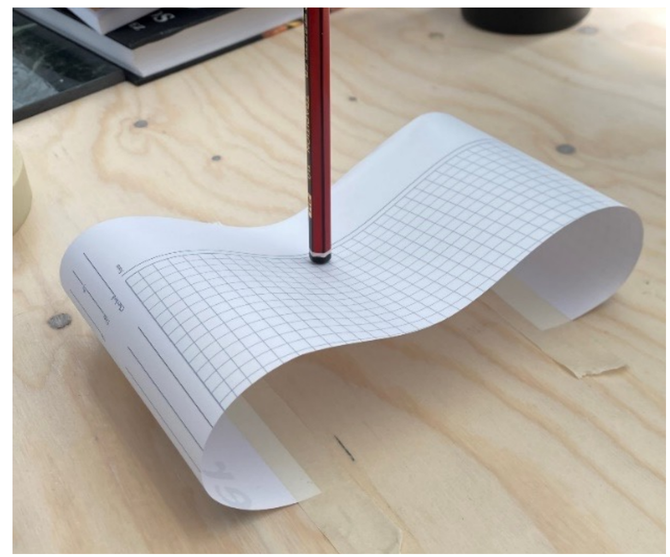




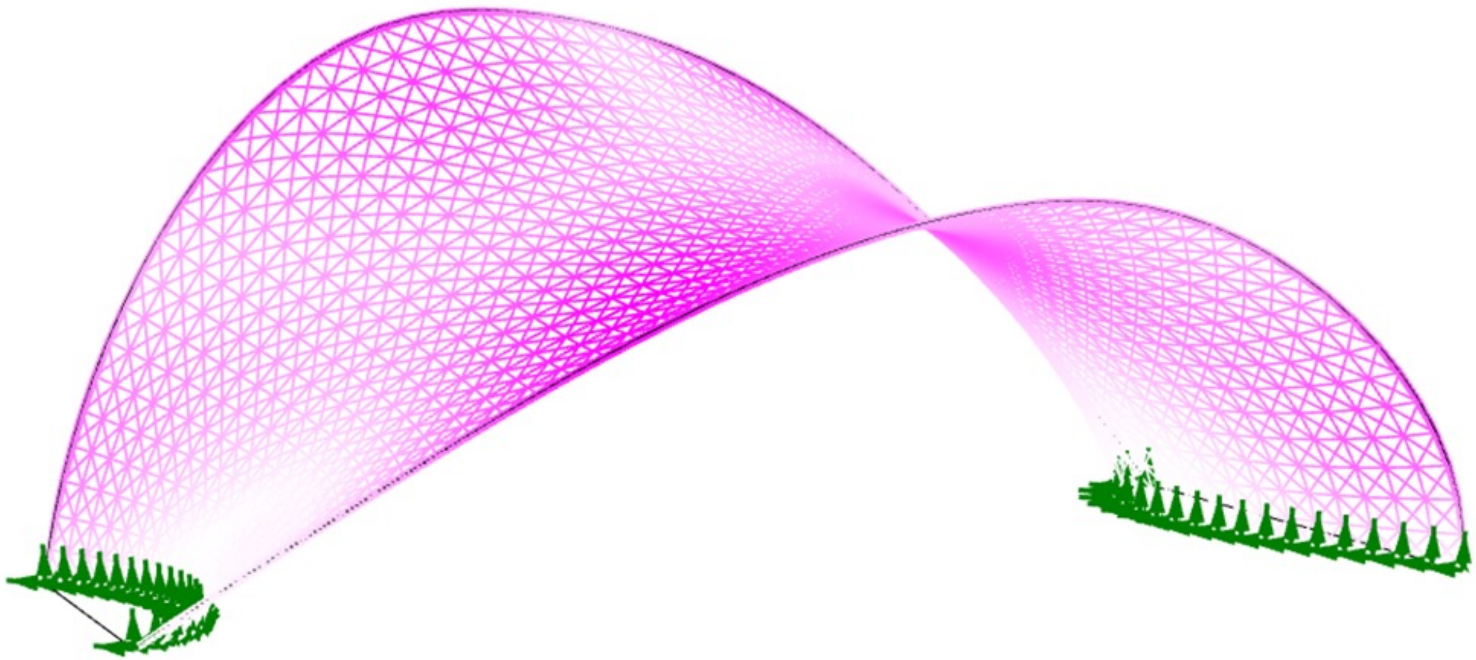
Bamboo shading canopies for a student campus in north Delhi, Ashoka university

The gridshell buckles under self- weight



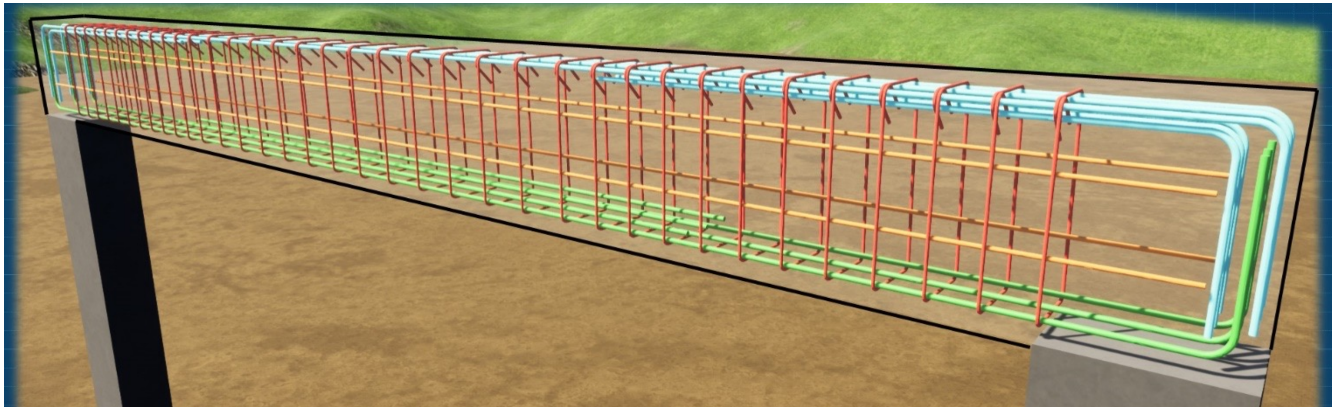


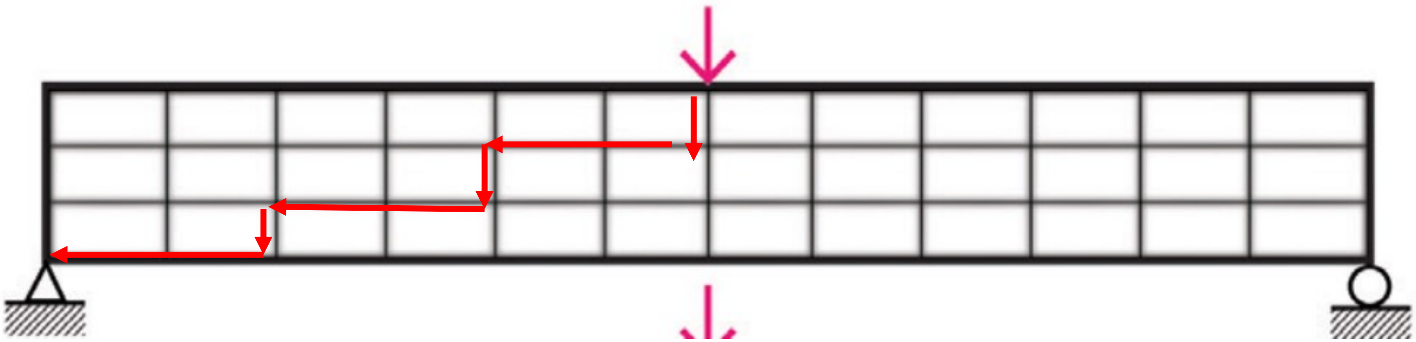
The gridshell deflects 6.4 mm under self-weight.



PRINCIPAL STRESS LINES

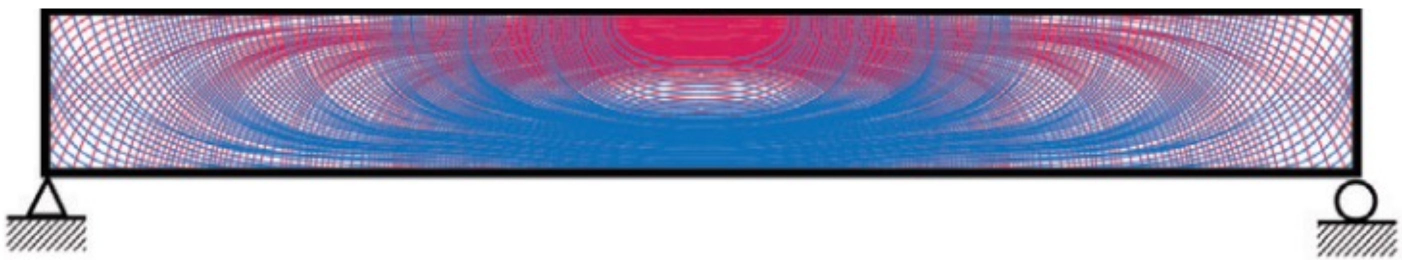
When form follows force



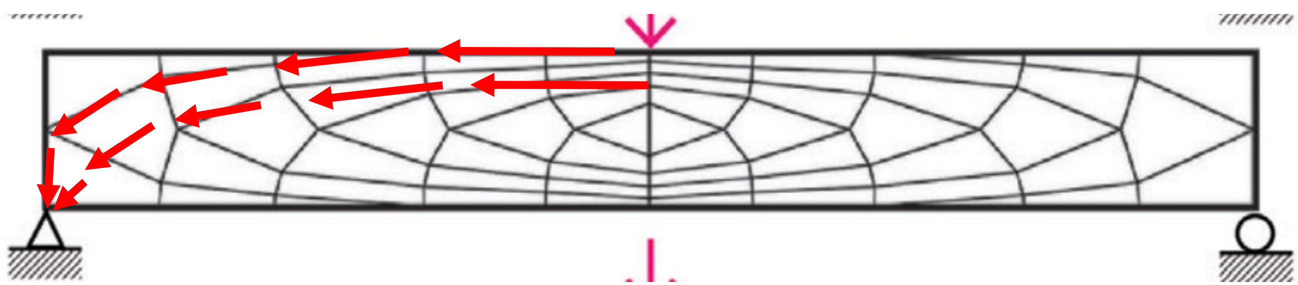


This is geometrically simple, but the load path is truncated. Elements must carry the forces by both normal forces and shear.

What are principal stress lines? Simply supported beam example

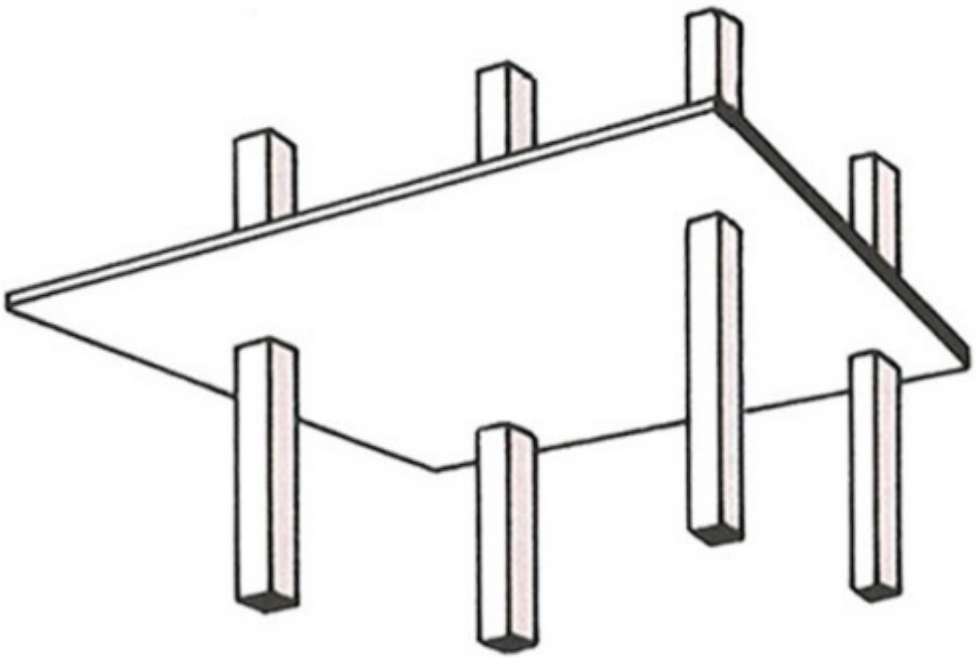


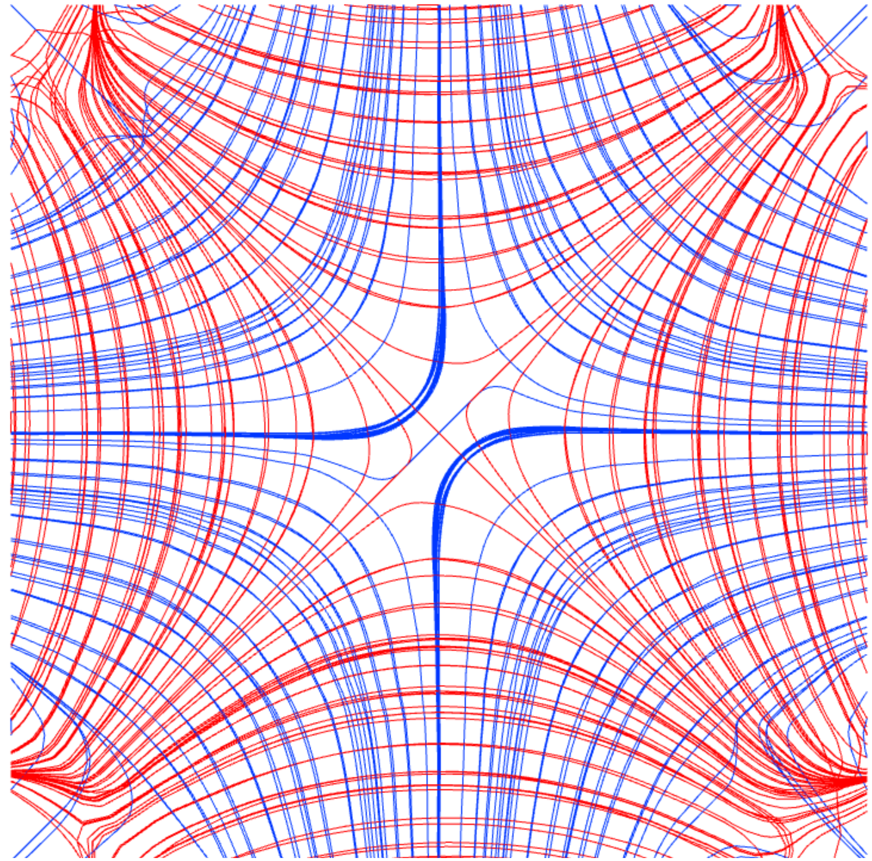
The principal stress lines define continuous force paths in a surface. These lines show the orientations at which load travels through normal stresses to the supports, with no shear involved.



This is geometrically complex, but material is saved by having the members aligned to the normal stresses.

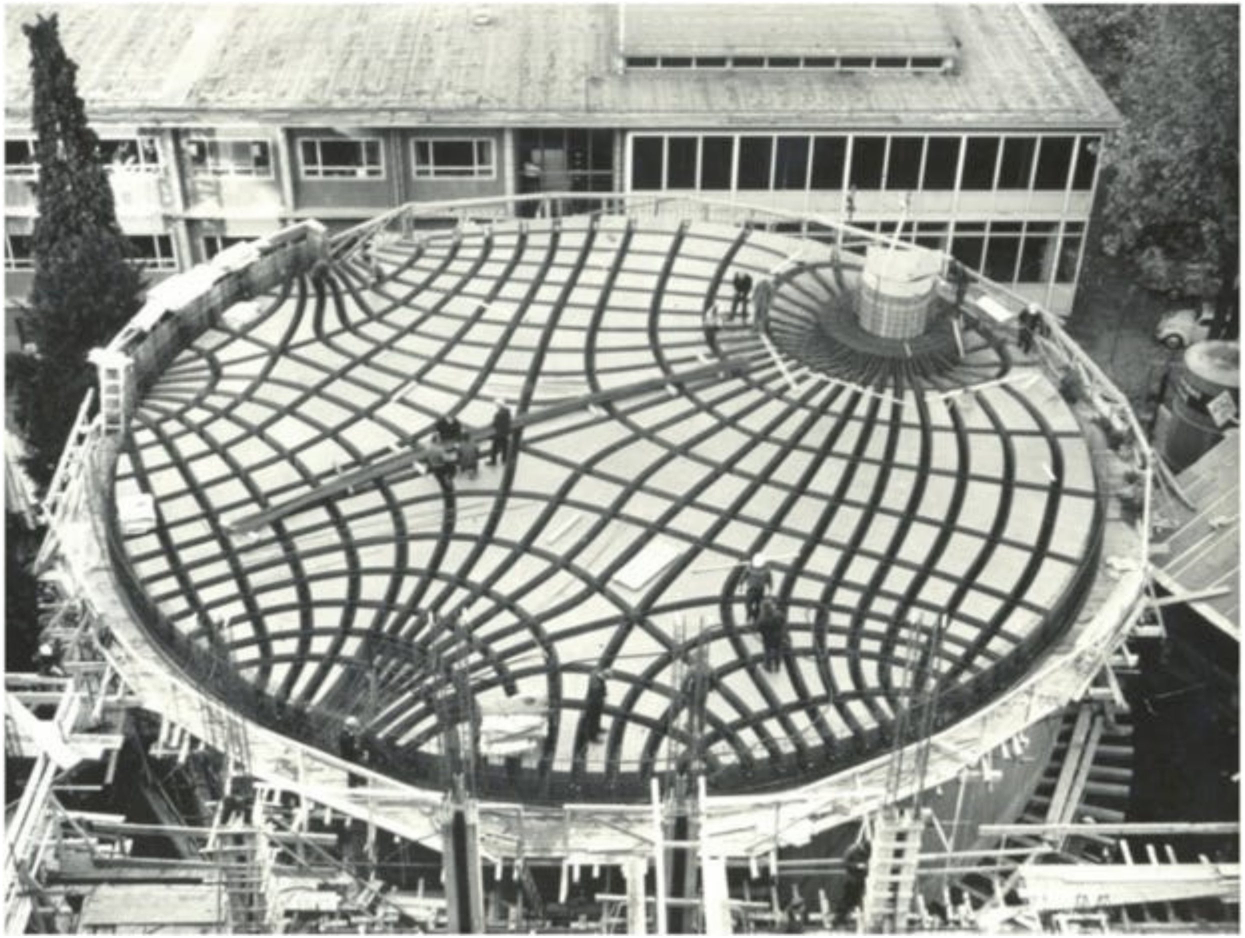
Principal stress lines of a flat slab
supported at the corners



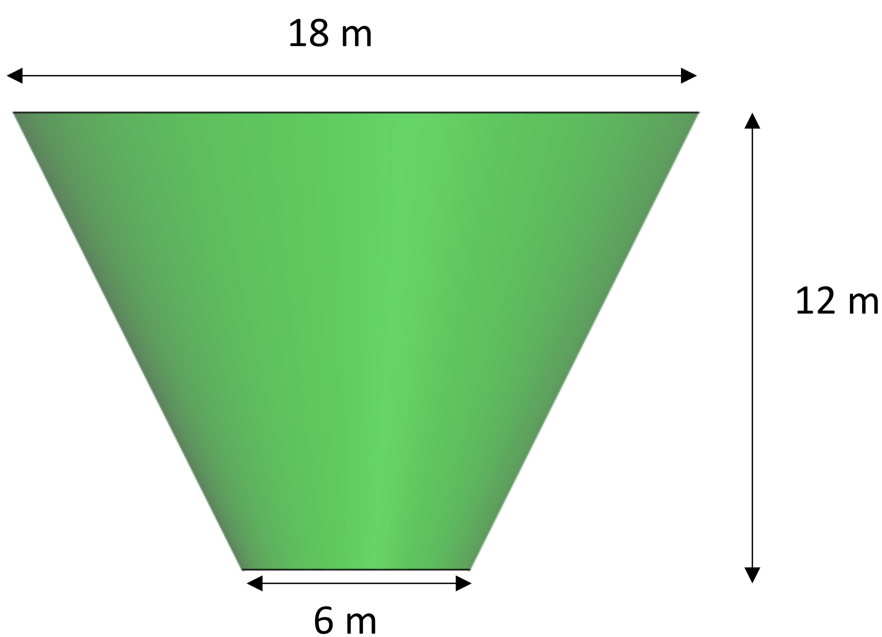


Example: Gatti wool factory - Nervi

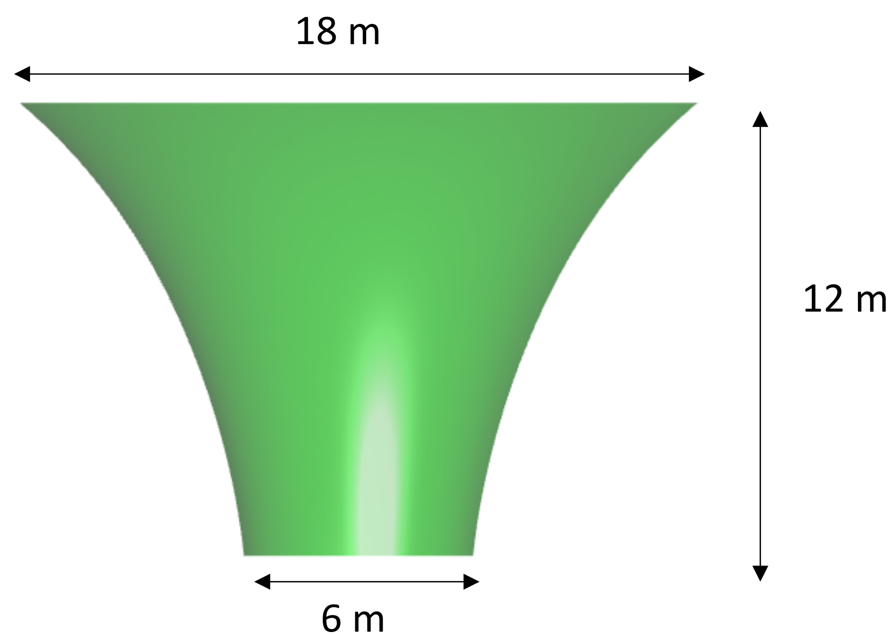
Example: Zoology lecture hall at Freiburg university - Hecker



Comparing cone principal stress lines

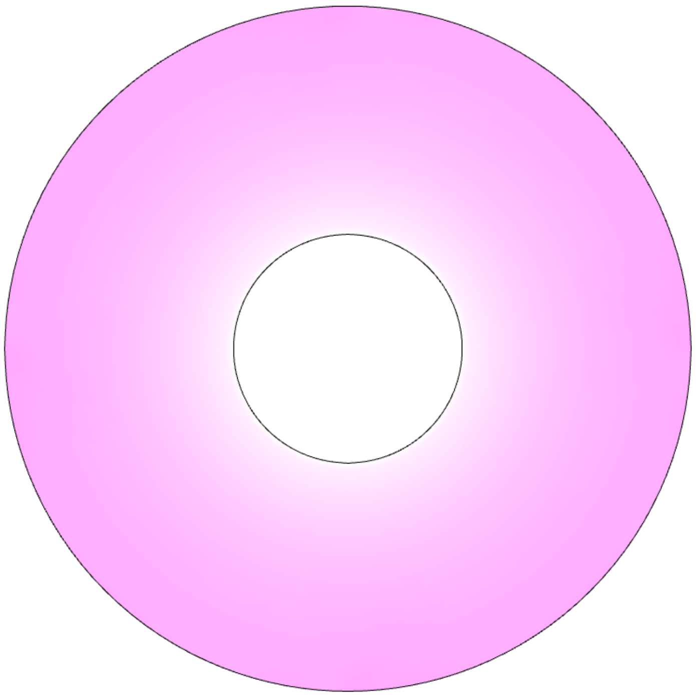


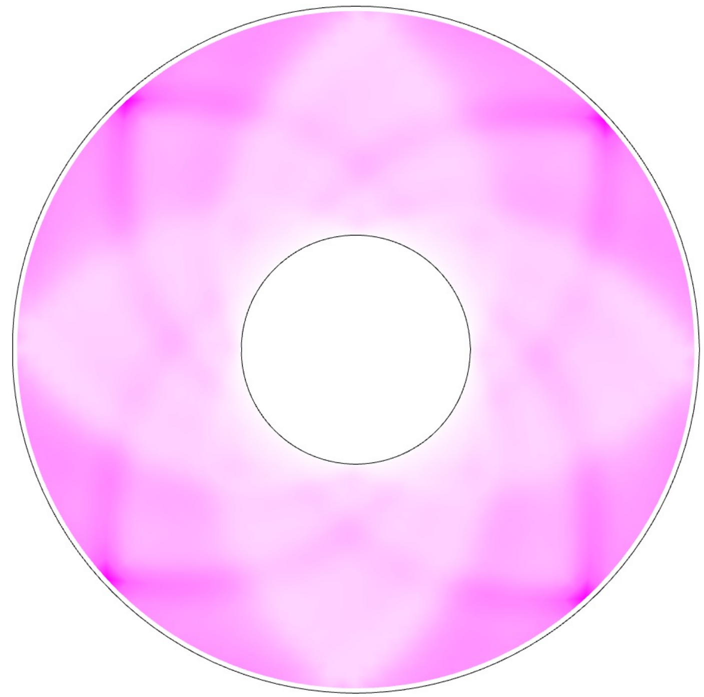
Cropped cone



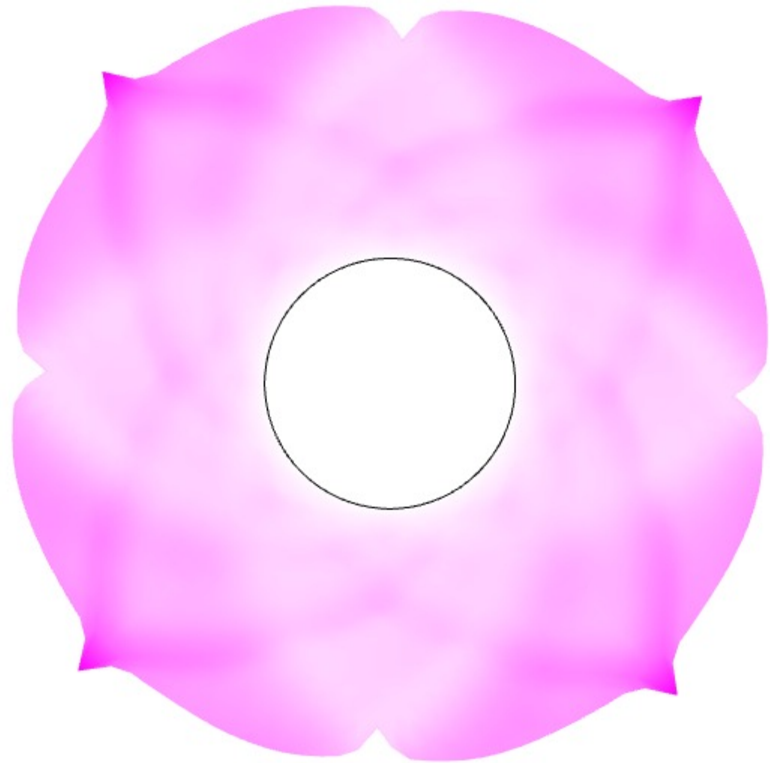
Cropped hyperboloid

Deflections under self-weight of a thin shell

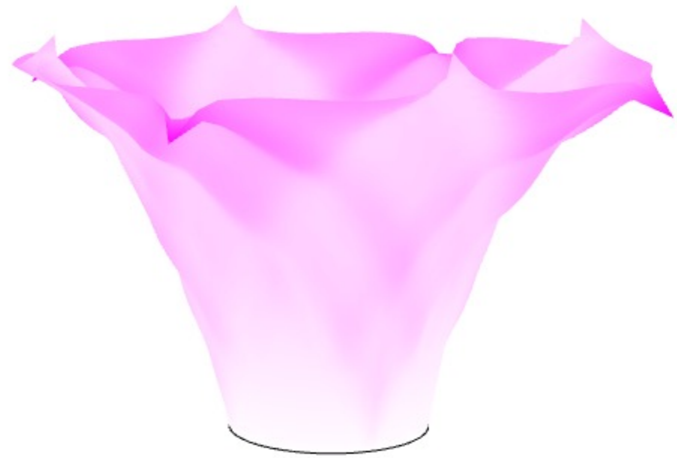




Morning glory

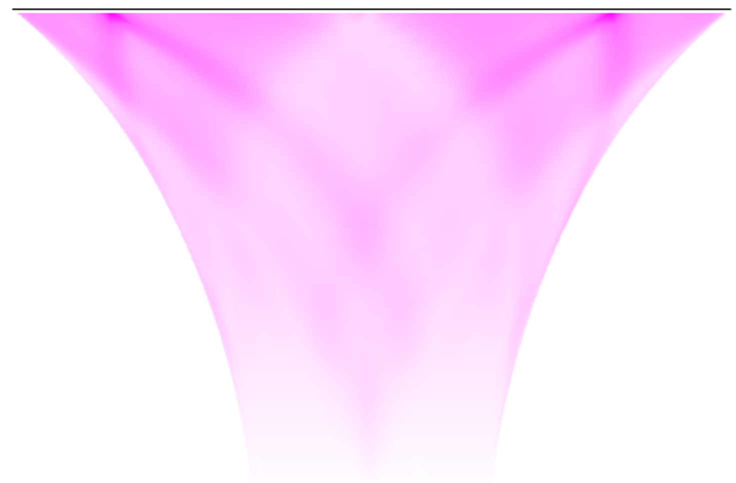


Morning glory

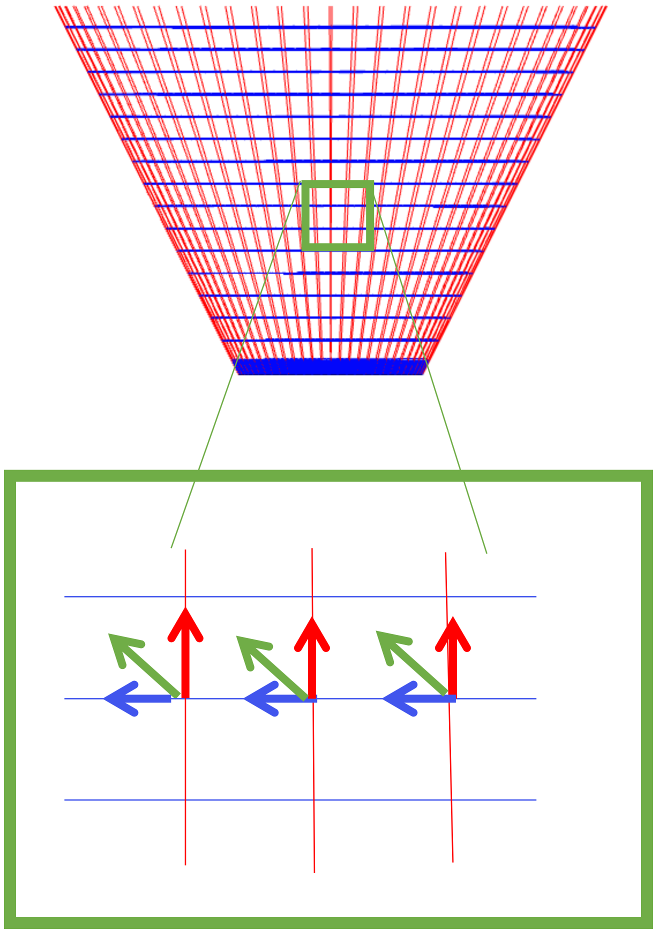


Corolla of the
Morning glory

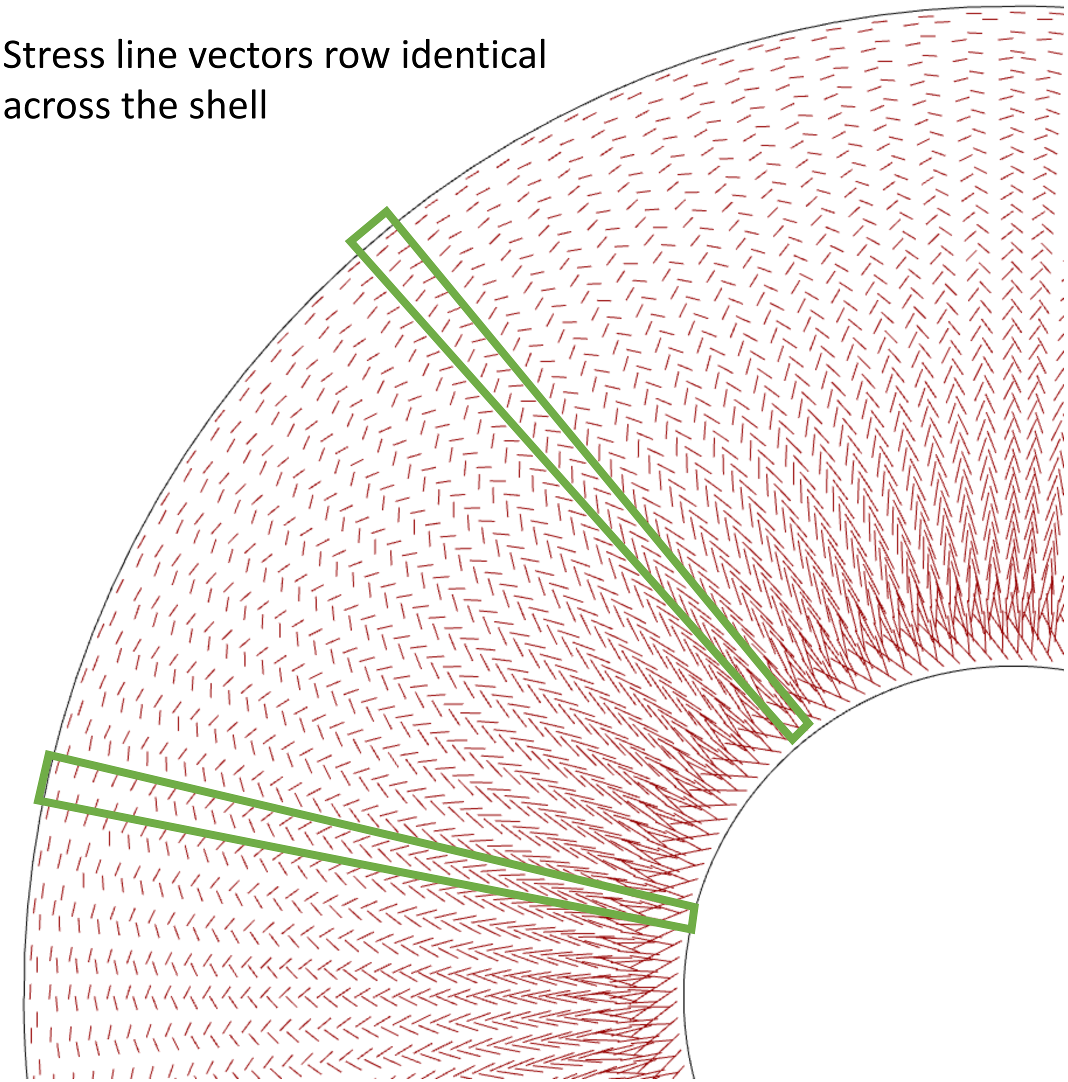
Deflections under self-weight of a thin shell



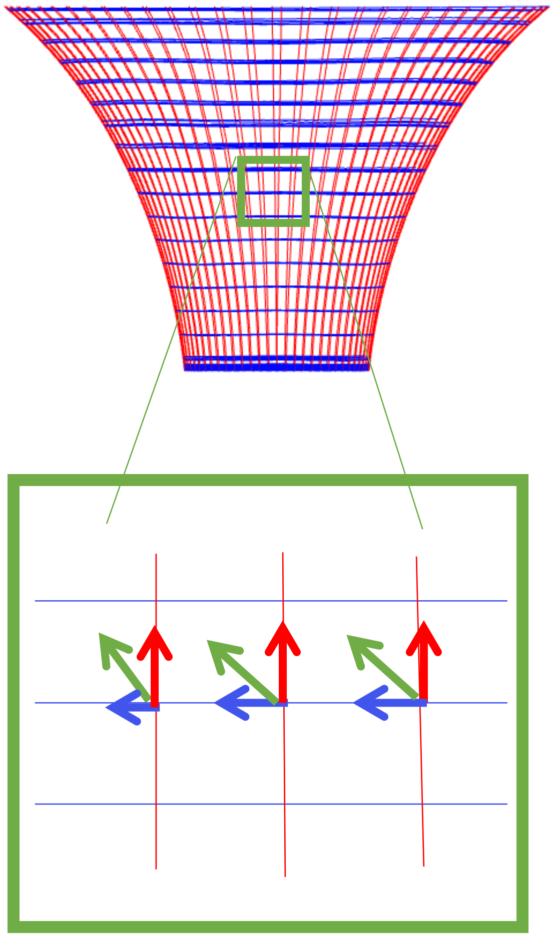
Principal stress lines cropped cone self weight



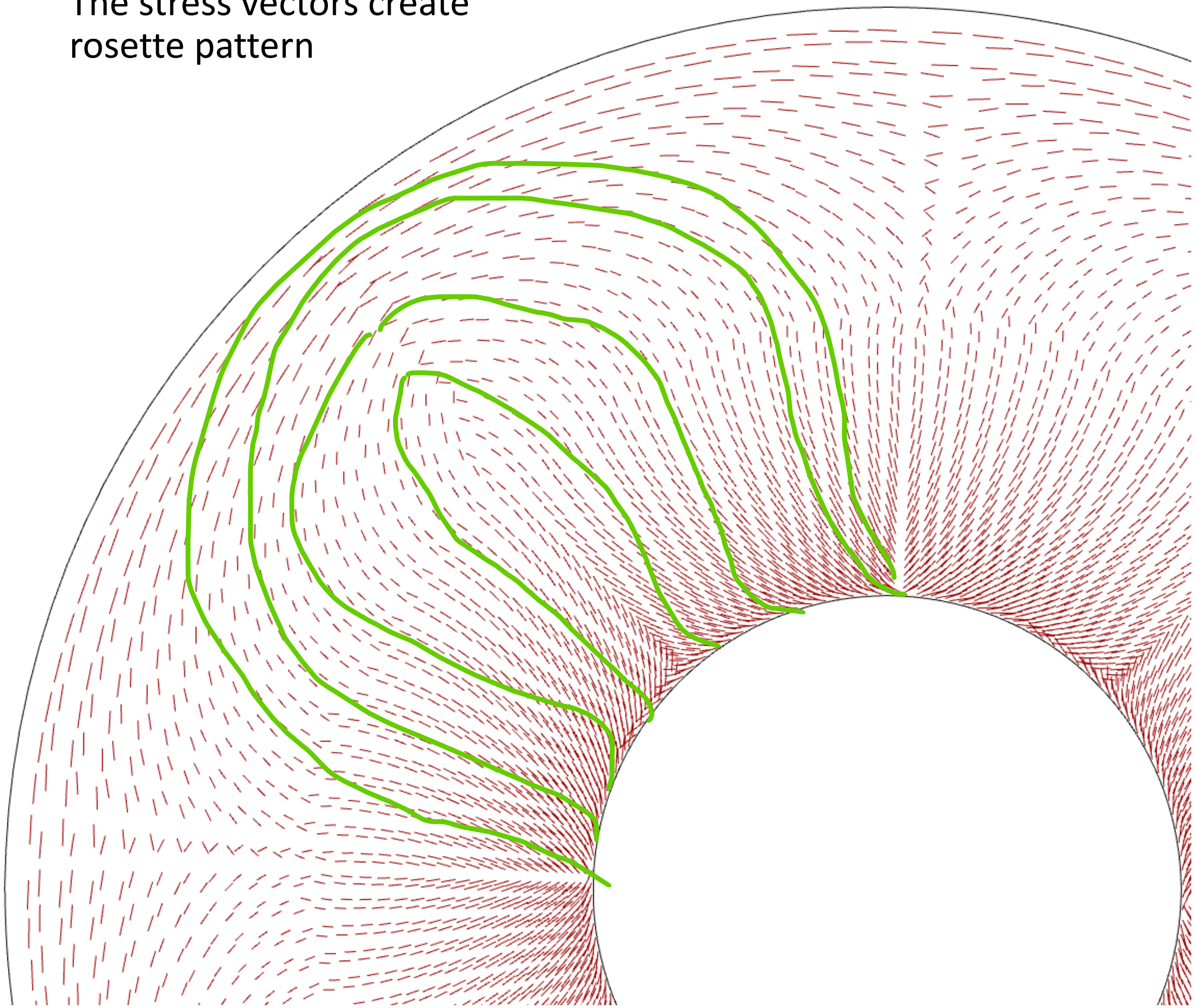
Stress line vectors row identical across the shell



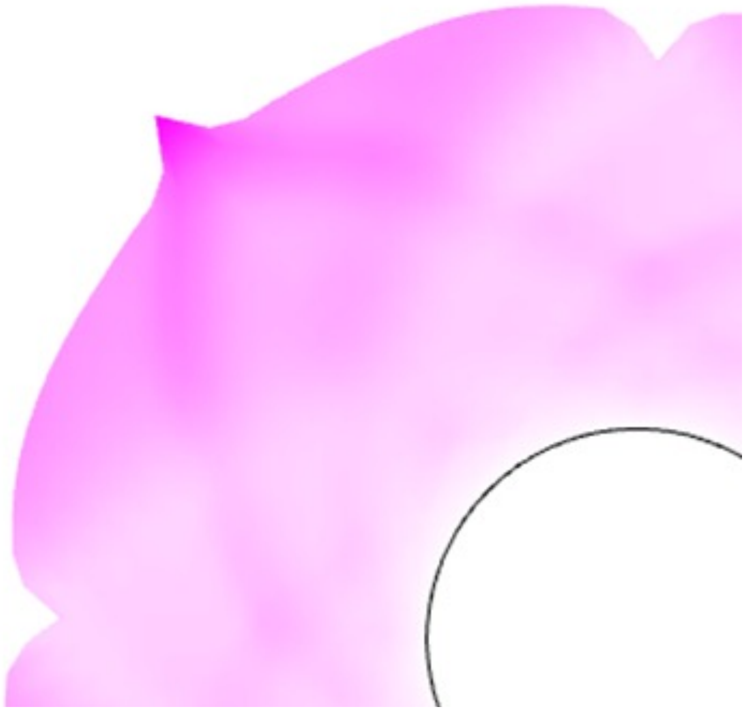
Principal stress lines
hyperboloid self weight



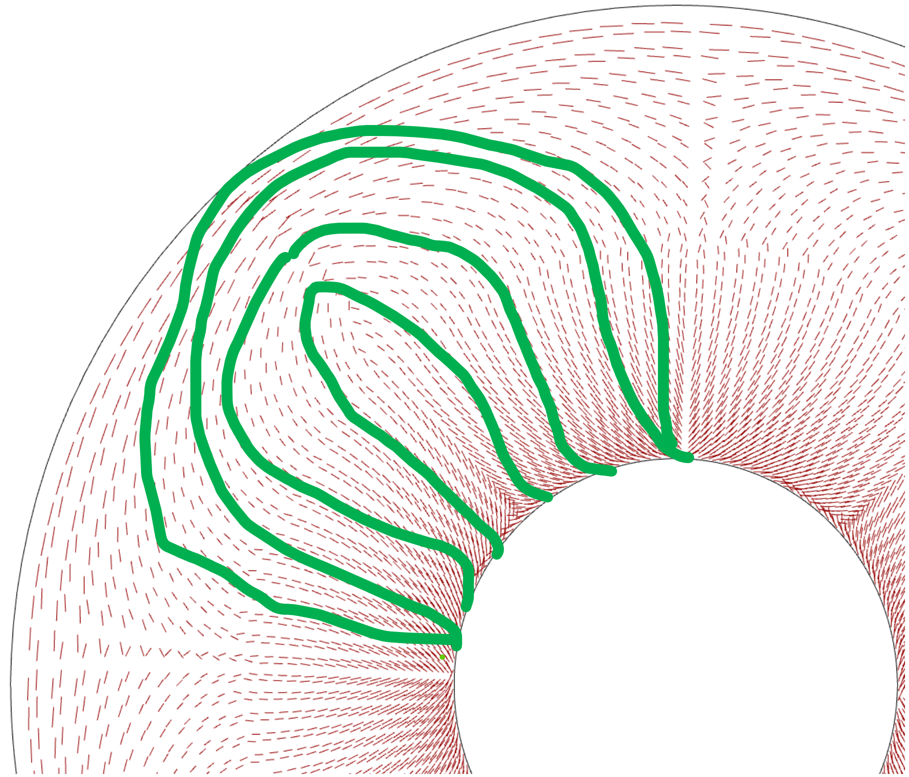
The stress vectors create
rosette pattern



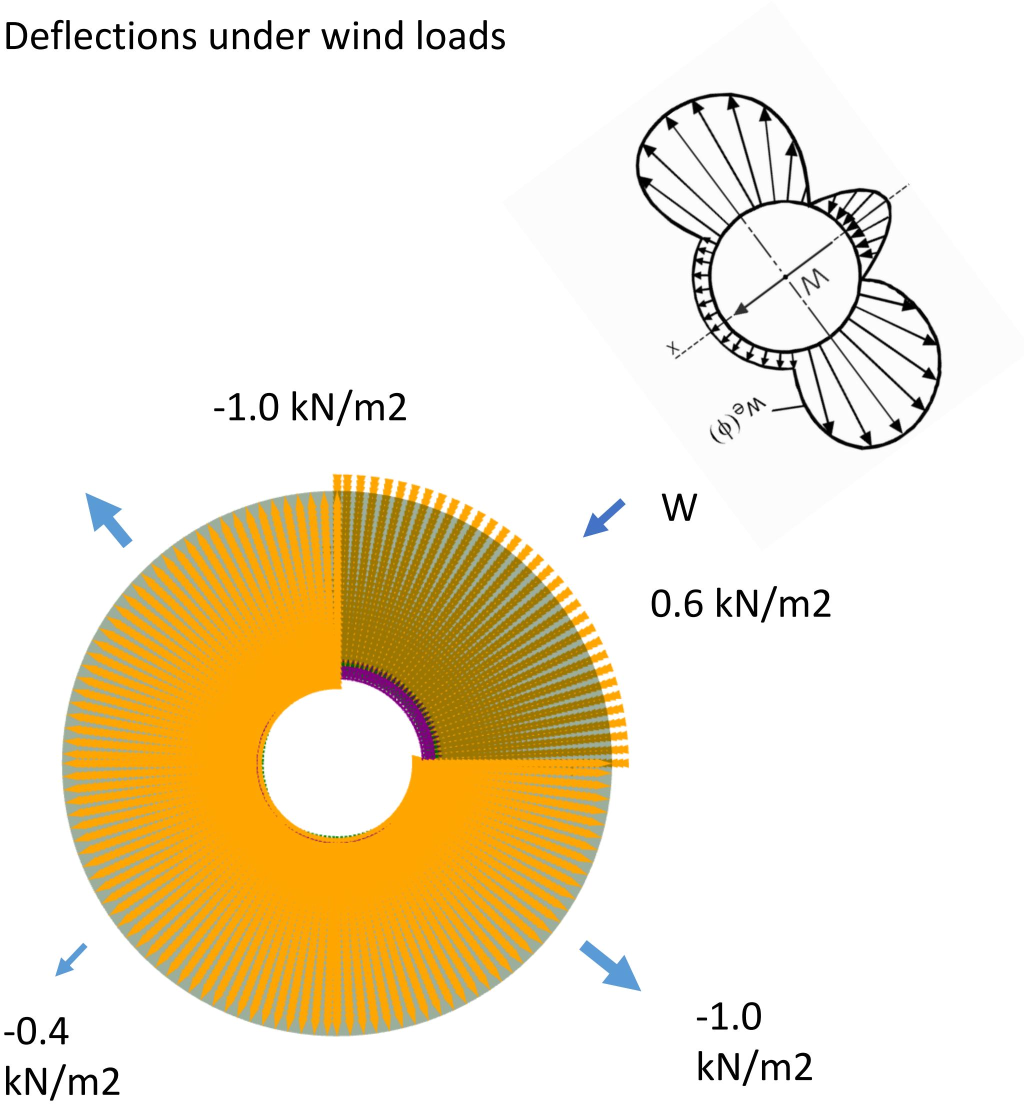
Deflections under self - weight

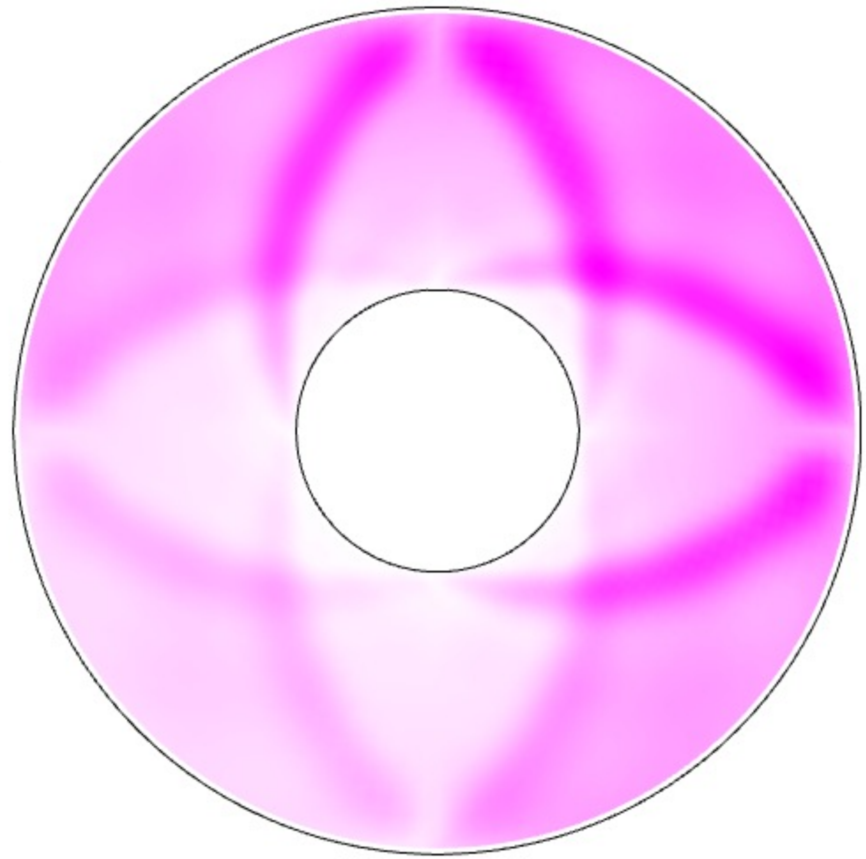


Added Vectors from the principal stresses at each point of the mesh for a hyperboloid.

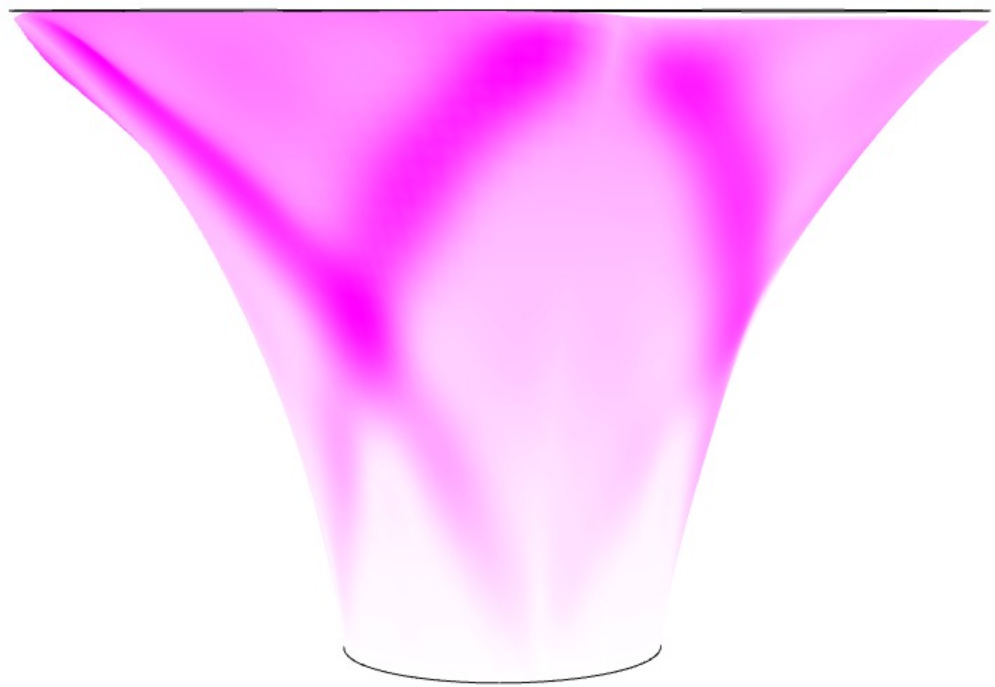


Deflections under wind loads

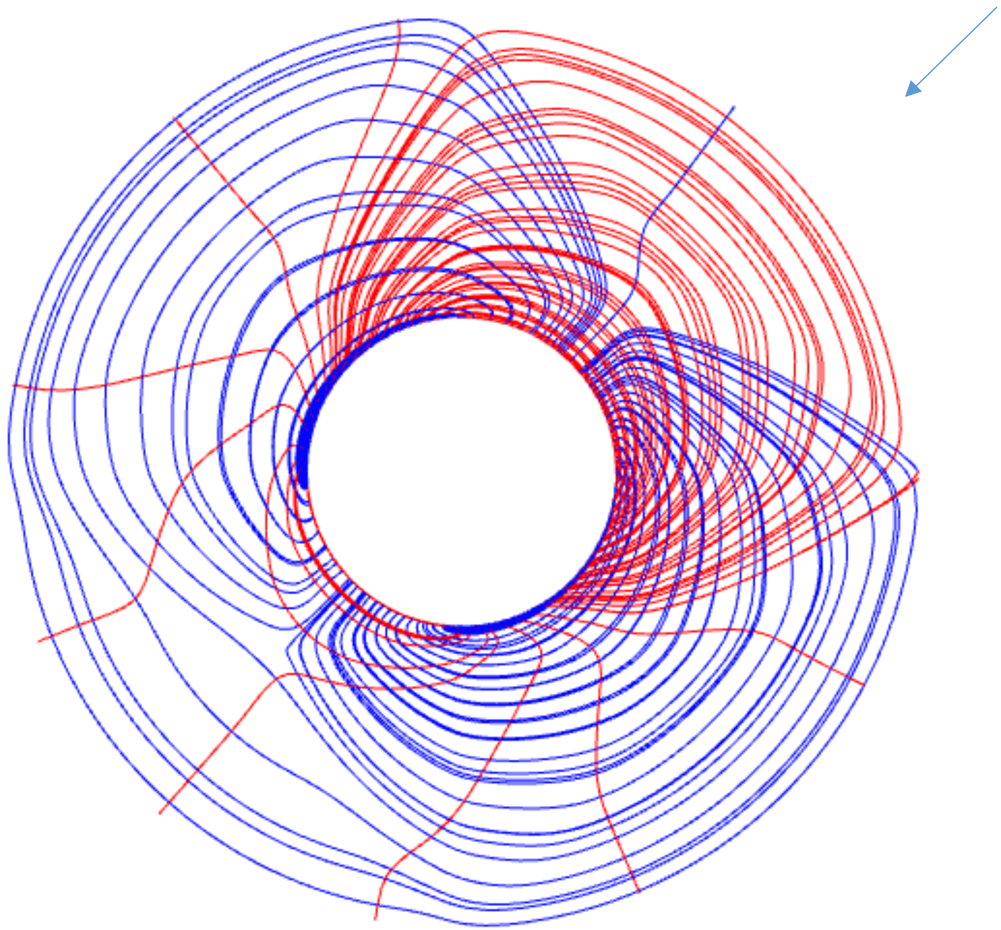




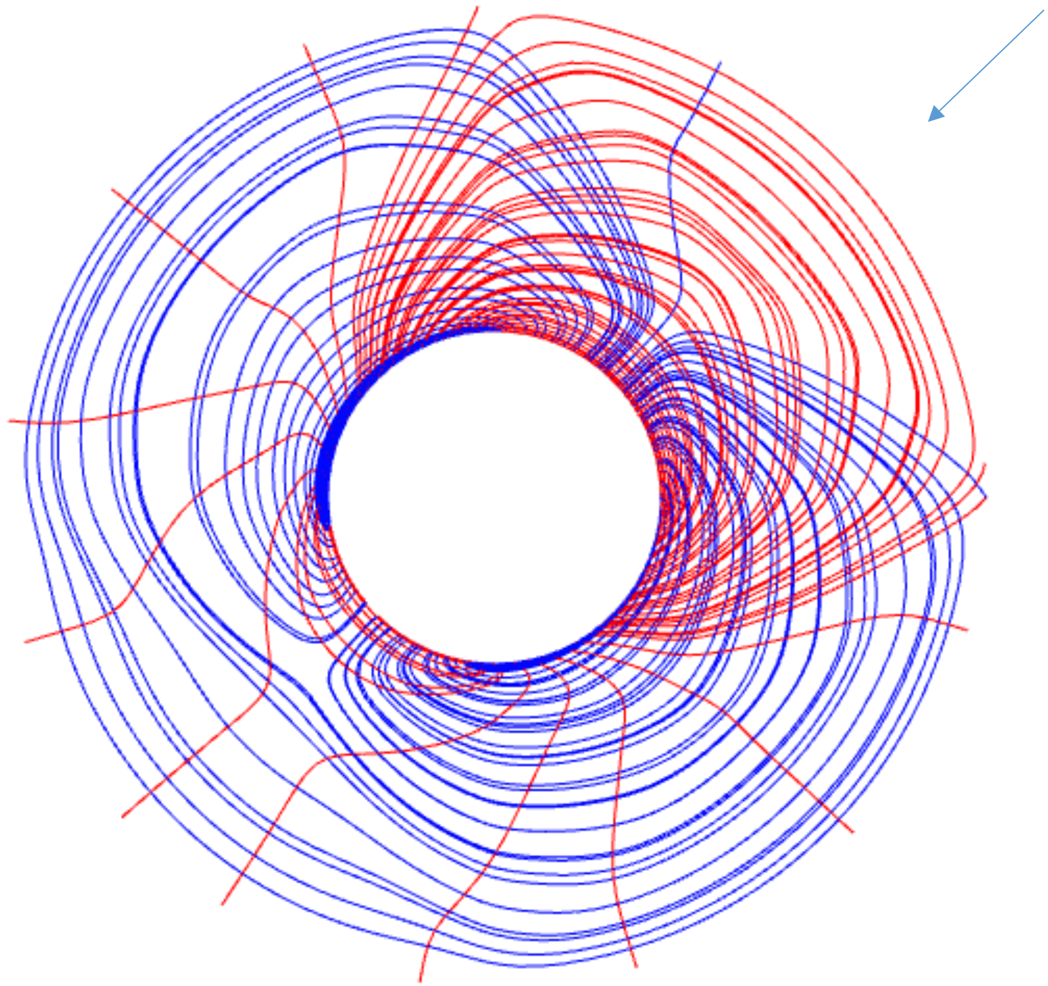
Deflections of hyperbolic cone



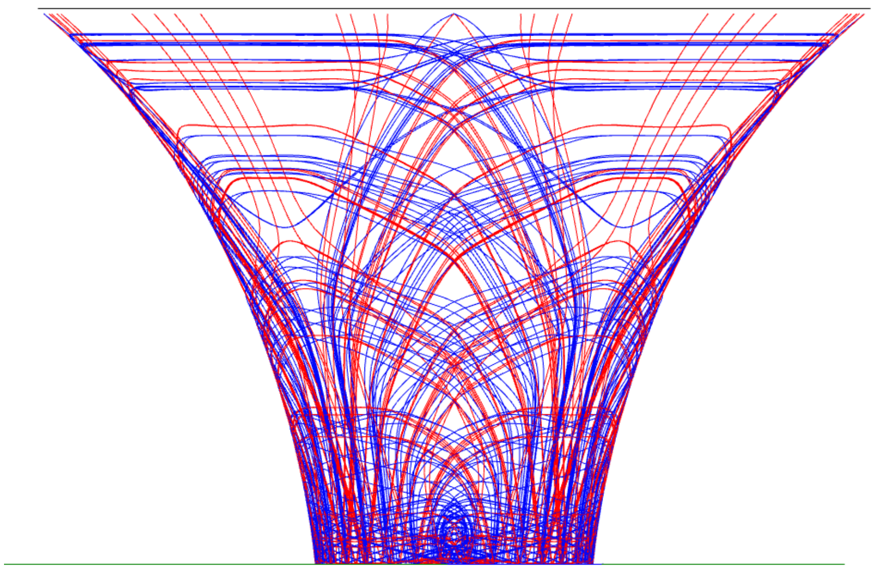
Principal stress lines with wind loading

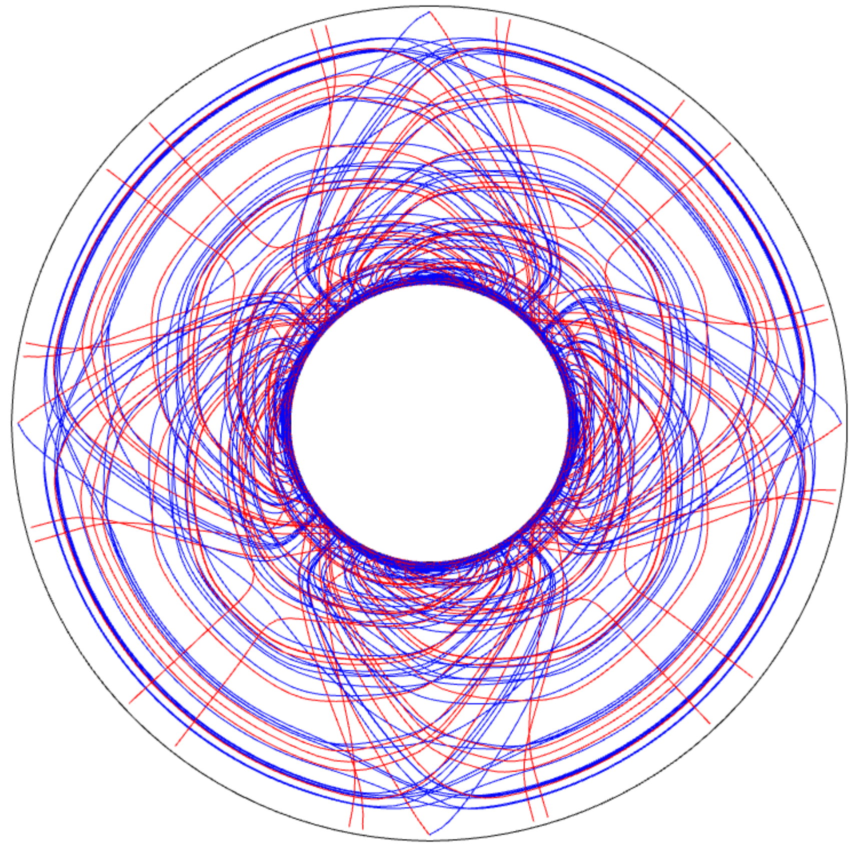


Stress lines with loads combined self – weight + wind load one direction

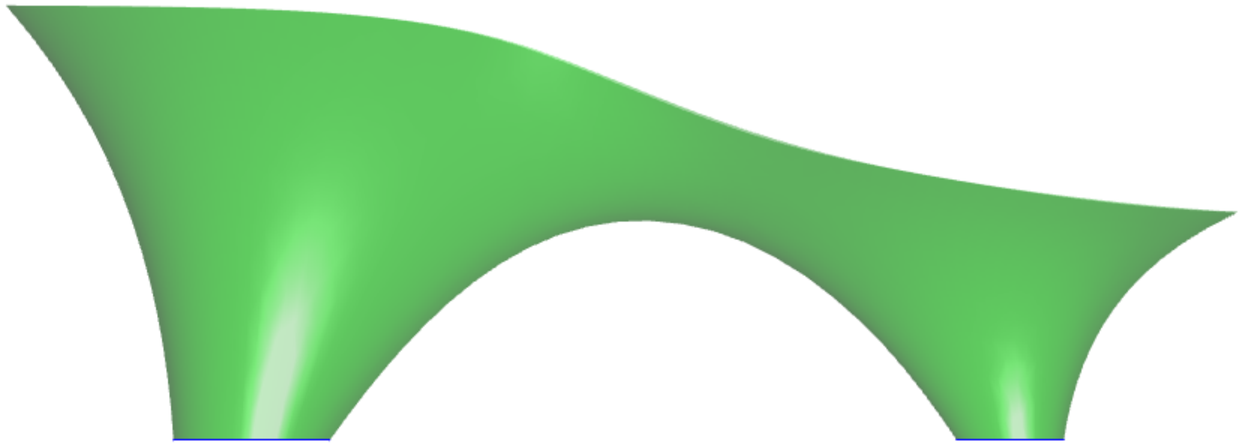


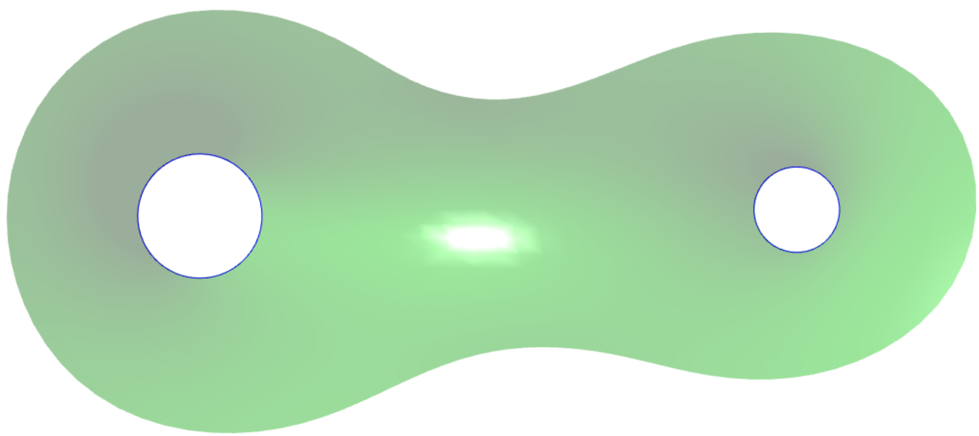
4 wind directions, principal stress lines superimposed for a hyperboloid



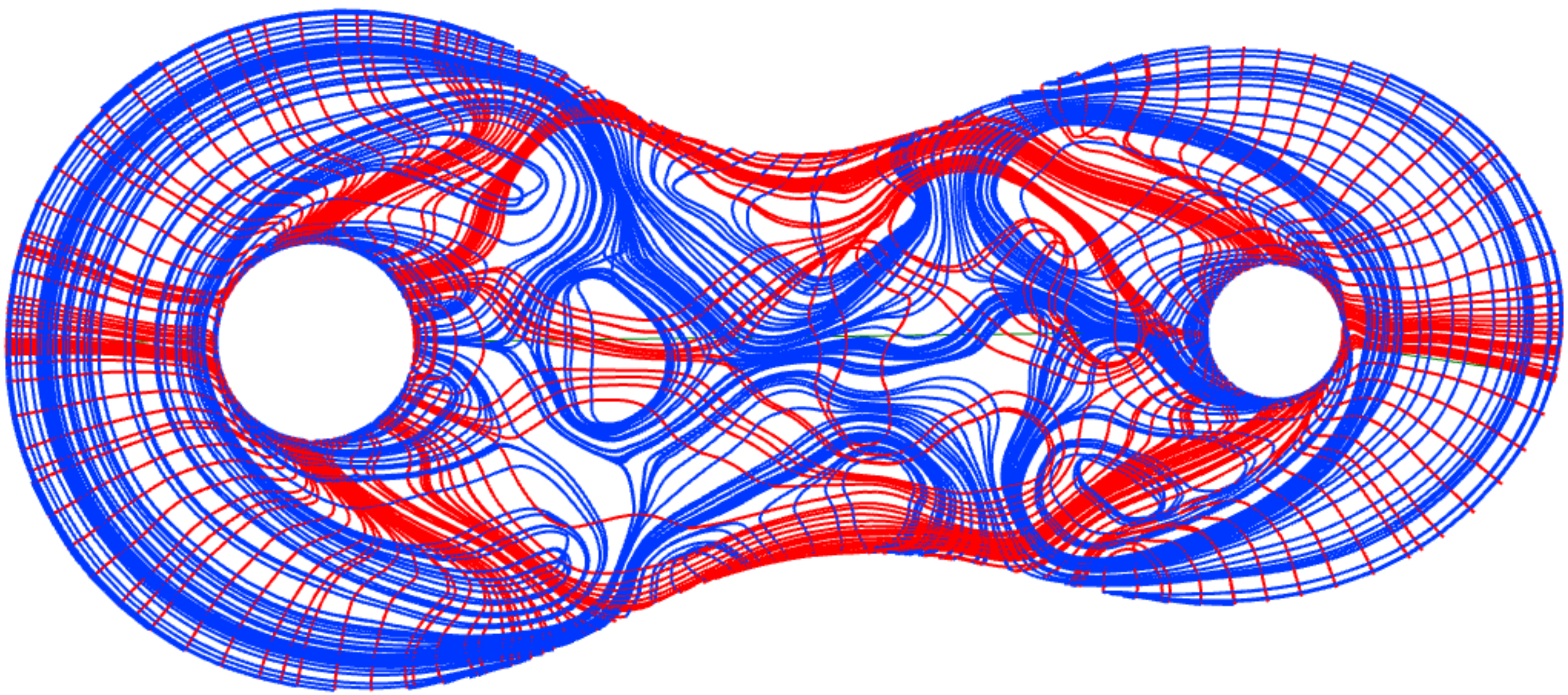


Two cones together

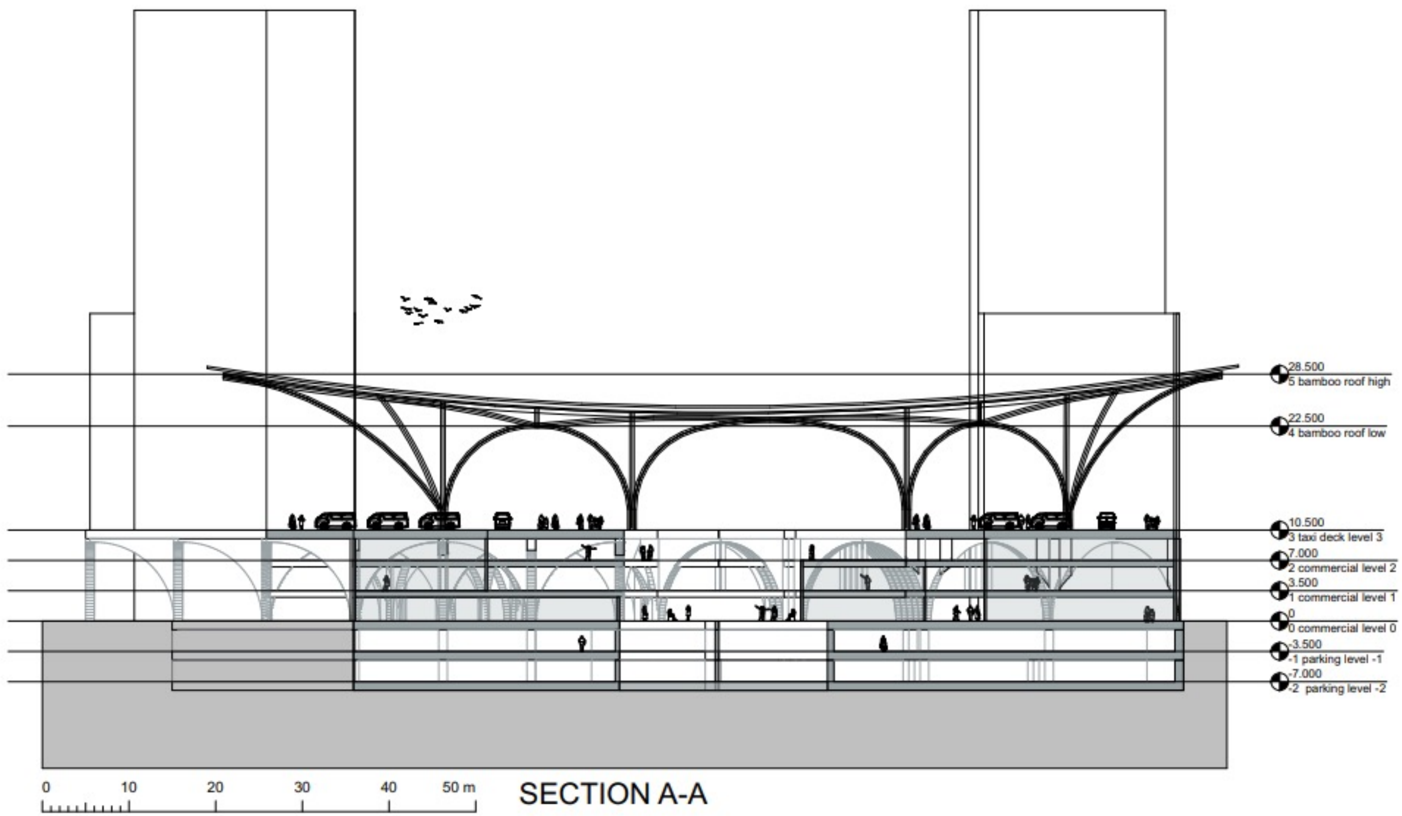




Principal stress lines under gravity loading

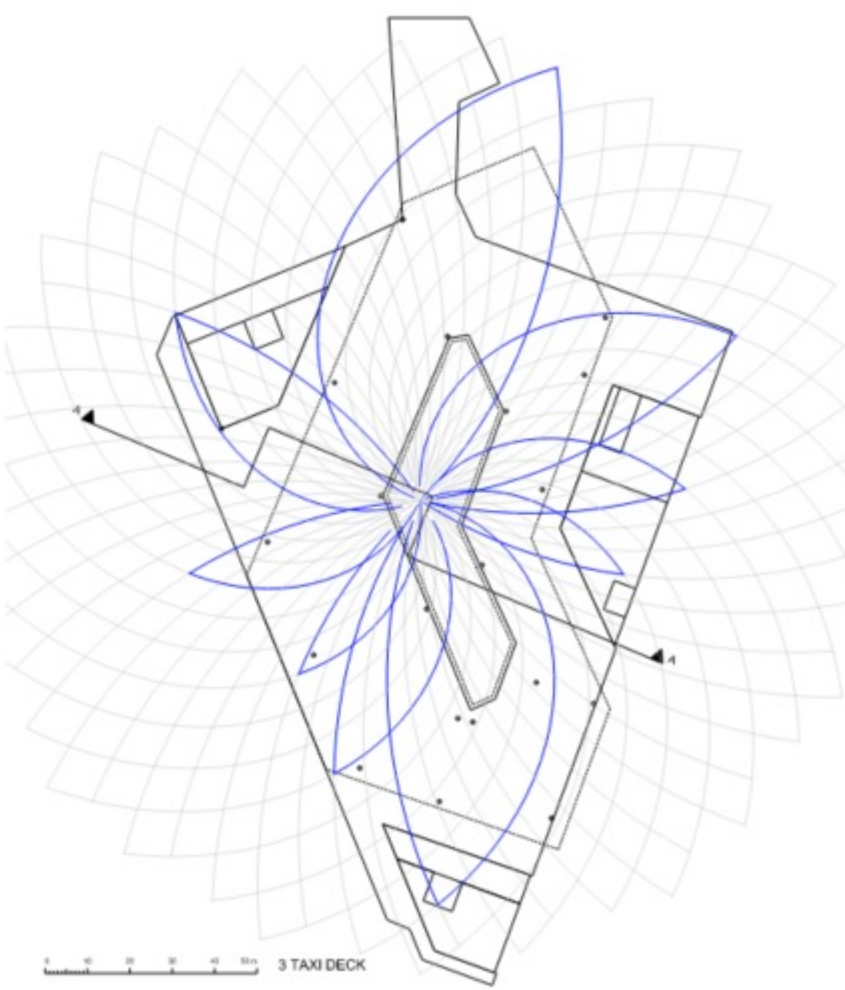


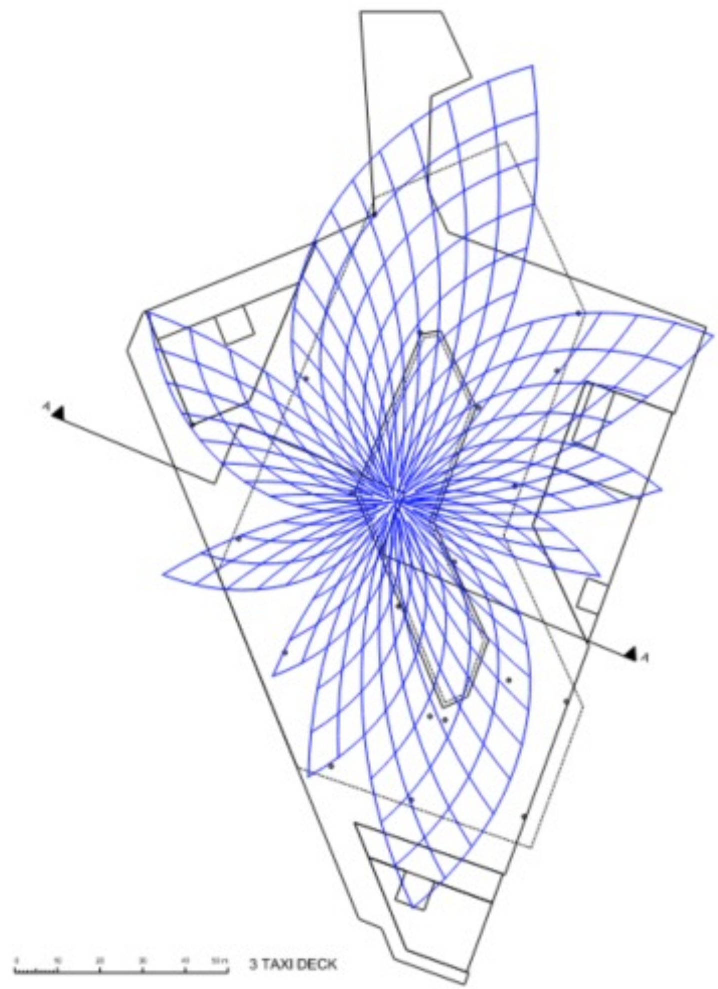
Bus station in Kampala Uganda, with BBKV architects



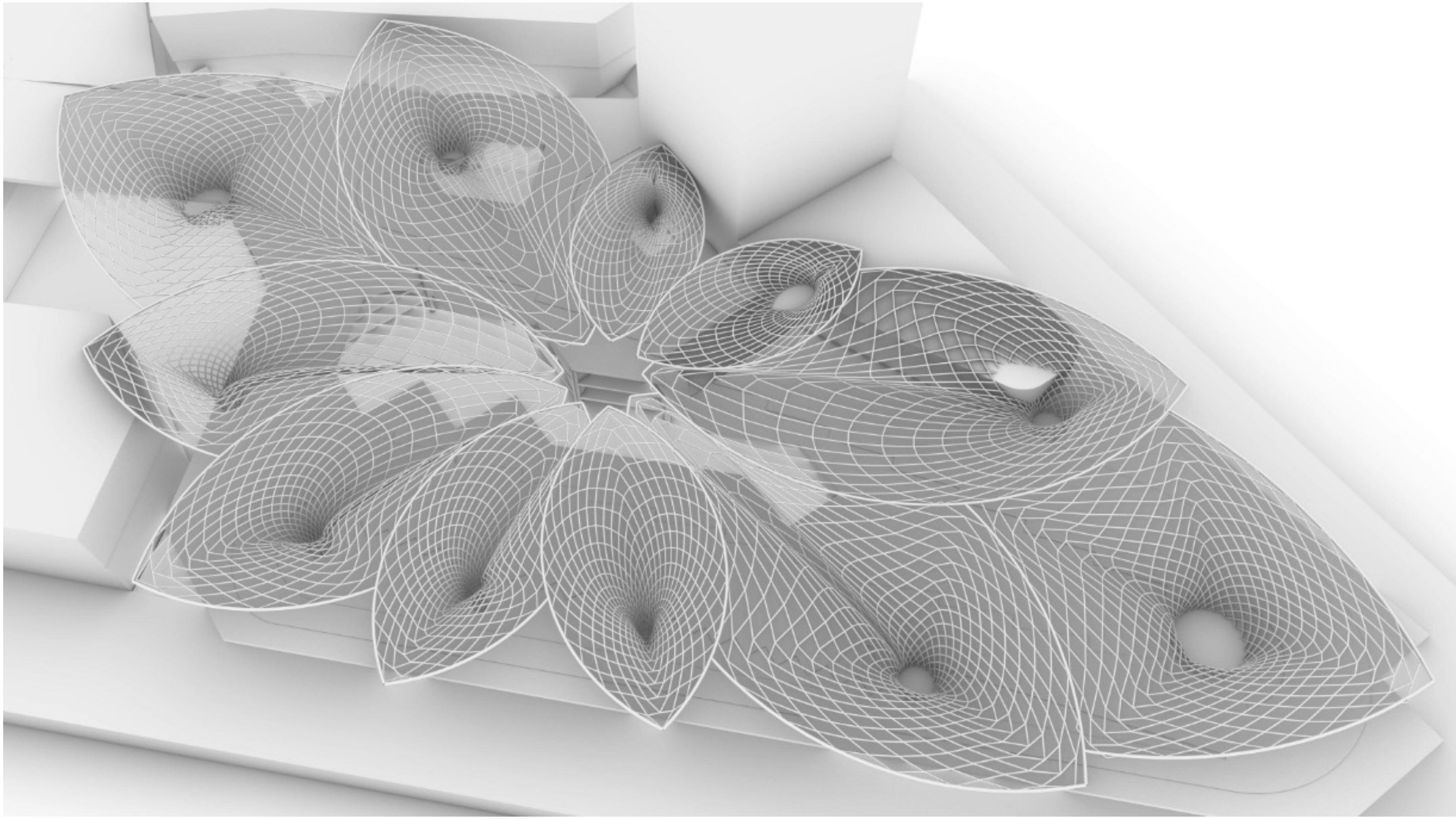
SECTION A-A

First idea: Fibonacci petals spanning from the centre

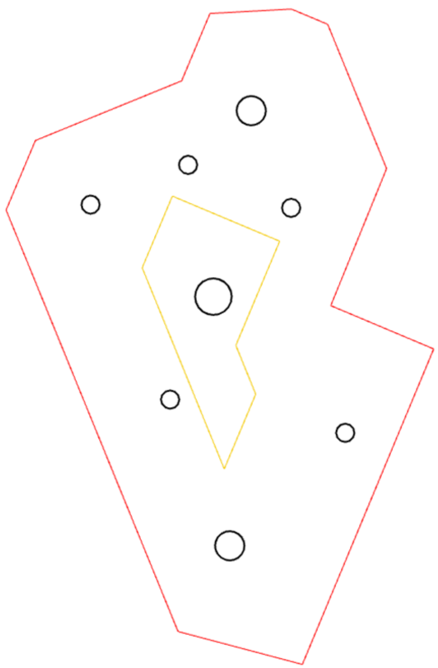




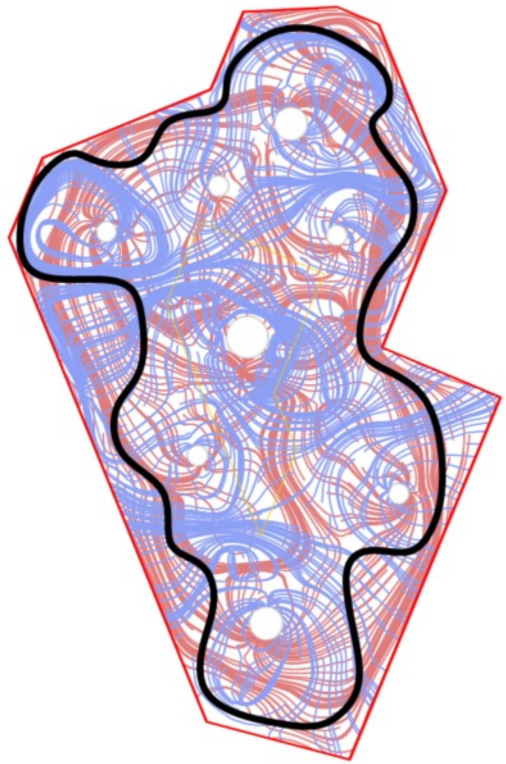
Fibonacci petals spanning at columns



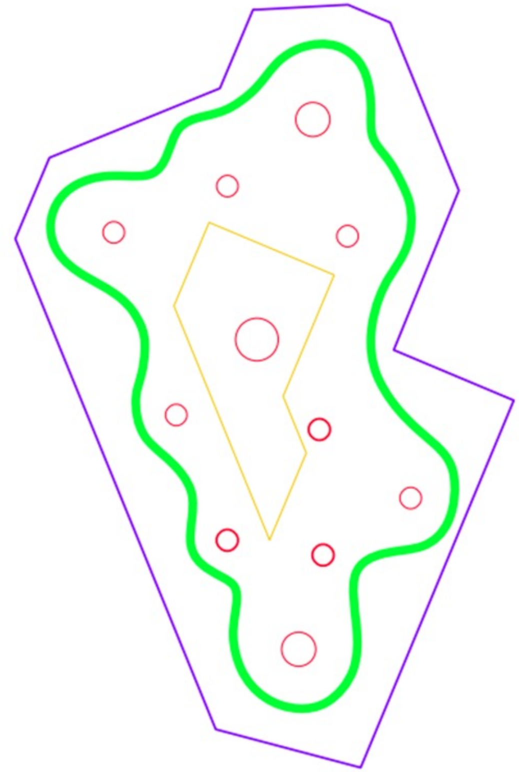
Design development



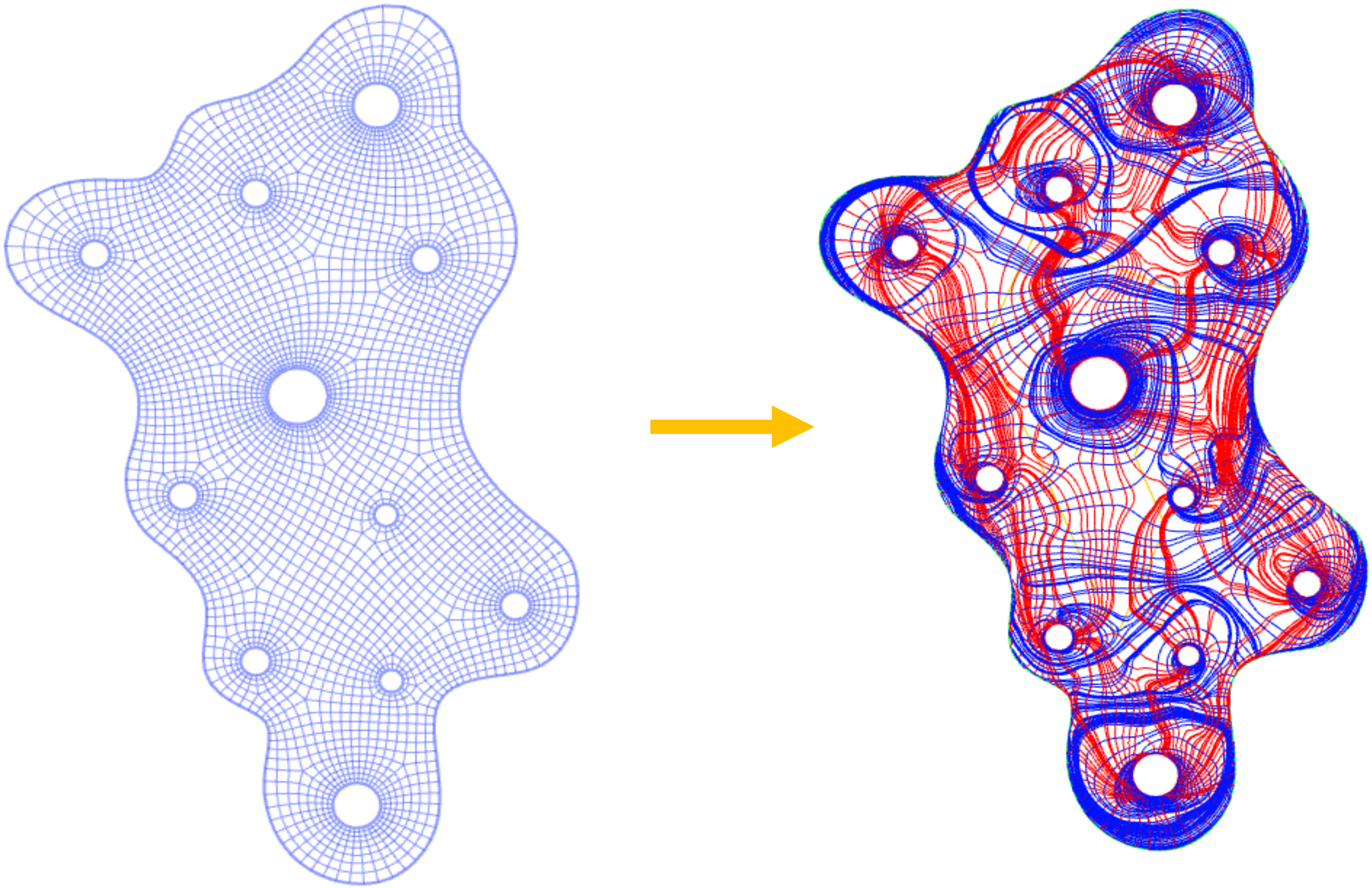
Starting point



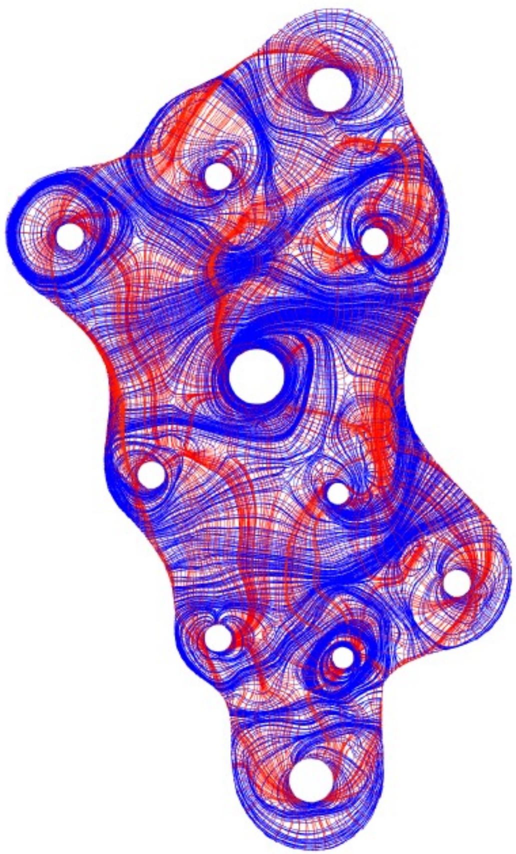
Iteration 1

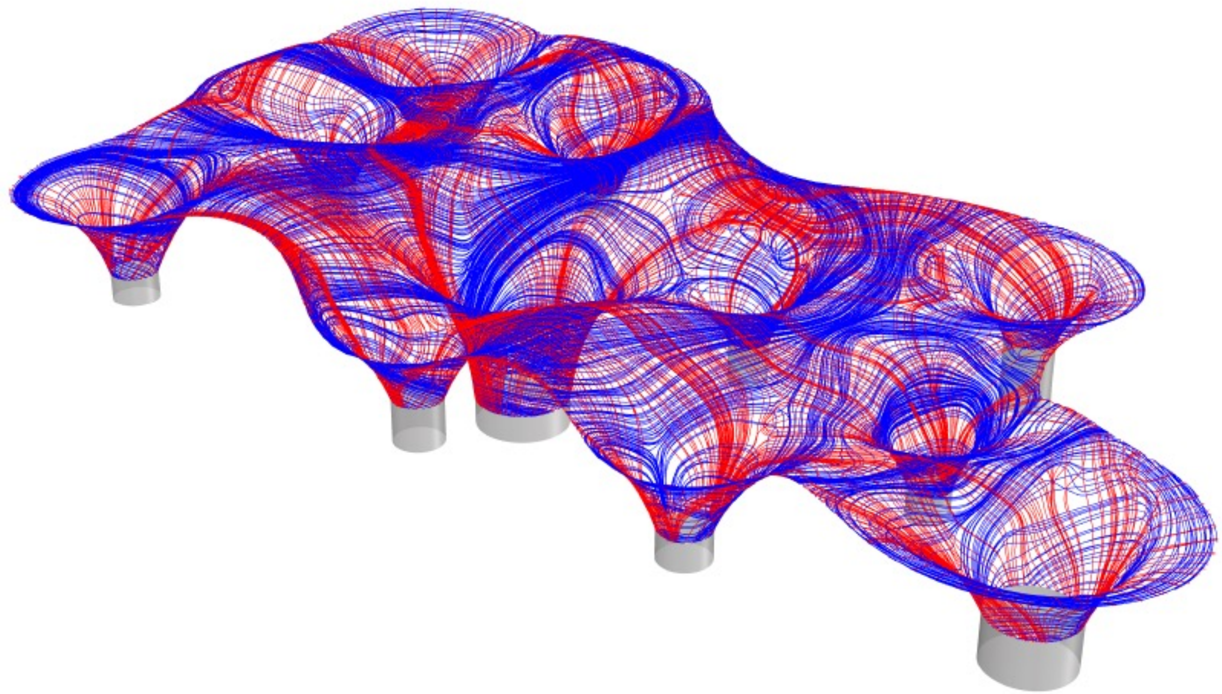


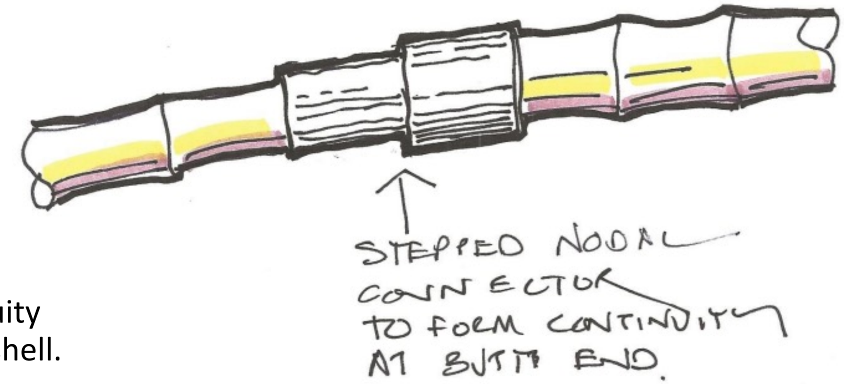
Iteration 5



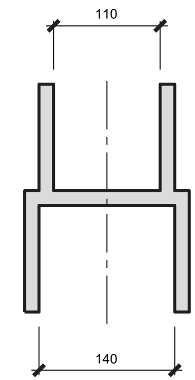
Adding secondary layer with higher density.



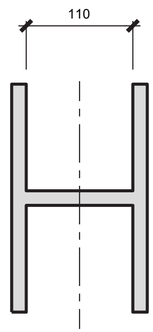




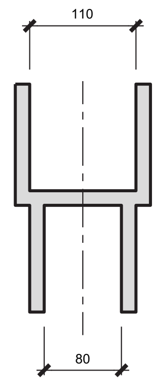
Typical detail to create continuity between the poles in the gridshell.



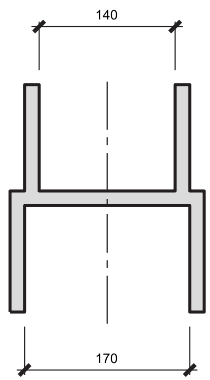
140 / 110
STEPPED



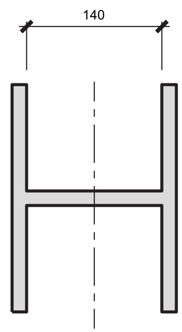
110 / 110
PARALLEL



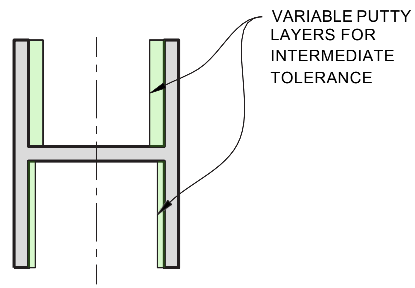
110 / 80
STEPPED



170 / 140
STEPPED

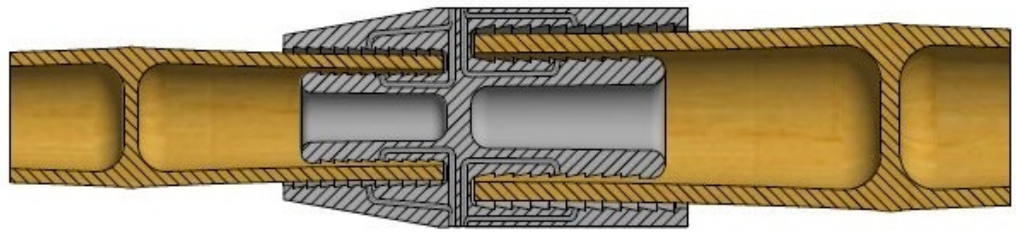


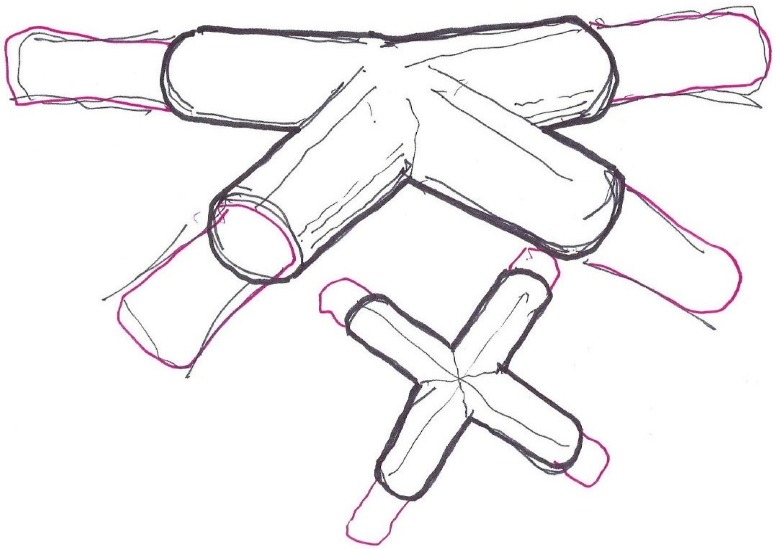
140/140
PARALLEL



CONNECTION NODE VARIANTS


Juniordentist.com





BENDING BAMBOO

Bamboo is traditionally used in its natural straight form for construction throughout the tropical regions of the world.

Traditional bamboo house

This is an example of IBUKU designing the impressive Sharma Springs. Still utilising straight bamboo.

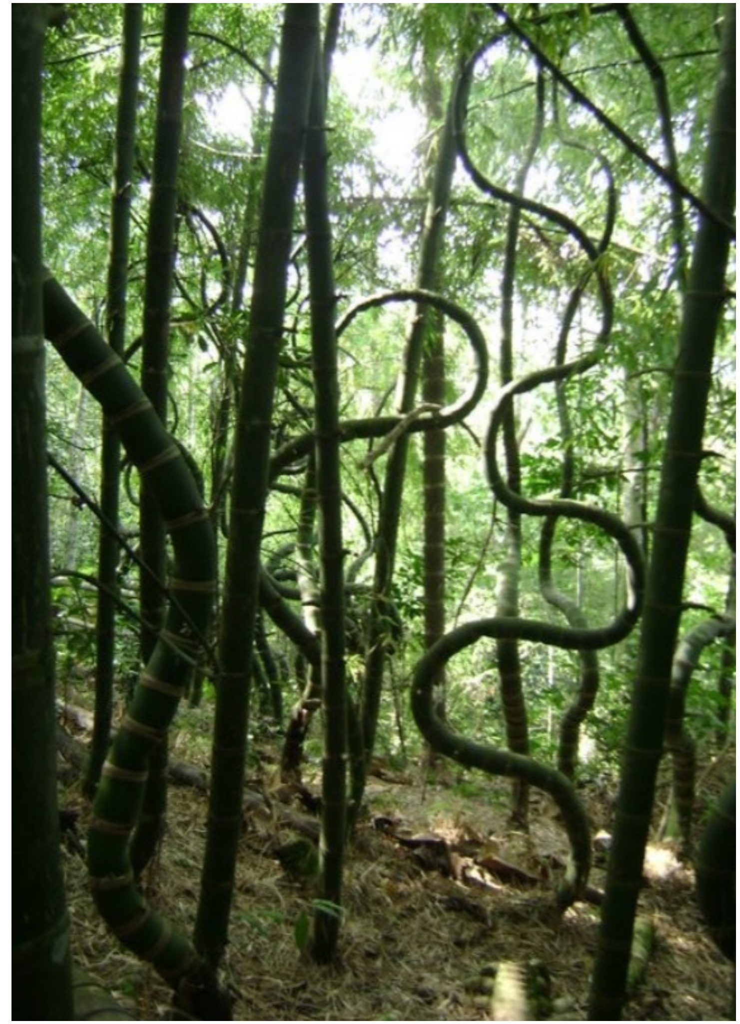
Bamboo can also grow naturally curved. In very dense clumps of bamboo, the culms at the perimeter of the clump tend to bend outwards to reach the sun.

Historically, these bent culms have often been deemed unusable

With the growing interest on 3D dimensional surfaces, an increasing appreciation of curved bamboo has sparked over the last years.

Traditional house from curved bamboo

Trained bamboo



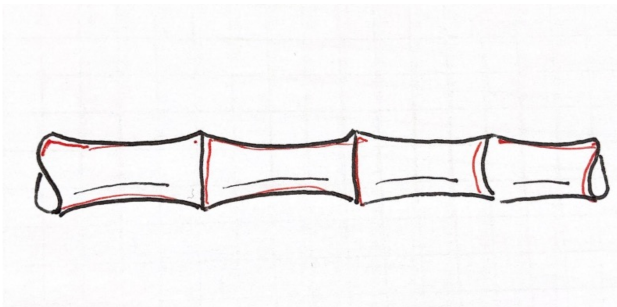
Tallest freestanding bamboo structure in the world,
(Pakistan, 74 metres)

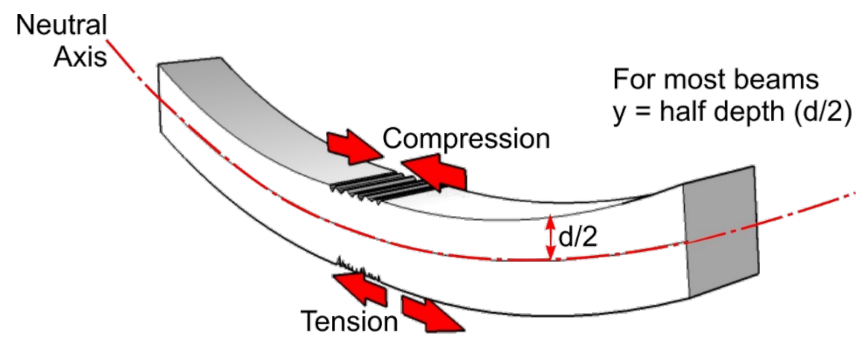
Cold/Elastic bending

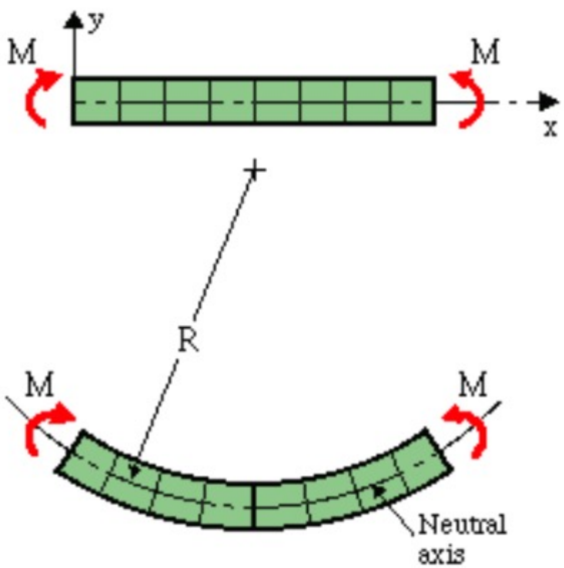
As well as growing bamboo curved, it is possible to physically bend it employing its elastic nature.

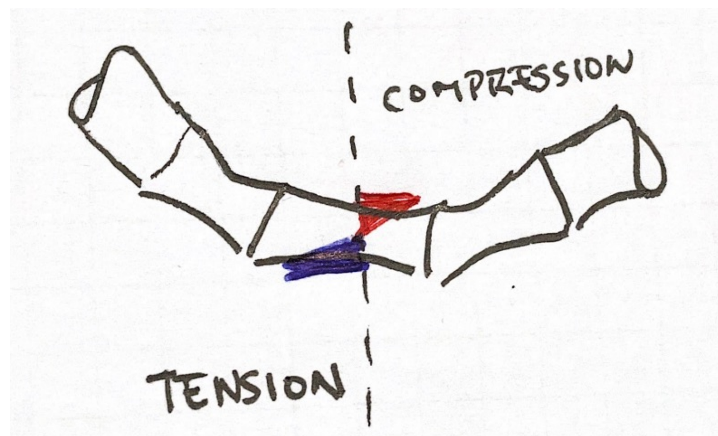
The Moon House, Bamboo Indah, Bali.

This process induces a prestress into the bamboo, reducing its capacity to carry load. The mechanical properties can be measured shortly after bending (instant prestress) or long after bent (creep).

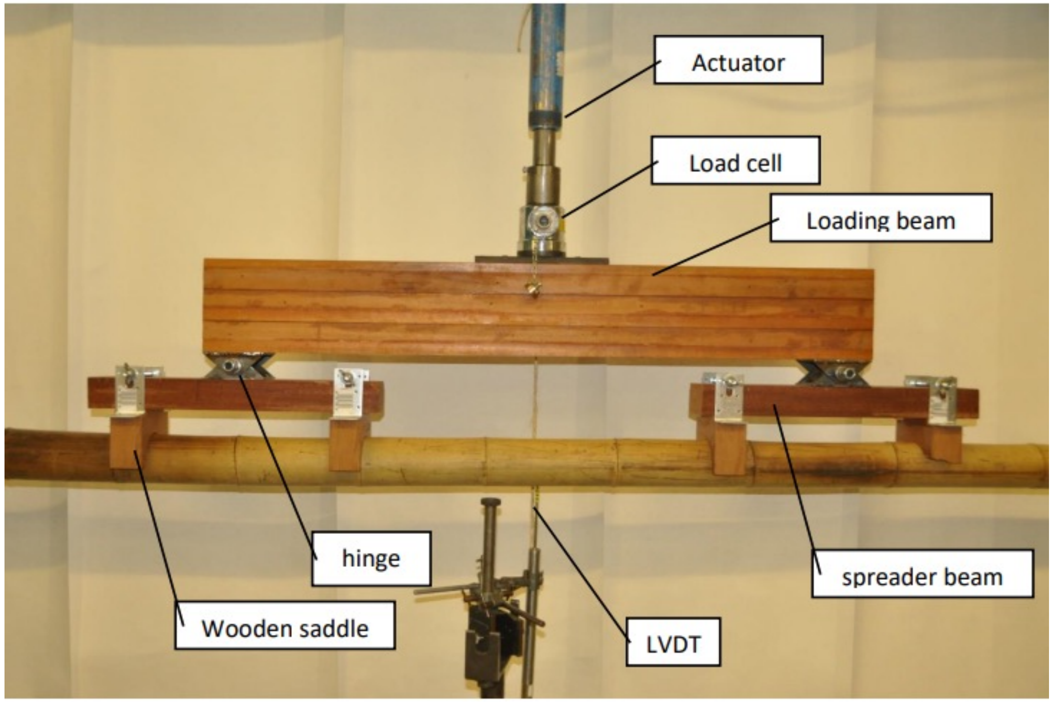


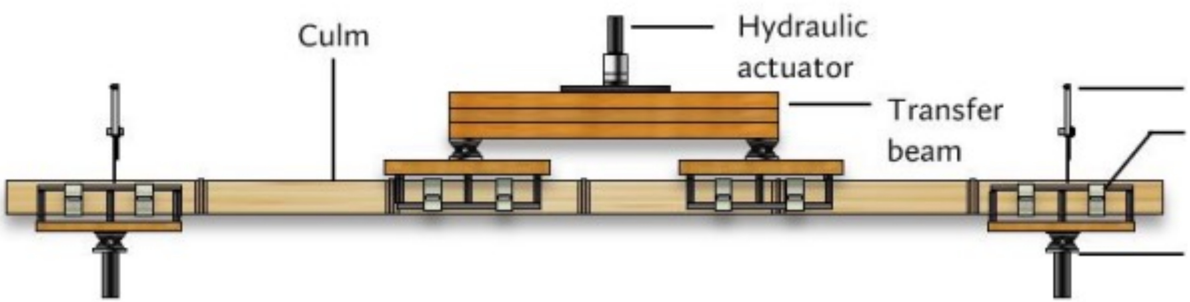






Testing of cold bent bamboo. 4-point flexural test.

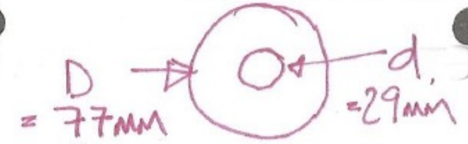




Courtesy of Bamboo U

RADIUS BREAKING = 6550
LOAD BREAKING = 190 kg

D = 77MM, d = 29MM



d = 77 − 24 × 2
= 29mm.

3

MOMENT CAP
= M = PL / 4
= 190 × 4.33 / 4
= 204 KgM

SPAN

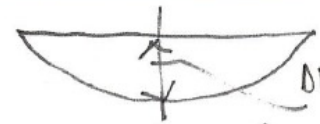
Specimen ref	ct5		
Number of nodes		34	
Time until failure (s)		250	
Location of failure	Left	Middle	Right third
Maximum load (N)/kg		190	
Mass at time of testing (kg)		15	
Moisture content (%)		16	
lenght 1 piece (m)		6,51	
lenght 2 of piece (m)		6,505	
Average lenght of piece (m)		6,5075	3,25375
Distancia del claro (m)		4,33	4330
	Bottom		Top
Diameter 1 at end of piece mm		80	55
Diameter 2 at end of piece mm		75	55
Average diameter end of piece (mm)	77.5MM	77,5	55
wall thickness 1 at end of piece (mm)		21	16
wall thickness 2 at end of piece (mm)		25	17
wall thickness 3 at end of piece (mm)		27	16
wall thickness 4 at end of piece (mm)		24	16
Average wall thickness at end of piece (mm)	25mmt	24,25	16,25

Time (s)	Load (N)/kg		Displacement (mm)
0	45		
	52	95	
	39	135	140
120	24	160	180
180	20	180	250
240	10	190	280
250	**190**		**Falla**

(2)

6500

✓ A



DIP AT FAILURE ≃ 300

RADIUS = $(L^2 + 4d^2) / 8d$
= 6550 mm.

$M = Z \times \sigma$

$Z = \pi(D^3 - d^3) / 32$

$= \pi(77^3 - 29^3) / 32$

$= 42{,}430\ mm^3$

$\sigma = 204e4 / 42{,}430$

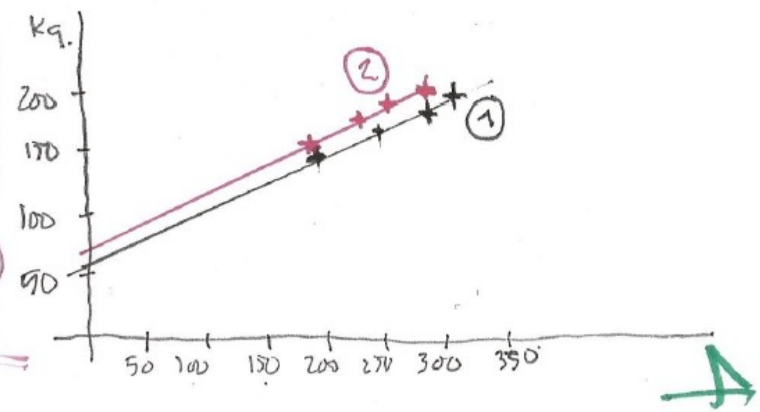
$= 48\ N\ mm^{-2}$

Specimen ref	ct6		
Number of nodes		27	
Time until failure (s)		270	
Location of failure	Left	Middle	Right third
Maximum load (N)/kg		194	
Mass at time of testing (kg)		14,5	
Moisture content (%)		16	
lenght 1 piece (m)		6,43	
lenght 2 of piece (m)		6,45	
Average lenght of piece (m)		6,44	3,22
Distancia del claro (m)		4,33	
	Bottom		Top
Diameter 1 at end of piece mm		75	50
Diameter 2 at end of piece mm		75	50
Average diameter end of piece (mm)	75MM	75	50
wall thickness 1 at end of piece (mm)		18	15
wall thickness 2 at end of piece (mm)		17	14
wall thickness 3 at end of piece (mm)	18.25mt	19	14
wall thickness 4 at end of piece (mm)		19	13
Average wall thickness at end of piece (mm)		18,25	14

Time (s)	Load (N)/kg		Displacement (mm)
0	52		
	39	90	
	45	135	190
80	24	160	230
150	20	180	280
210	14	195	320
270	**194**		**Falla**

(1)

✓ B
6550



NATURAL CULM BENDING TEST

FOS = 2

ALLOWABLE STRESS = 24 Nmm⁻²

RADIUS = 6550

THEORETICAL FROM ANALYSIS = DEAD = 13.5
LIVE = 17.0
WIND = 22.5

A

ZCB Bamboo pavilion in Hong Kong – SUP atelier and Kristof Crolla

Bamboo Gridshell for the UNAM (National Autonomous University of Mexico) – Designer: Armando Moreno

Bamboo canopy by DZ architects and associates

Riverbend House by IBUKU at Bambu Indah, using splits bundles

Lidi Bundles

Three-dimensional curvature can be achieved with this technique.

Low tech split beams

Heat bending bamboo

Heat bending investigation into the material composition of bamboo has shown that on heating, the internal structure undergoes a physical change that allows for bamboo to be bent plastically. Once it cools down it fixes into the new curved form.

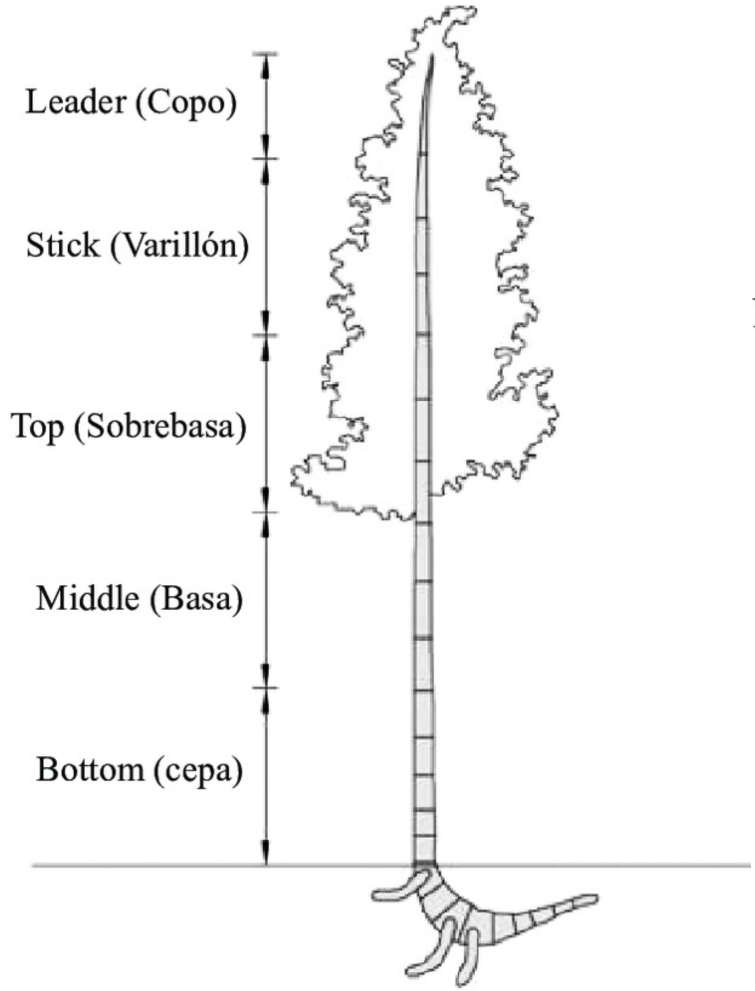
Source: BambooU

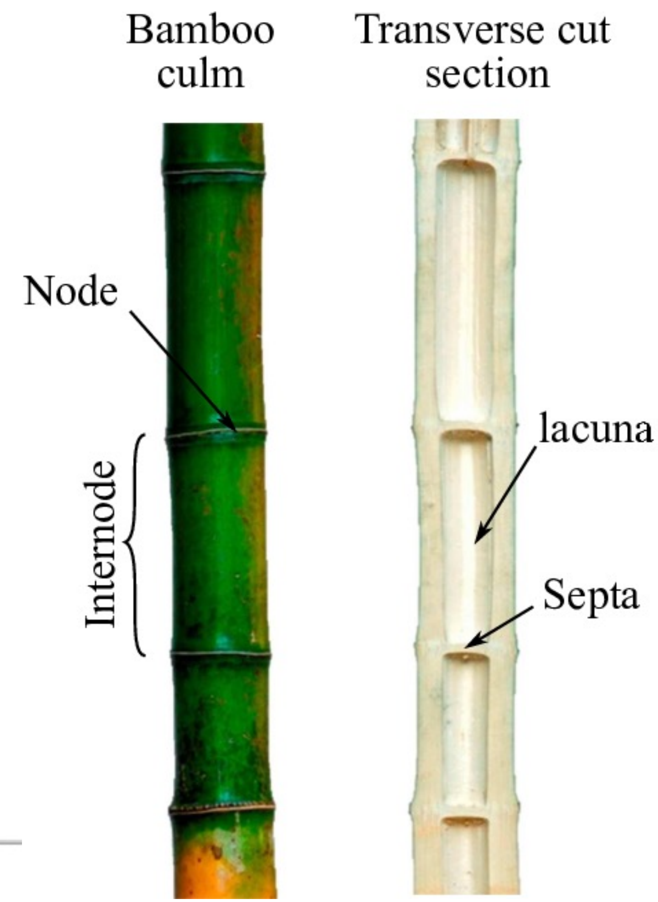
Anatomy of bamboo

Bamboo grows at its full diameter from birth, so as it grows in height the girth does not change, as a tree does.

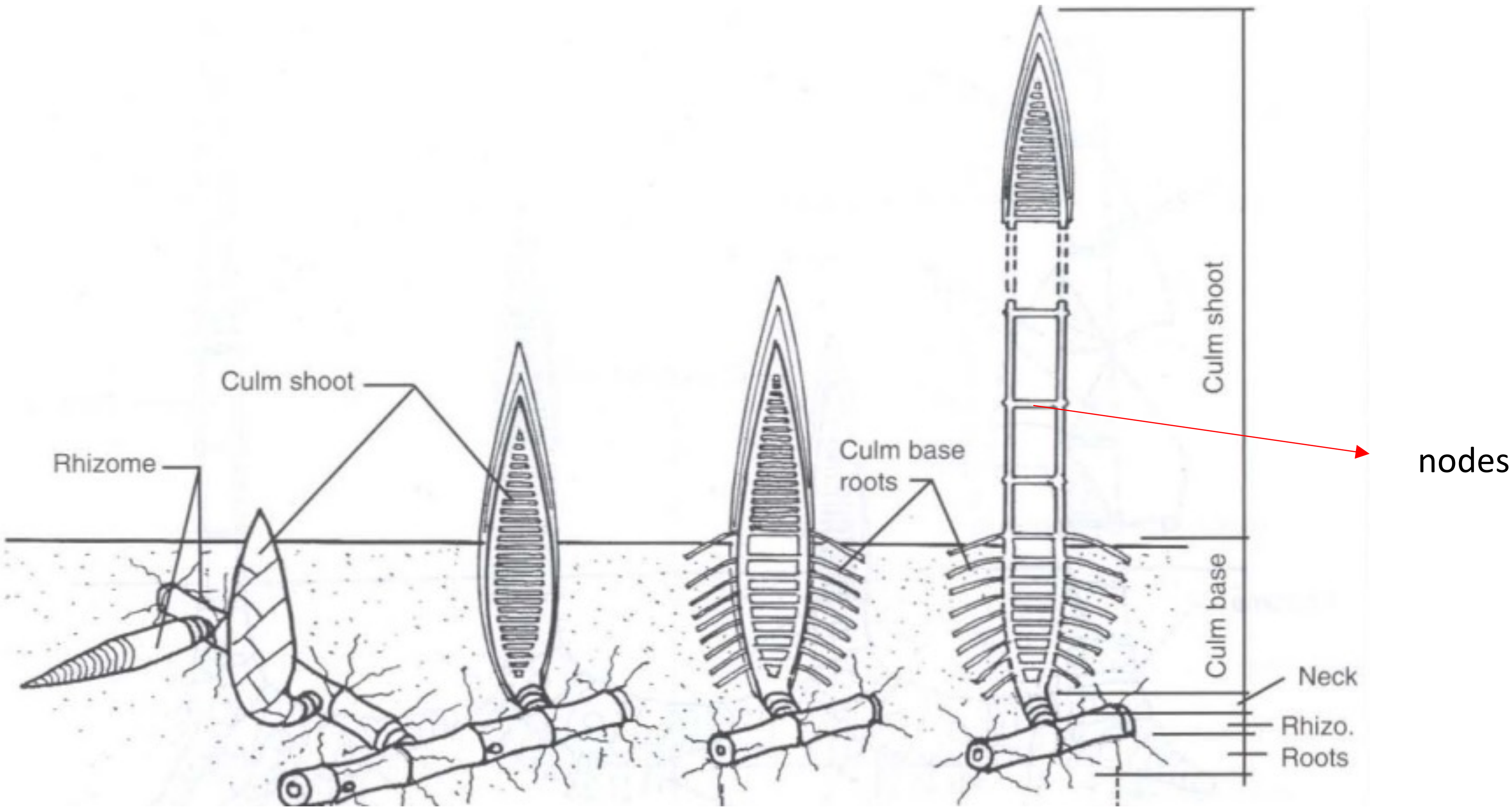
This has a fundamental effect on its properties.

In the growth, from the rhizome, the bamboo develops a series of diaphragms that fully form within the culm shoots and base.



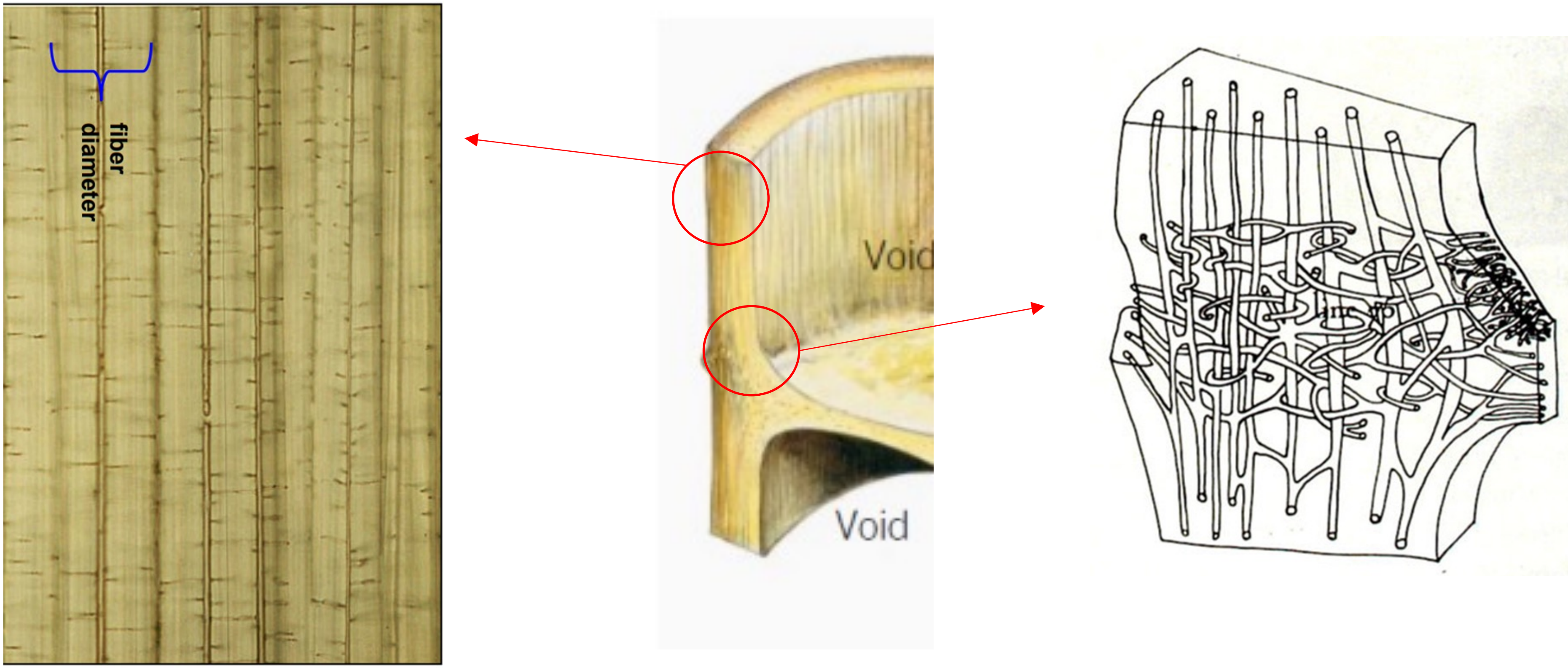


Below, the development of the diaphragms as the culm grows.



Fibres at the internodes

Fibres at the nodes

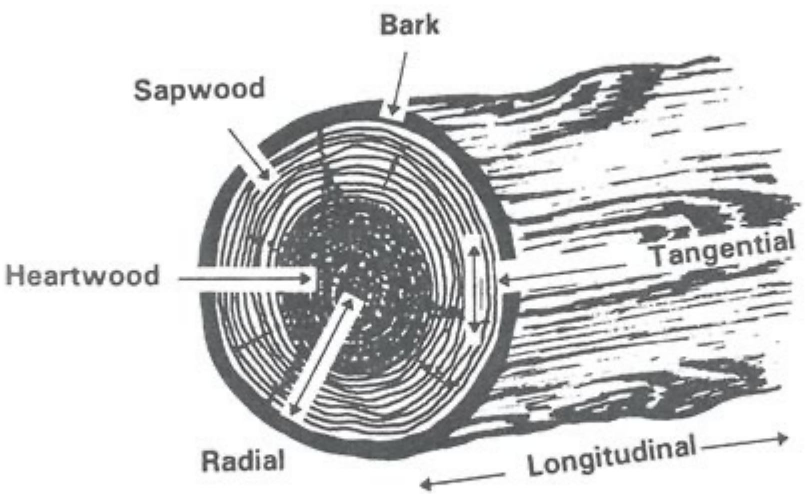


Bamboo fibres run only longitudinally. It is the parenchyma matrix that links all fibres together.

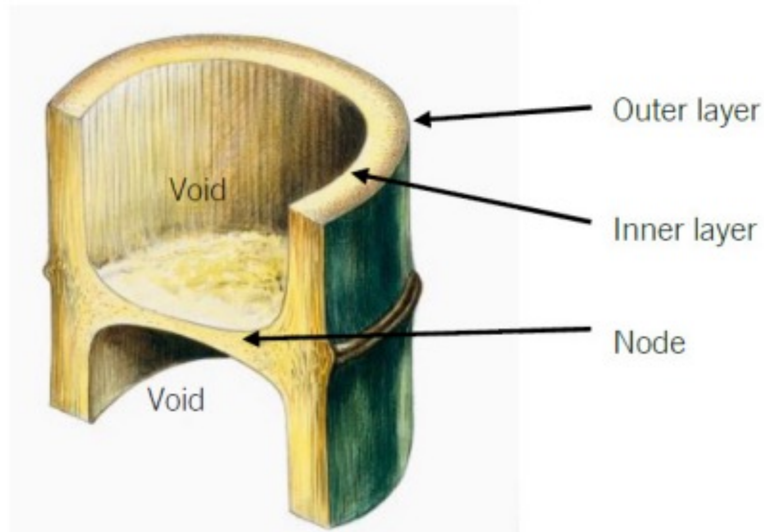
At the nodes (diaphragms), horizontal fibres bounce off the longitudinal fibres and also form loops around the other fibres.

Anatomy comparison between wooden tree and bamboo

Wood

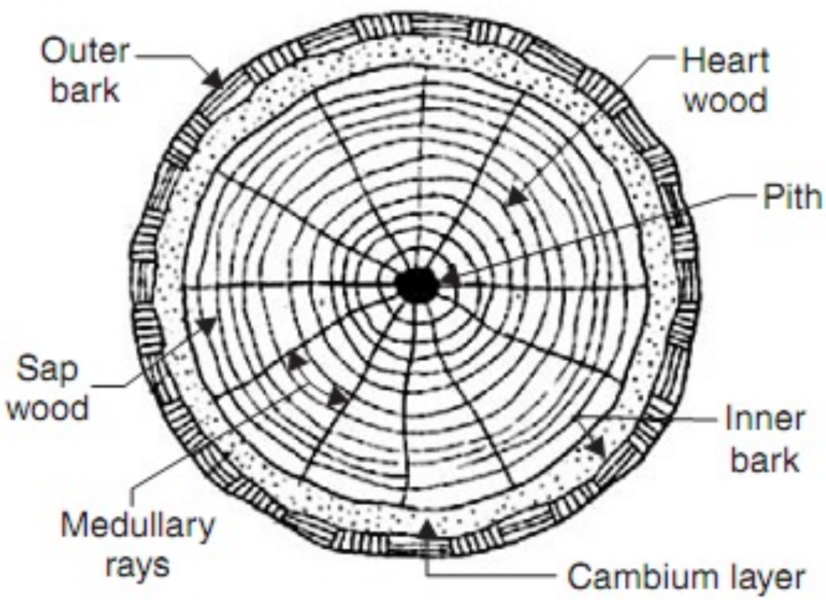


Bamboo

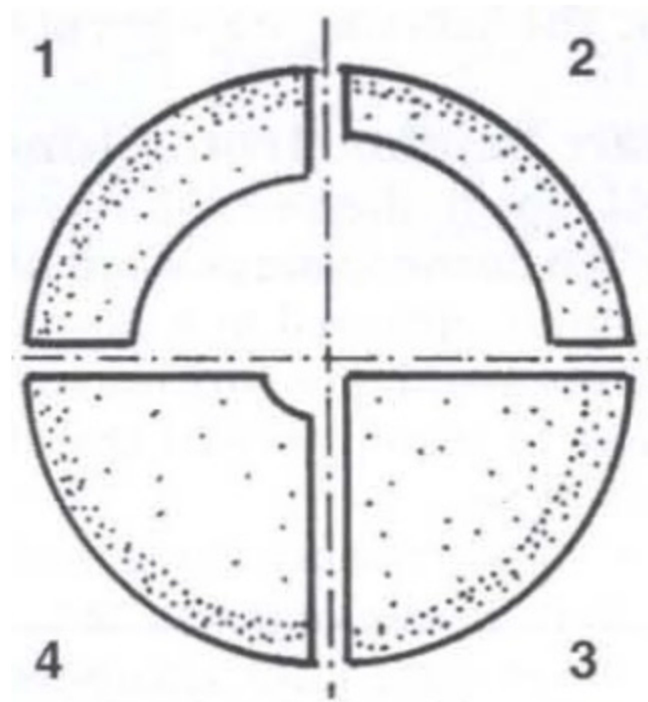


Anatomy comparison between wooden tree and bamboo

Wood



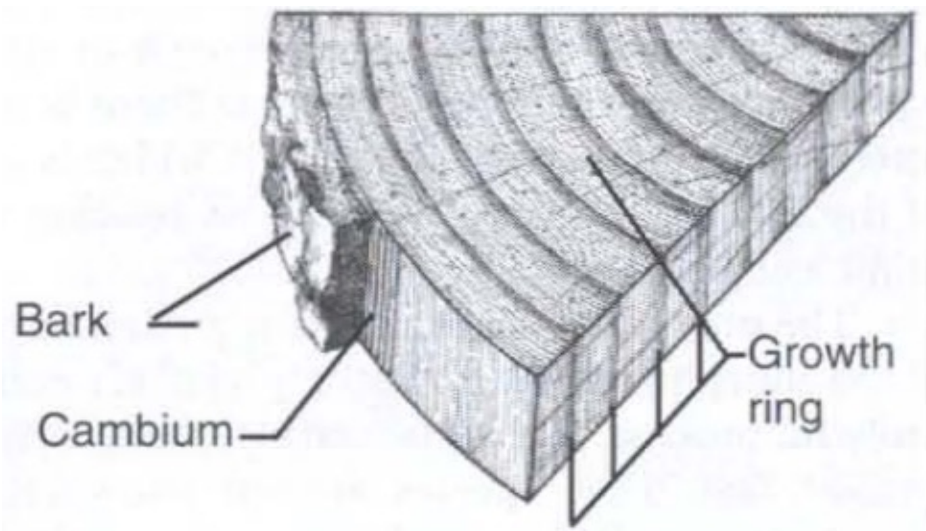
Bamboo



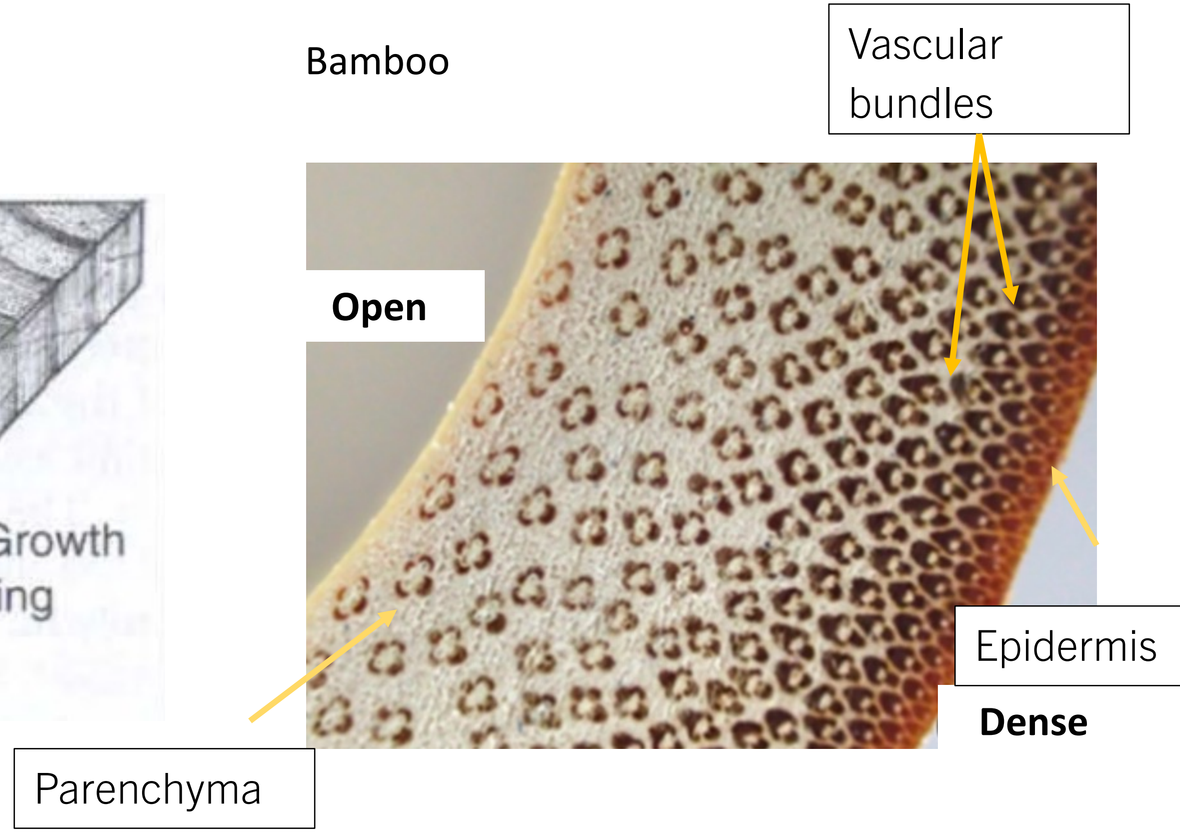
1. Guadua Agunstifolia
2. Guadua cebolla
3. Dendrocalamus strictus
4. Guadua amplexifolia

Anatomy comparison between wooden tree and bamboo

Wood



Bamboo



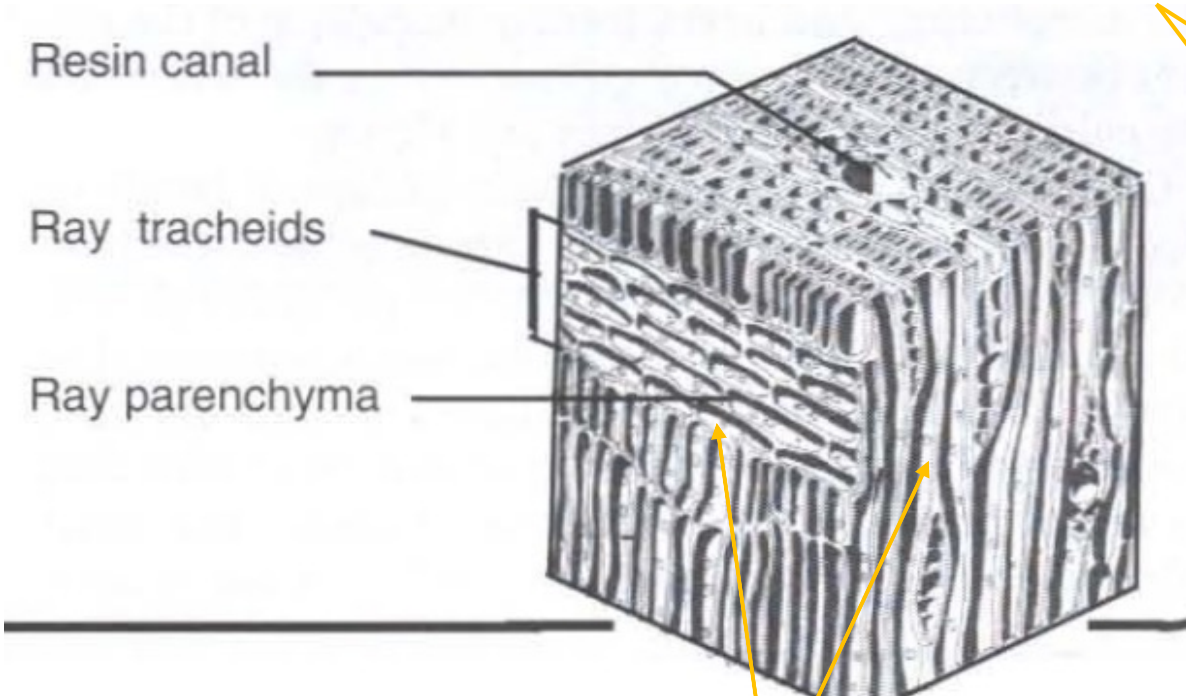
The culm wall consists of a series of vascular bundles containing longitudinal fibres. These are surrounded by Parenchyma. The former provides strength while the latter provides ductility. The vascular bundles increase in density towards the outer wall.

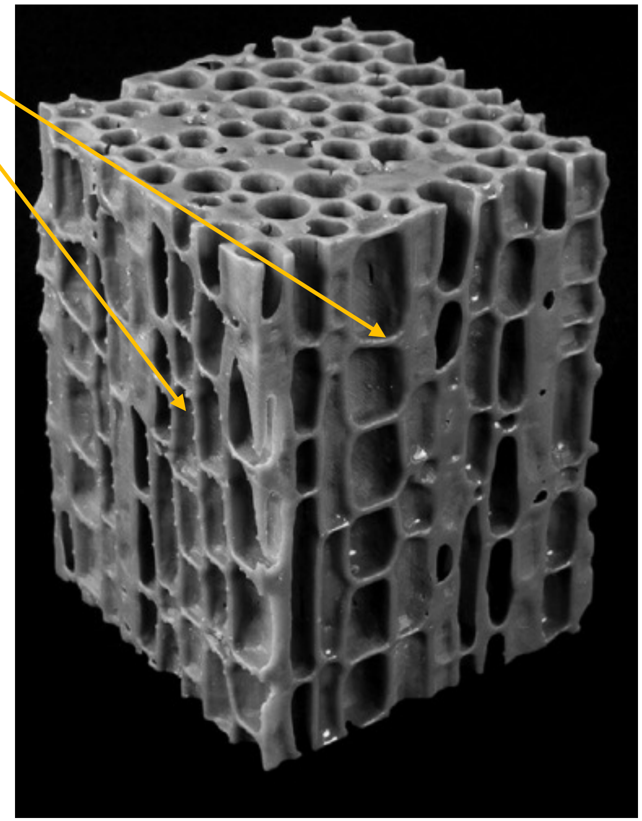
Orientation of the parenchyma

Wood

Bamboo

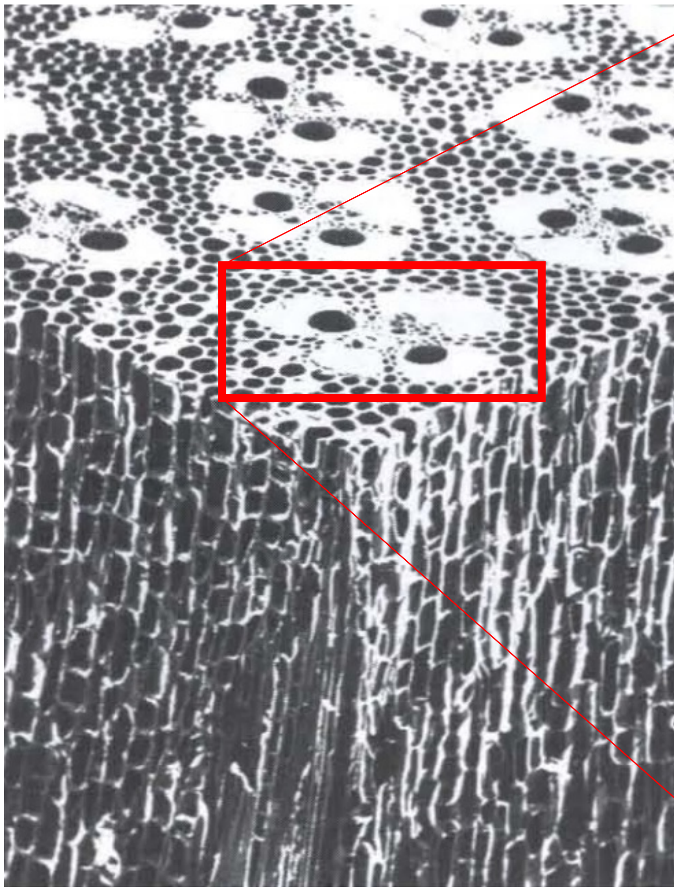
One direction



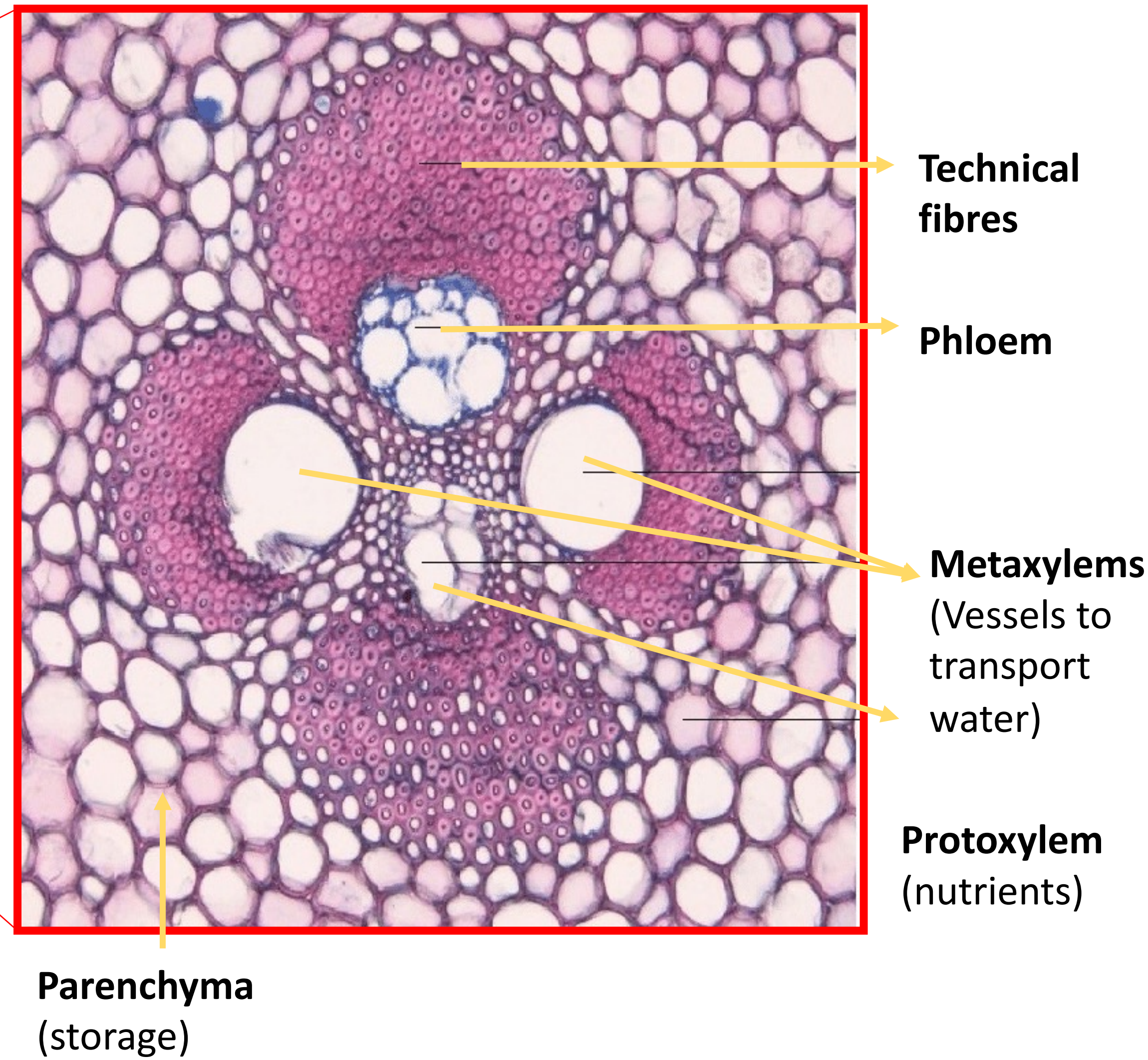


Two directions

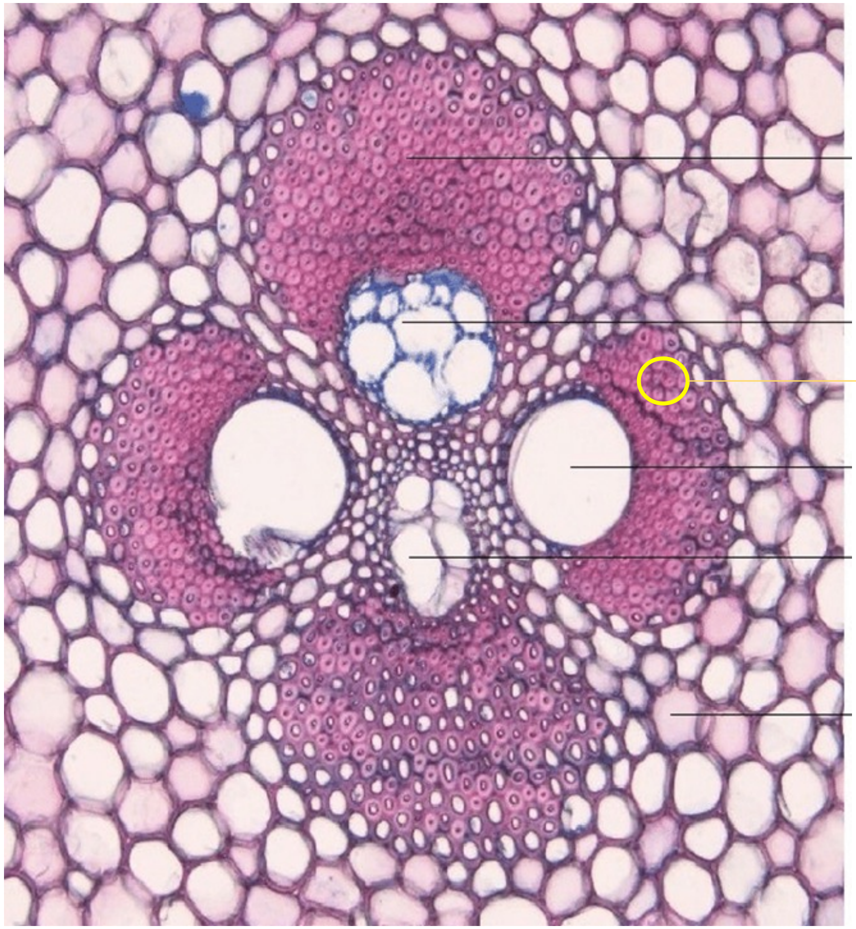
Bamboo molecular structure – transversal cross section

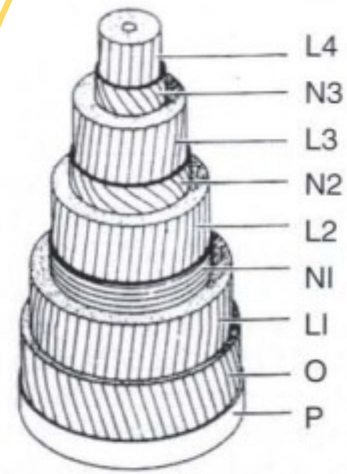


Isometric view of the culm wall



Bamboo fibre: dense polylamellate structure

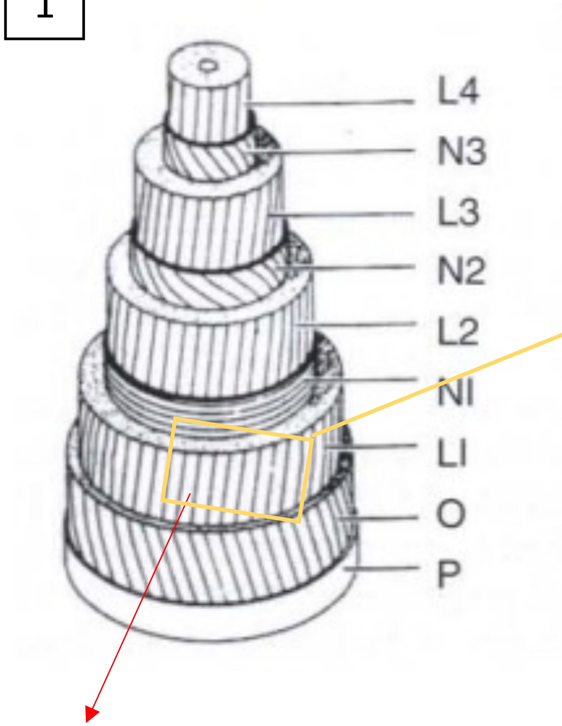




(b)
Bamboo fiber

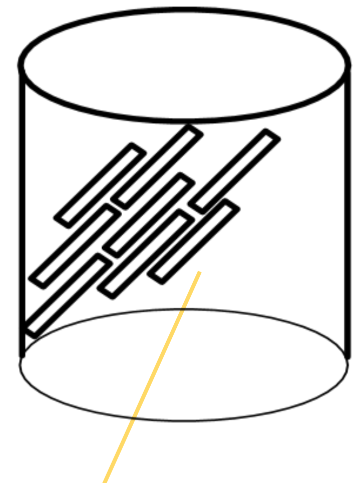
Zooming into the fibre structures

1

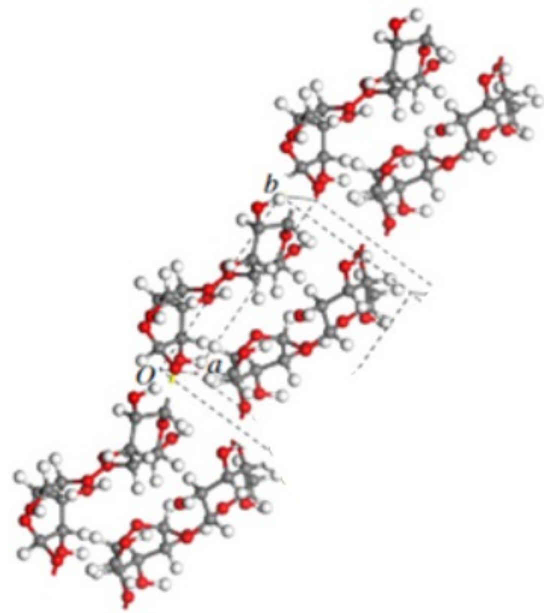


The fibres in each layer
are orientated at a
particular angle

2

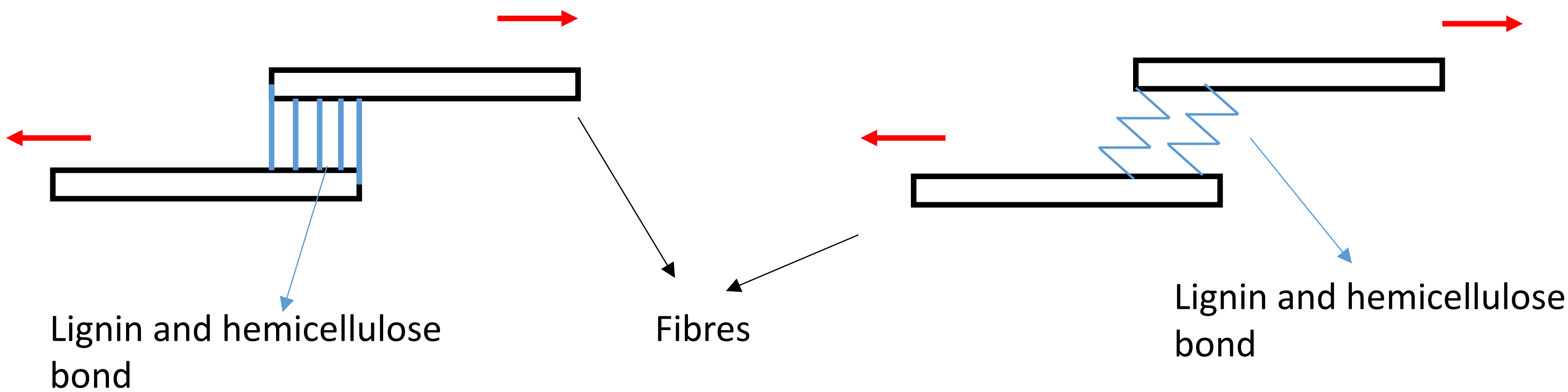


3



Room temperature and low moisture content

≈150 degrees and high moisture content



Very stiff bond, if the fibres are pulled apart the cell structure will break.

The bond acts like a spring, accepting deformation and allowing fibres to past each other. Once it cools down it sets into the new shape.

Heat Bending:
Recommendations

- The bamboo should be wet or green. MC around 25%.

- Species with large wall thicknesses are recommended to avoid buckling of the wall. It is not needed to fill the culm with sand if the wall is thick enough.

Guadua Velutina or Madake bamboo are examples of this.

Heat bending: Process

1. The bamboo should be brushed with palm or cooking oil. This helps distribute the heat along the culm. Water evaporates at 100 degrees which is not enough to heat bamboo polymers.

Heat bending: Process

2. Start applying heat. Use torches with reasonable flame spread.

Apply heat evenly across the culm, and at regular intervals, with special emphasis on the area that will be in compression.

Monitor the temperature.

Heat bending: Process

3. When the culm has reached a temperature of around 150 degrees, start slowly bending the culm. Keep applying heat at regular intervals but do not go over 150 degrees or the bamboo will charr.

Do not try to bend the bamboo when it opposes too much resistance, if bent too drastically the internal structure will be damaged.

One should start with the thickest part of the culm.

Heat bending: Process

4 .Once the desired curvature is met, the culm can be let to cool naturally in sheltered conditions, or it can be cooled with a water soaking jacket.

Process variations:

Multiple poles bending at once with heat and leverage on stationary fixtures (James Wolf)

Resulting bent poles



Blowtorch bending of large diameters by BambooU

Gridshell structure built in Mexico by Jaime Pena using blowtorch from small diameters

Achieving small radius of curvature