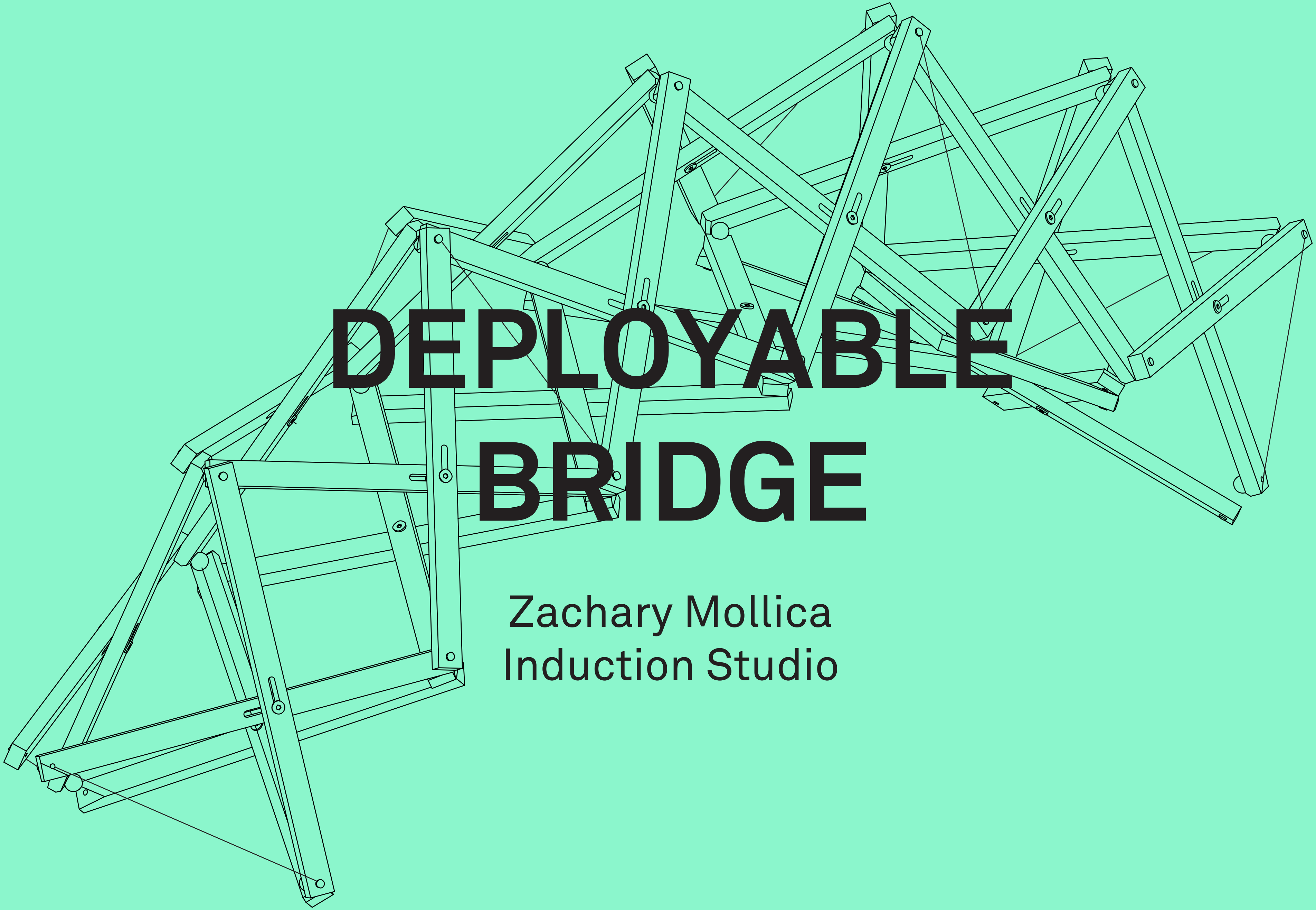


DEPLOYABLE BRIDGE

Zachary Mollica
Induction Studio

Introduction

PROJECT BRIEF

The goal of this project is to use parametric modeling and physical making as a means of analyzing an existing construction technique in order to reapply it in a non-conventional way.

Along with the digital tools created through this process, the aim is to produce a furniture scale physical prototype displaying the ideas developed.

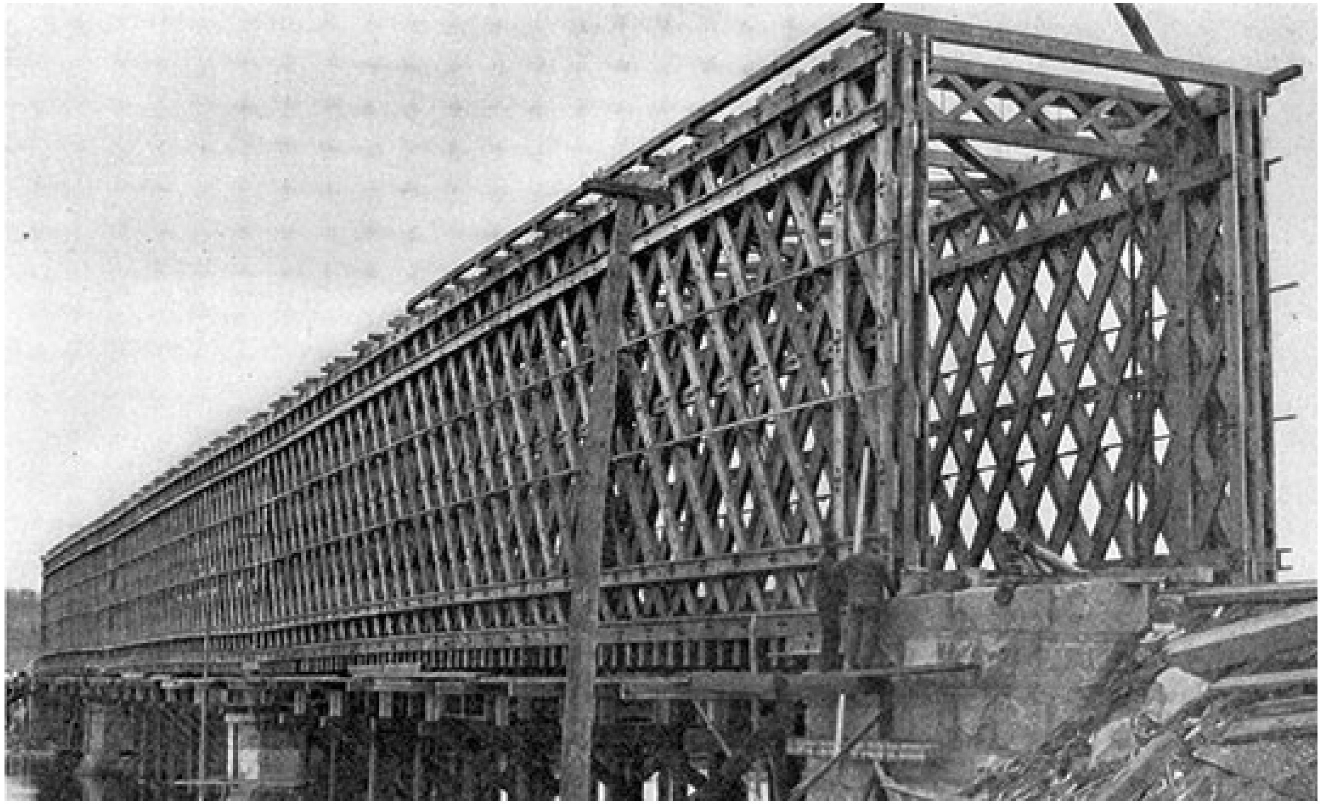
SELECTED TECHNIQUE: LATTICE TRUSS BRIDGE

Used for foot and vehicle crossings, the lattice truss is a type of truss bridge which employs a large number of relatively small diagonal members to carry load. Longer members are attached at top and bottom to prevent pin joints from allowing the bridge to change length under load.

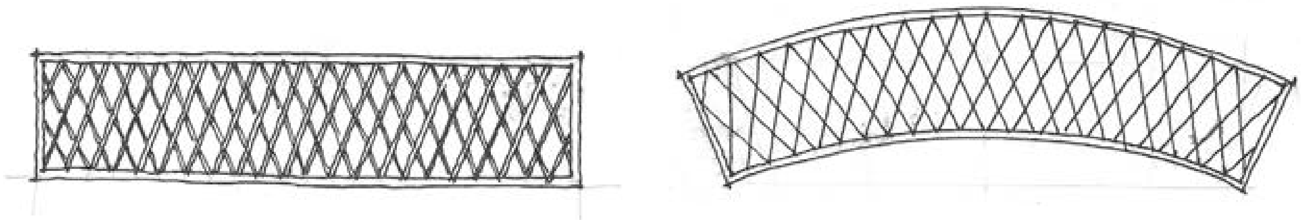
Attributes

- Small members work together to create span
- Few unique members with most members of approximately equal dimensions
- Easily constructed/deployed

Intent
To use parametric modeling in Grasshopper together with physical prototyping to create a non-conventional application of the lattice truss bridge which maintains its main attributes.



Lattice truss rail bridge



Initial sketch suggesting new approach to lattice bridge

Early Research

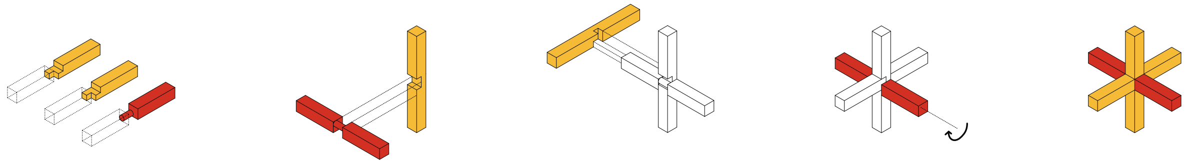
RIGID JOINTS

<u>Lap Joint Lattice Bridge</u>
In an attempt to remove bottom and top chords, Grasshopper is used to generated a series of member lengths and a pattern for lap joints.

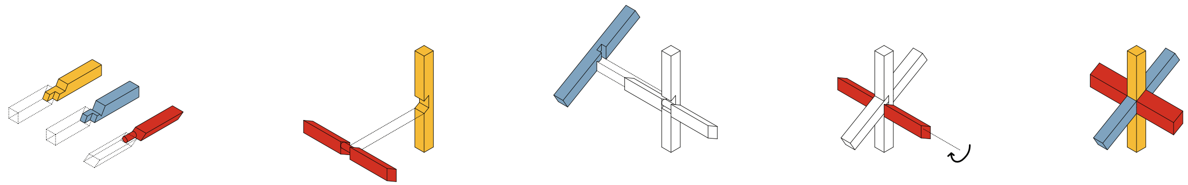
Joints resist forces which would expand/contract structure. Initial Grasshopper definition generates a range of member lengths in order to achieve curve.

<u>Chidori Joint</u>
A few joints which allow 3 pieces of material to pass through each other considered as a means of moving towards three dimensions.

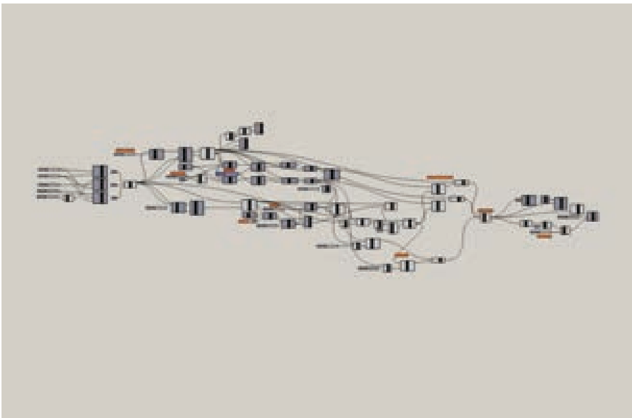
Standard Chidori joint works for three pieces at right angles. In order to connect non orthogonal substantial amount of material section is removed.

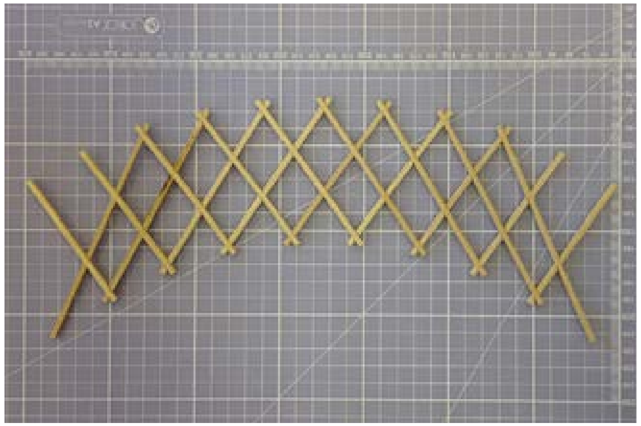


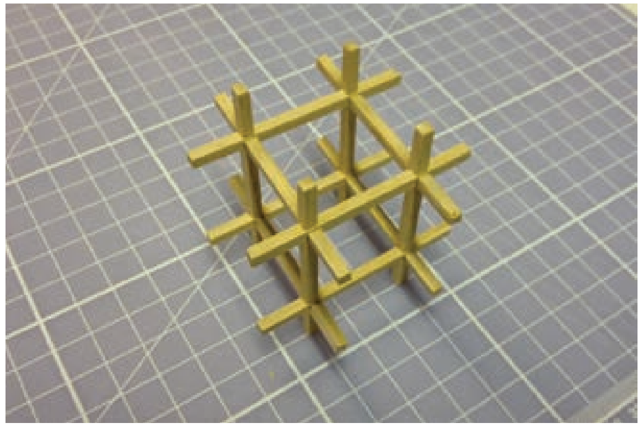
Traditional chidori joint



Reworked chidori joint







OPERABLE SCISSOR JOINT DIAGRAMS

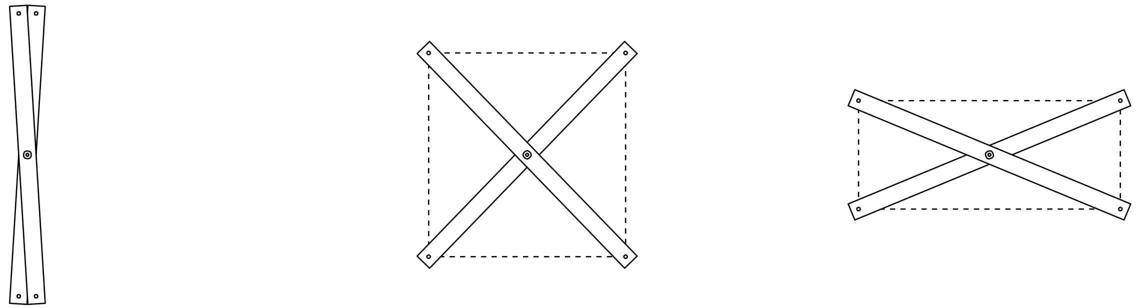
As well as fixed joints, looking at ways of developing pin/scissor joints already present in traditional bridge to create deployable structure.

Rotation About Middle
Unit opens equally, constantly forming a rectangle between its four end points.

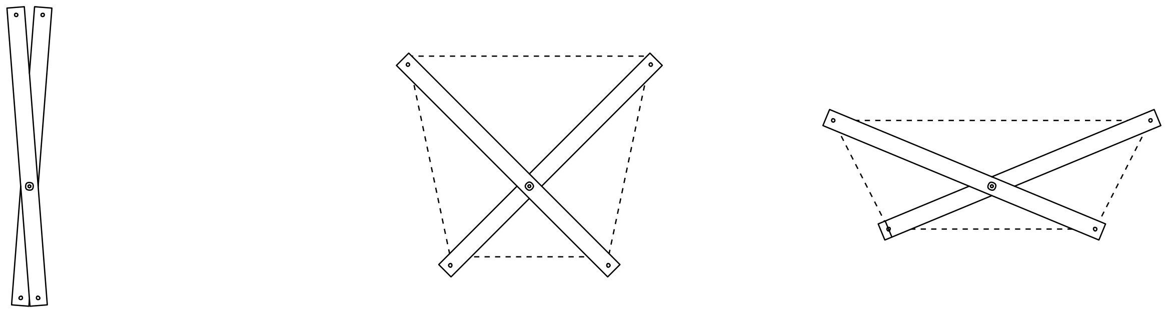
Offset Rotation Point
Offsetting the rotation point causes the end points to form a trapezoid, the steepness of which increases with the angle between members.

Due to different lengths from centre of end points, units are unable to completely collapse and will remain a small version of their expanded trapezoidal shape.

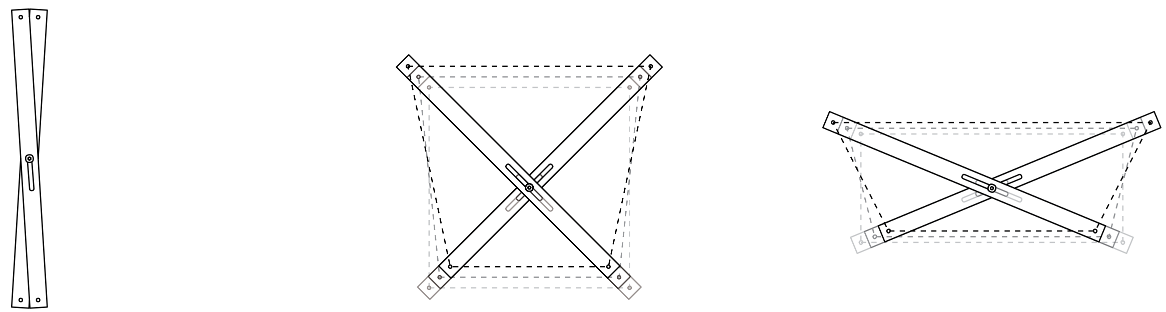
Slotted Rotation
By opening a slot between the centre and offset holes, the two members are able to collapse completely while being able to achieve the final trapezoidal shape and all others between.



Rotation about middle



Offset rotation point



Slotted rotation

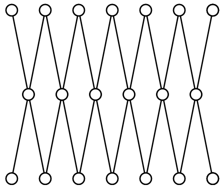
CONNECTING SCISSOR MODULES

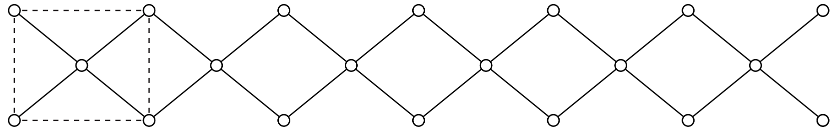
Joining multiple units together, rectangles and trapezoids from previous page determine expanded form.

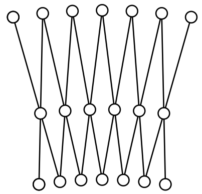
Units with a centre rotation point will always expand along a linear path.

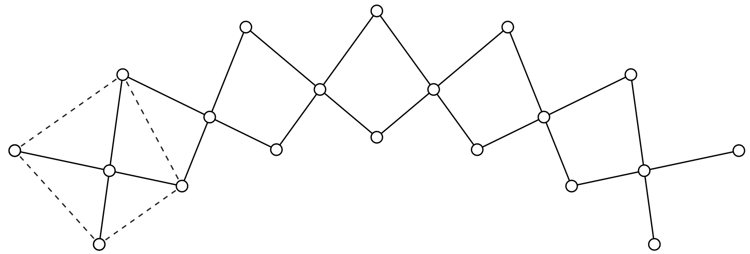
Those with offset rotation points will be able to achieve an arced path.

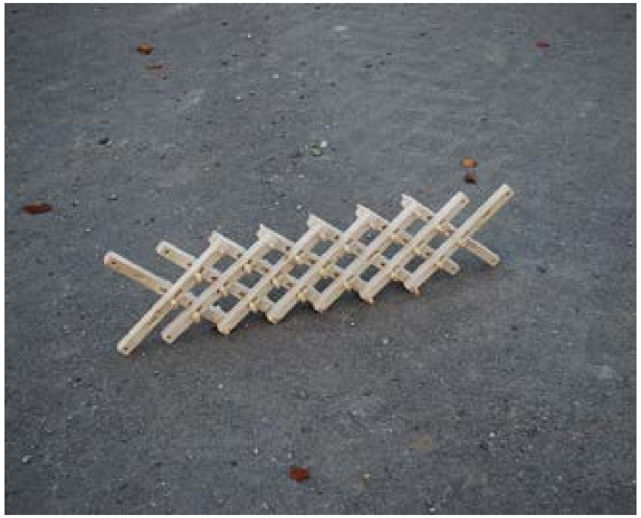
Introducing slots will allow the object to expand in both a linear and arced path as shown in the model below.











Development Models

Along with Grasshopper analysis, researching precedents for deployable structures, Chuck Hoberman's are of particular influence. As well as examining the paths the they expand along, exploring the need for a separate node element.

As well as including node elements, most precedents are restricted to linear or single arced paths.

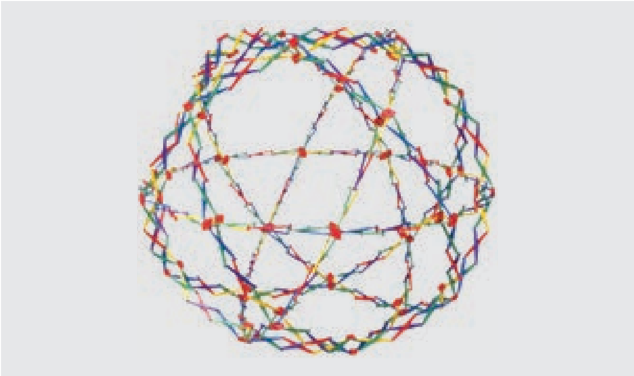
Working continuously between Rhino/Grasshopper and physical making in an effort to develop models which deploy in 3 dimensions

WOODEN NODES

Skewed Rectangular prism
4 two dimensional modules connected in a square arrangement. Member's slots can all be arranged in the same direction or with one axis reversed (shown).

Skewed Pyramidal Prism
3 two dimensional modules connected in a triangular arrangement. Member's slots arranged in same orientation.

Results
Rigid nodes constructed out of wood with pins prone to breaking due to pressure along wood grain. If created in another material, pressure will continue to cause problems for motion.



FLEXIBLE NODES

In an attempt to solve problems of rigid nodes, various options for more flexible node explored - including bent steel bolt, hydraulic hosing, string.

On their own, most remain either too rigid or too loose.

DIFFERENT BOTTOM MEMBERS

Experimenting with uneven expansion by using removing slot pattern from one side.

CONNECTING MODULES

Using more flexible connections understanding how multiple units interact with each other in motion.

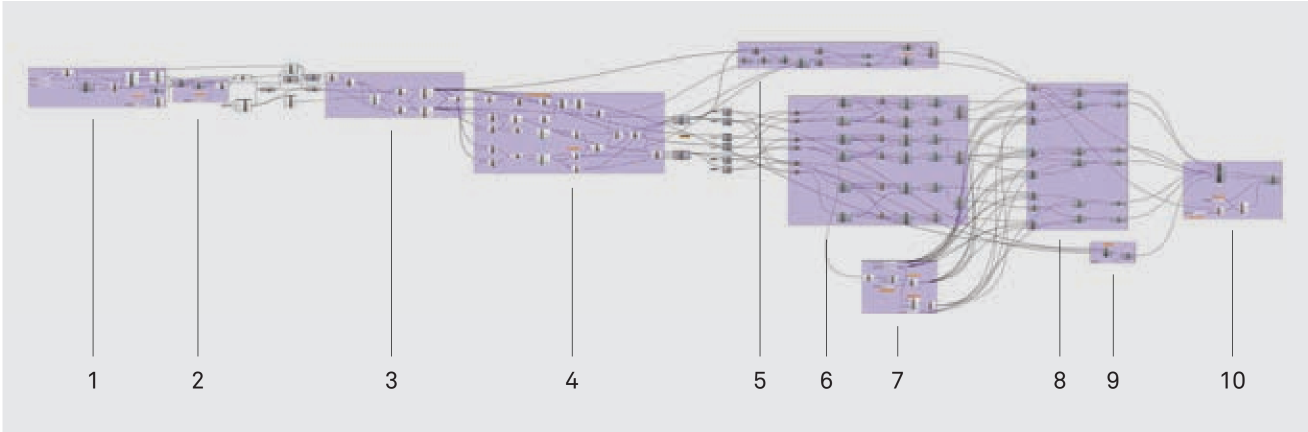
As units deploy, modules on the same side come out of plane with each other - will need to be addressed in final.

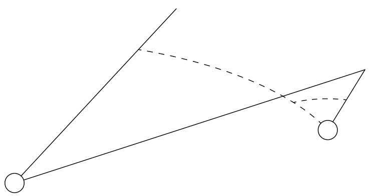
Grasshopper Definition

Final iteration of grasshopper definition. Primary difficulty in both 2 and 3 dimensions was establishing proper trigonometry to prevent Grasshopper from stretching/shrinking members to fit as structure expands/contracts.

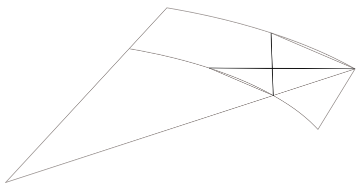
STEPS IN DEFINITION

1. Base geometry for arc established
2. Member length input
3. Cross members drawn in 2 dimensions
4. Trig calculations to maintain lengths in 3 dimensions
5. Orienting 3 new planes to the new faces
6. Drawing geometry in 3 dimensions
7. Inputs for member section
8. Creating depth between pieces
9. Adding Spheres
10. Input for number of modules and overlap

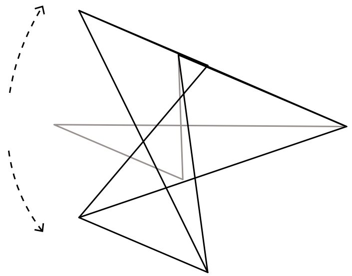




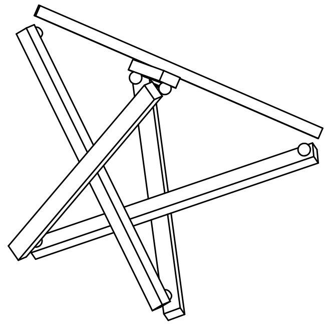
Definition is based on two related arcs. Larger arc sets the inner radius of the structure while small arc and its arm control the member length/angle



With module width and height determined from small arc, members drawn - as either arc moves members remain the same length



Members are rotated in both directions and a third plane drawn. Angle of rotation ensure all 6 members are the same length.



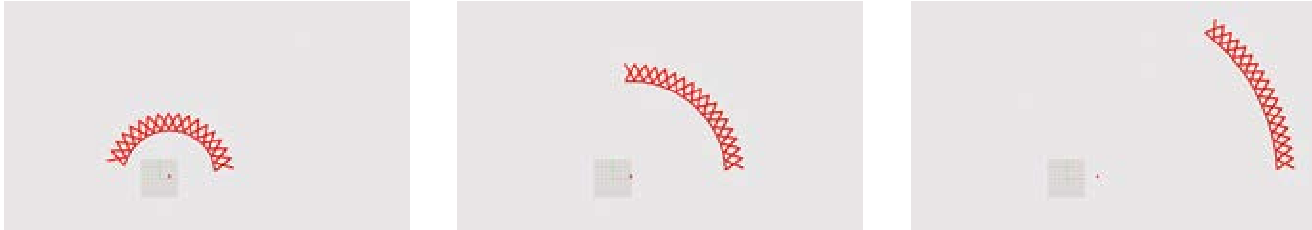
With underlying geometry established in, members are given drawn with their thickness and offset from each other.

DEFINITION INPUTS

Using controls built in to Grasshopper definition, able to output a range of models (next page) for different applications based on the following direct inputs as well as a number of outputs measurable from within definition (eg. Overall extended height/span)

1. Inner Radius
2. Angle Between Members
3. Member Length
4. Number of Modules
5. Overlap of Modules

1



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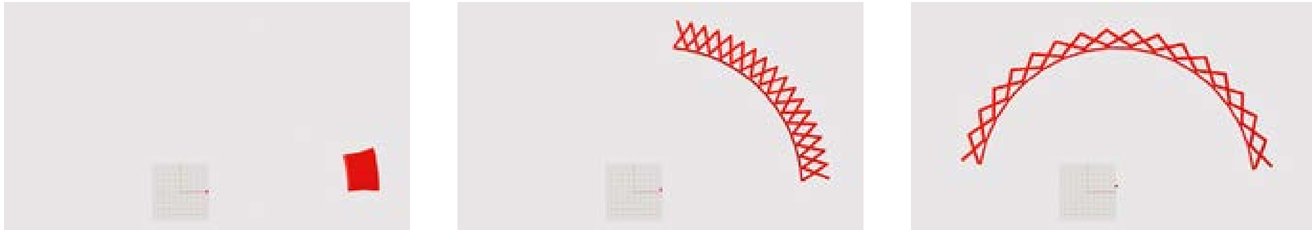

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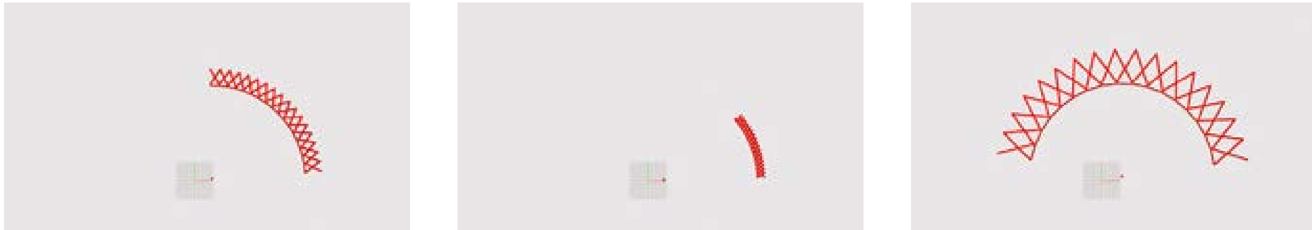

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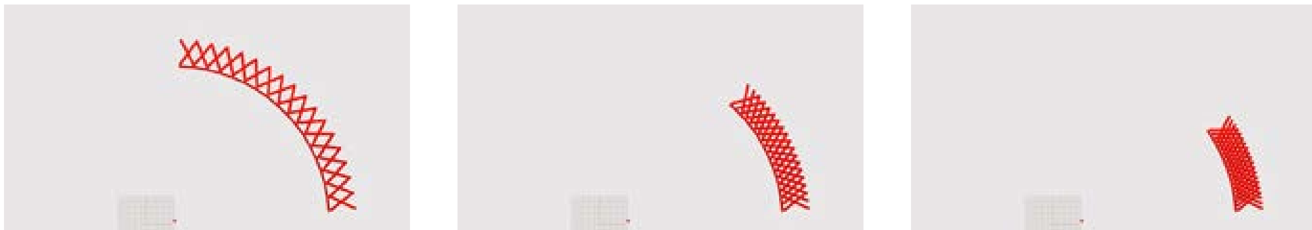
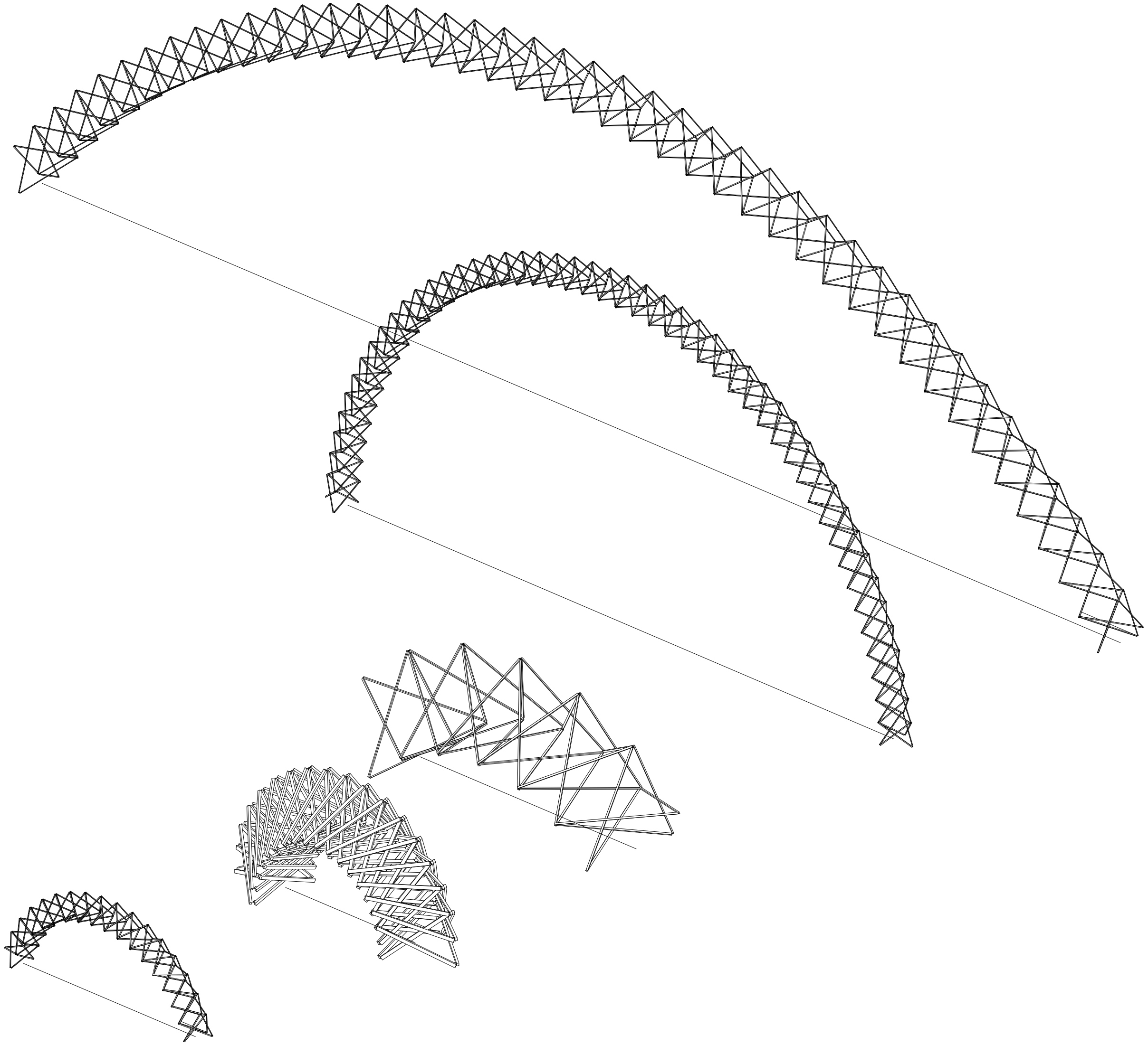


OUTPUT VARIANTS

Grasshopper definition is capable of producing a range of variations based upon different spans, member sizes overlaps etc.

Current definition is limited to expansion along a single line or arc which is consistent throughout the structure.



Output for Prototype

Using controls built in to Grasshopper definition, able to output model which is based on a selected span and height as well as the size of materials available.

Some of these are entered as direct settings in Grasshopper while others are accurately measurable before baking into Rhino.

DIRECT INPUTS

Member Length
55.0 cm

Member Section
3.2 cm x 2.0 cm

Radius of Sphere
1.1 cm

Number of Modules (6 members each)
6

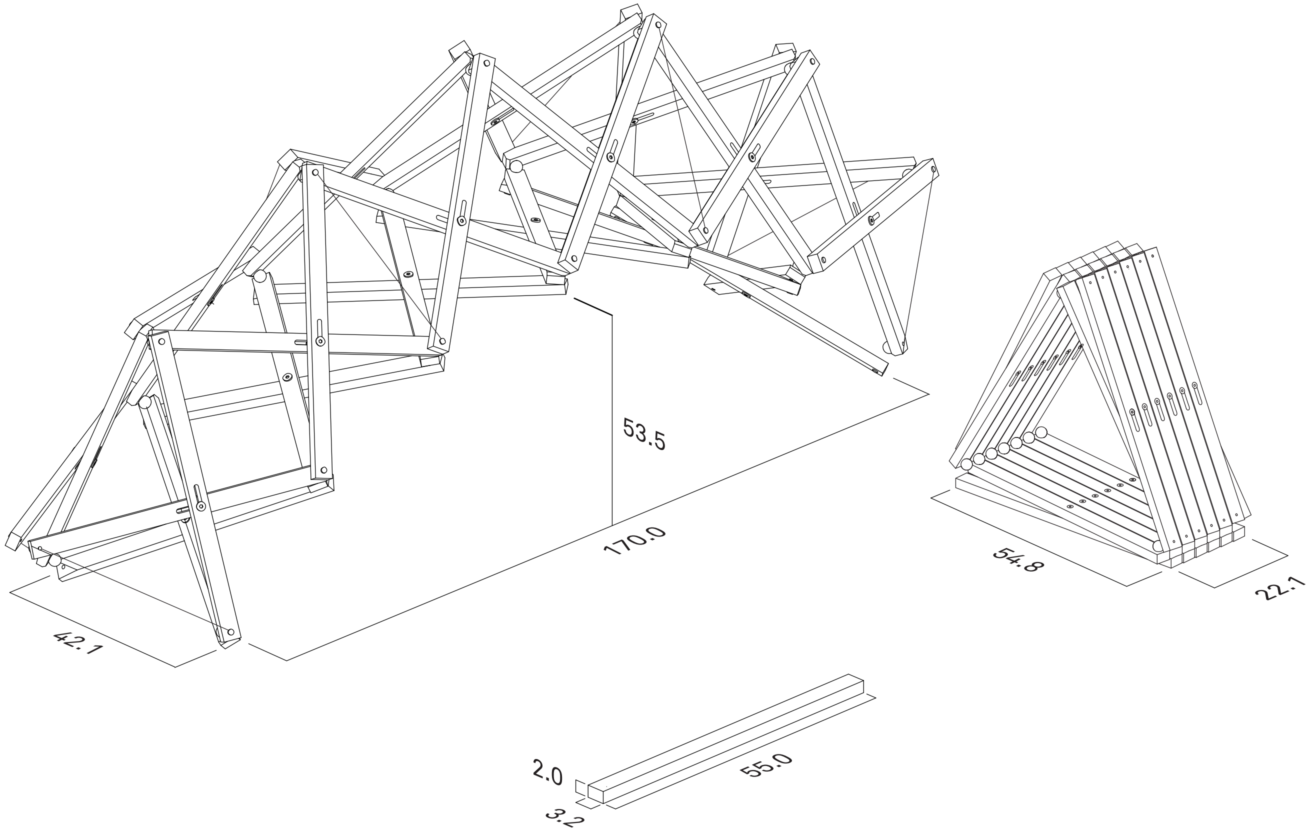
Overlap of Modules
1

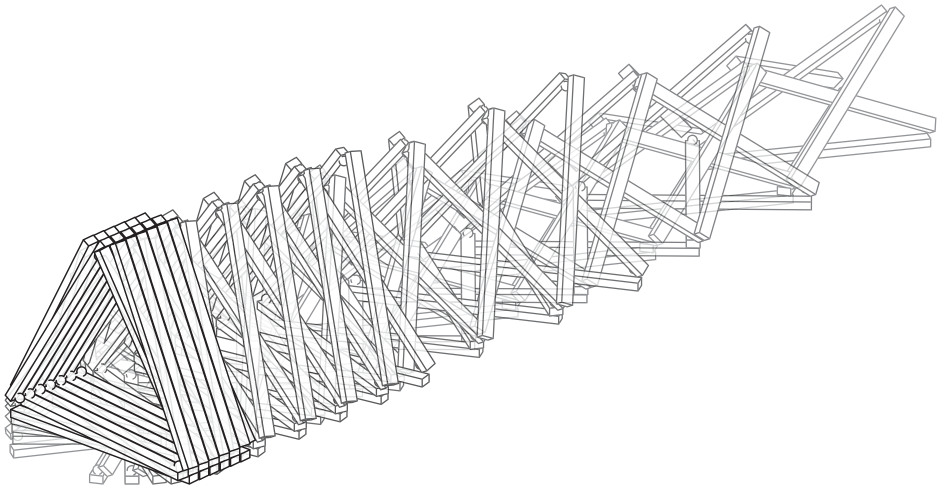
MEASURABLE OUTPUTS

Overall Span
170 cm

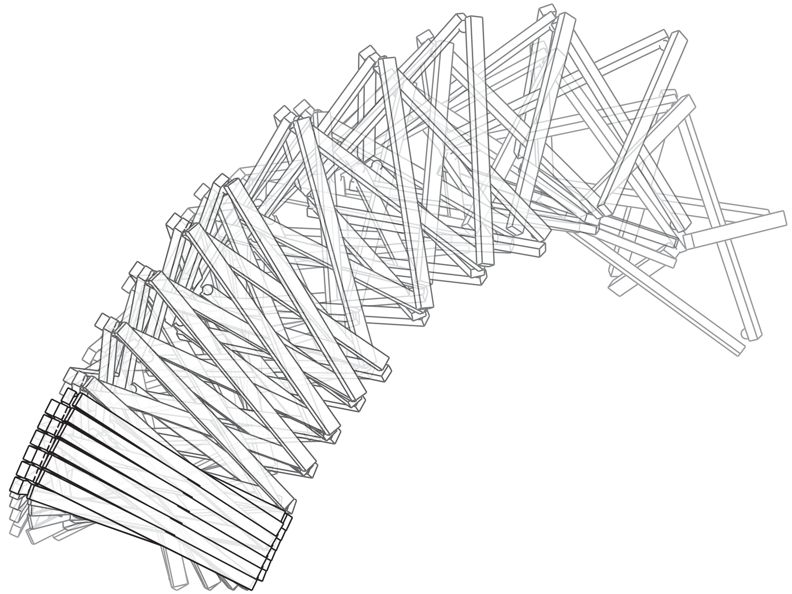
Centre of Arch Height
53.5 cm

Length of Tension Cables
30 cm

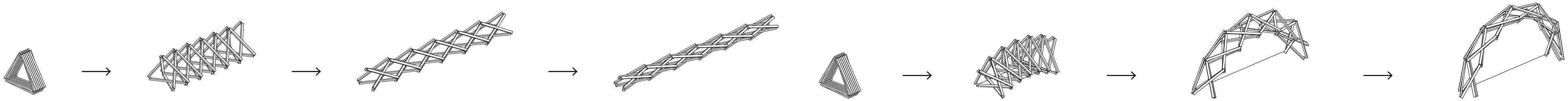




Linear Extension



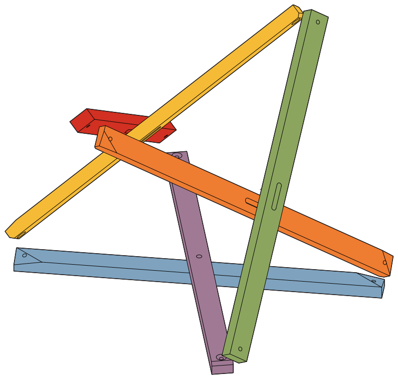
Arched Extension

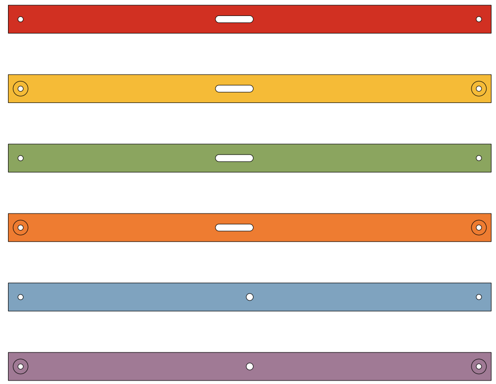


Prototype Construction

SEPARATED INTO GROUPS

36 members of equal overall dimension are colour coded in order to aide production. Although split in to six groups there are four unique types of members since Orange = Yellow and Green = Red



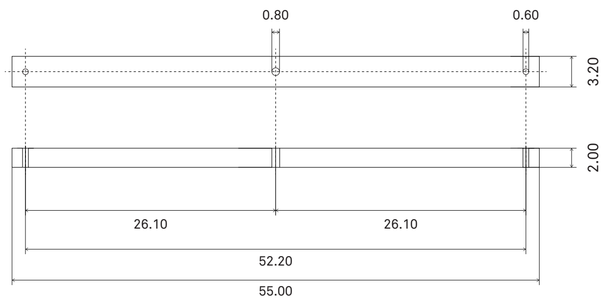


CONNECTING HOLES & SLOTS

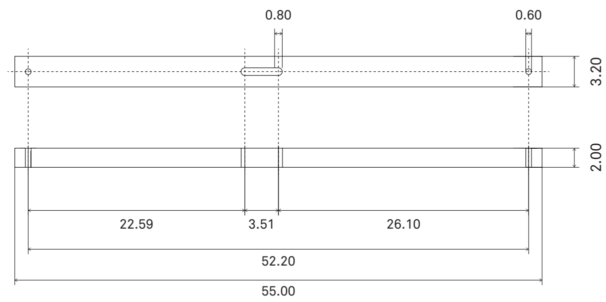
<u>End Hole</u>
All 36 members receive 6 mm holes centred 14 mm from each end

<u>Middle Hole</u>
Blue and Purple groups receive a centred 8 mm hole

<u>Middle Slot</u>
Orange, Green, Red and Yellow groups receive 8 mm wide slots



Middle hole dimensions



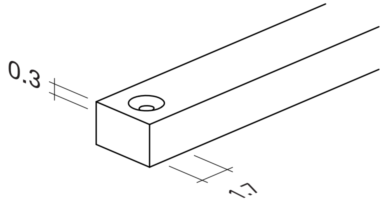
Middle slot dimensions

BALL AND SOCKET

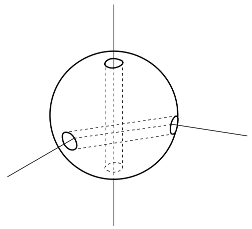
Based on experimentation with a number of flexible joints, ball and socket selected as ideal for balance of mobility and stiffness required.

Orange, yellow and purple members receive two sockets 17 mm across x 3 mm deep and centred on end holes.

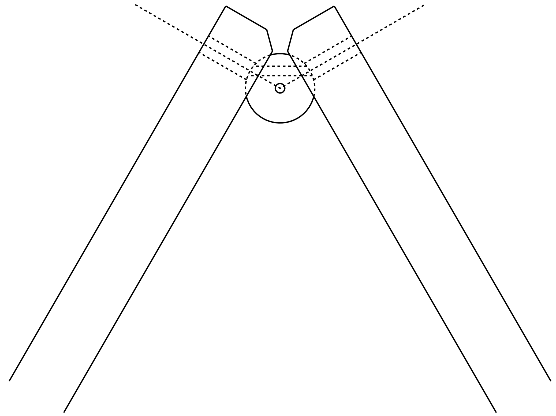
Each wooden sphere is drilled through twice. First vertically through the centre. Second, horizontally and offset from centre to simulate 30 degree angle from centre of sphere at surface.



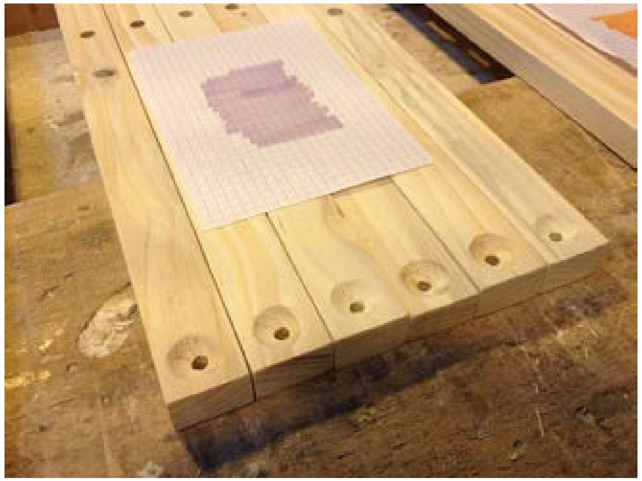
Dimensions for socket

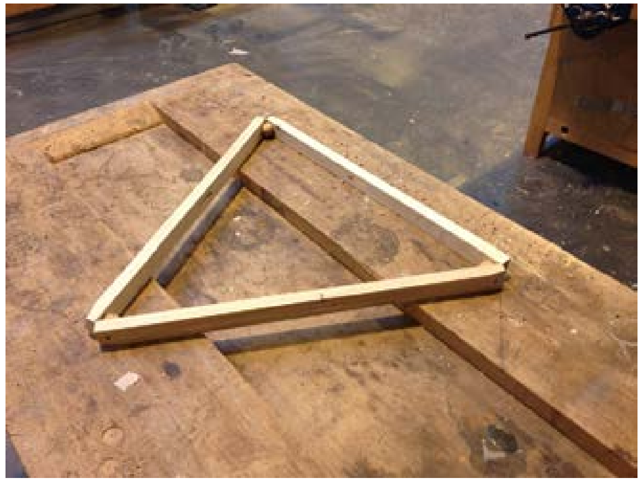


Sphere Drilling



Joint Alignment





CHAMFERS

Four groups receive chamfers in order to allow realignment between modules which occurs while arching. This tolerance prevents over stretching the joint and smooths the motion.

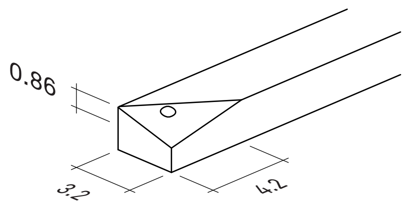
Chamfers appear open while structure is collapsed and extended straight while closing in arched position.

Four chamfer types output from grasshopper:

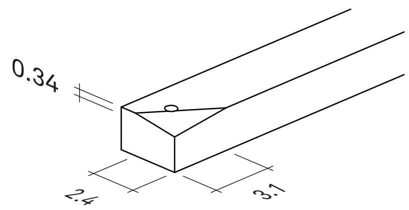
Chamfer 1 - Blue members receive two of these chamfers, one at each end of the same surface.

Chamfer 2 & 3 - Orange and yellow members receive one of each of these chamfers on the surface opposite their circular socket.

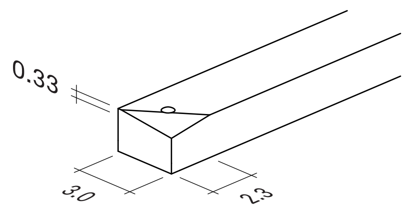
Chamfer 4 - Orange, yellow and purple members receive two of these chamfers on the same surface as their socket



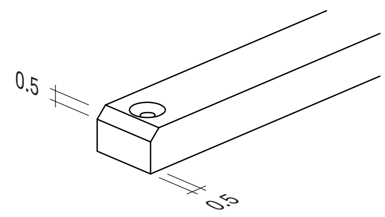
Chamfer 1



Chamfer 2



Chamfer 3



Chamfer 4

Chamfers in collapsed position

Chamfer in straight extension

Chamfer closed in arched position

MEMBERS PAIRED

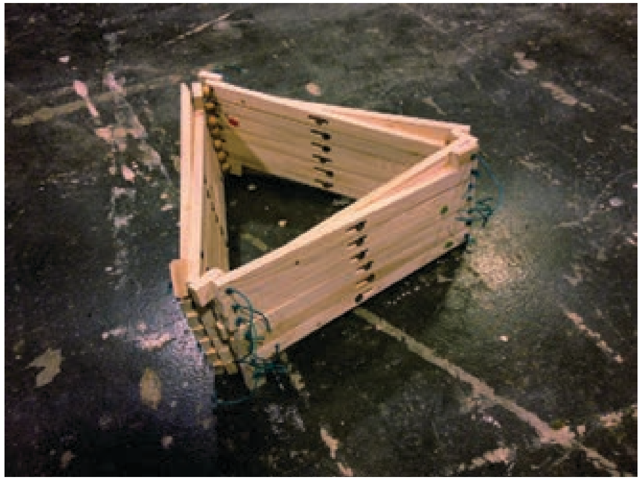
With holes, slots and chamfers completed, members are paired up using a bolted connection.

Red & Yellow, Green & Orange, Purple & Blue

Smooth sleeve on nut allows for cleaner sliding in slot than previous versions had allowed.

LOOSE ASSEMBLY

With all members fully cut and paired up modules are roughly assembled using string as a temporary connection.



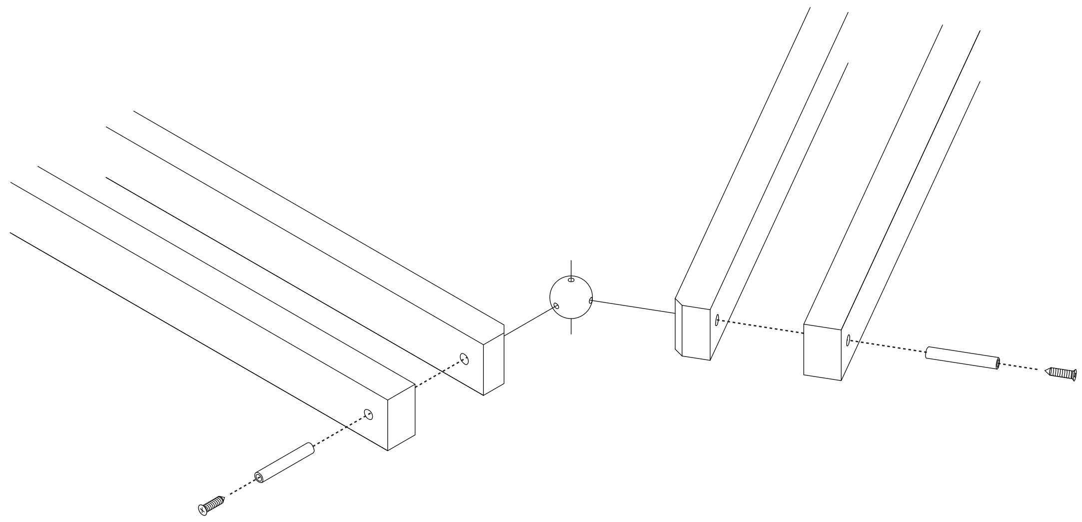
FINAL NODE CONNECTION

With structure loosely assembled, string connections are replaced one at a time with final assembly. Connection allows both the needed mobility and rigidity.

Wooden Sphere – 24 mm diameter wooden sphere fits into sockets in two inner members allowing a tight joint.

Hydraulic Hose – 6 mm hose prevents two members on each side from shifting while allowing the necessary rotation and flex for the chamfer to close.

Steel Cable – Passing through the entire connection, a cable is pinched at each end by a screw, pulling the connection together.



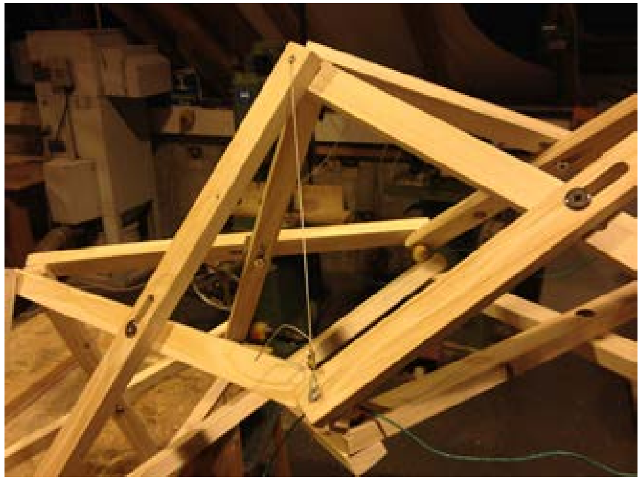
Exploded axonometric of final connection

TENSION MEMBERS

Two kinds of tension members resist the scissor joints' tendency to expand/contract. Lengths for each are output from Grasshopper definition.

1. Green ropes prevent structure from expanding beyond certain length. Additionally provide an efficient means of collapsing structure.
2. Wires which are attached after extension resist contracting inwards.

1



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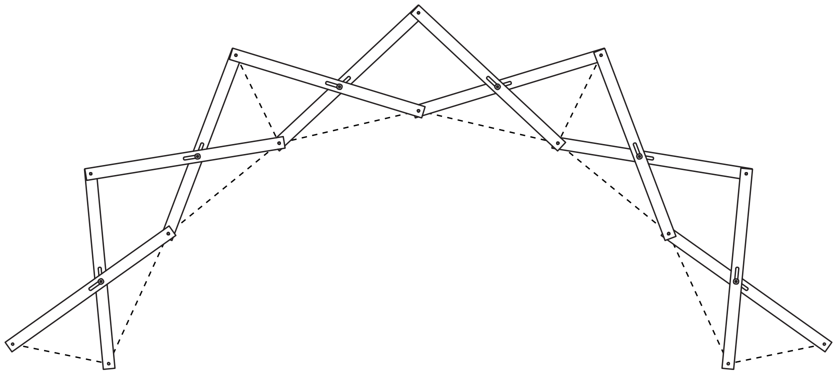
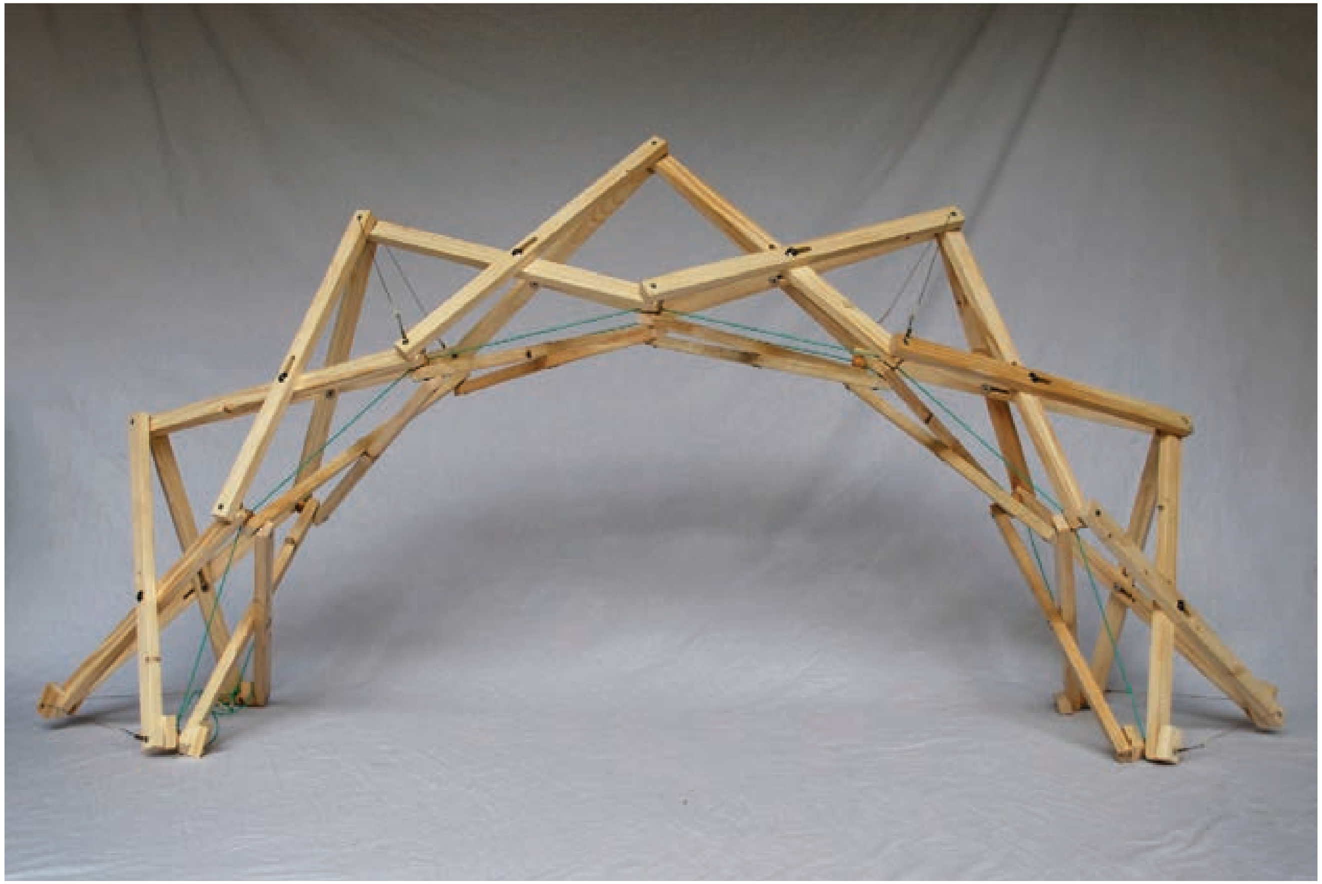
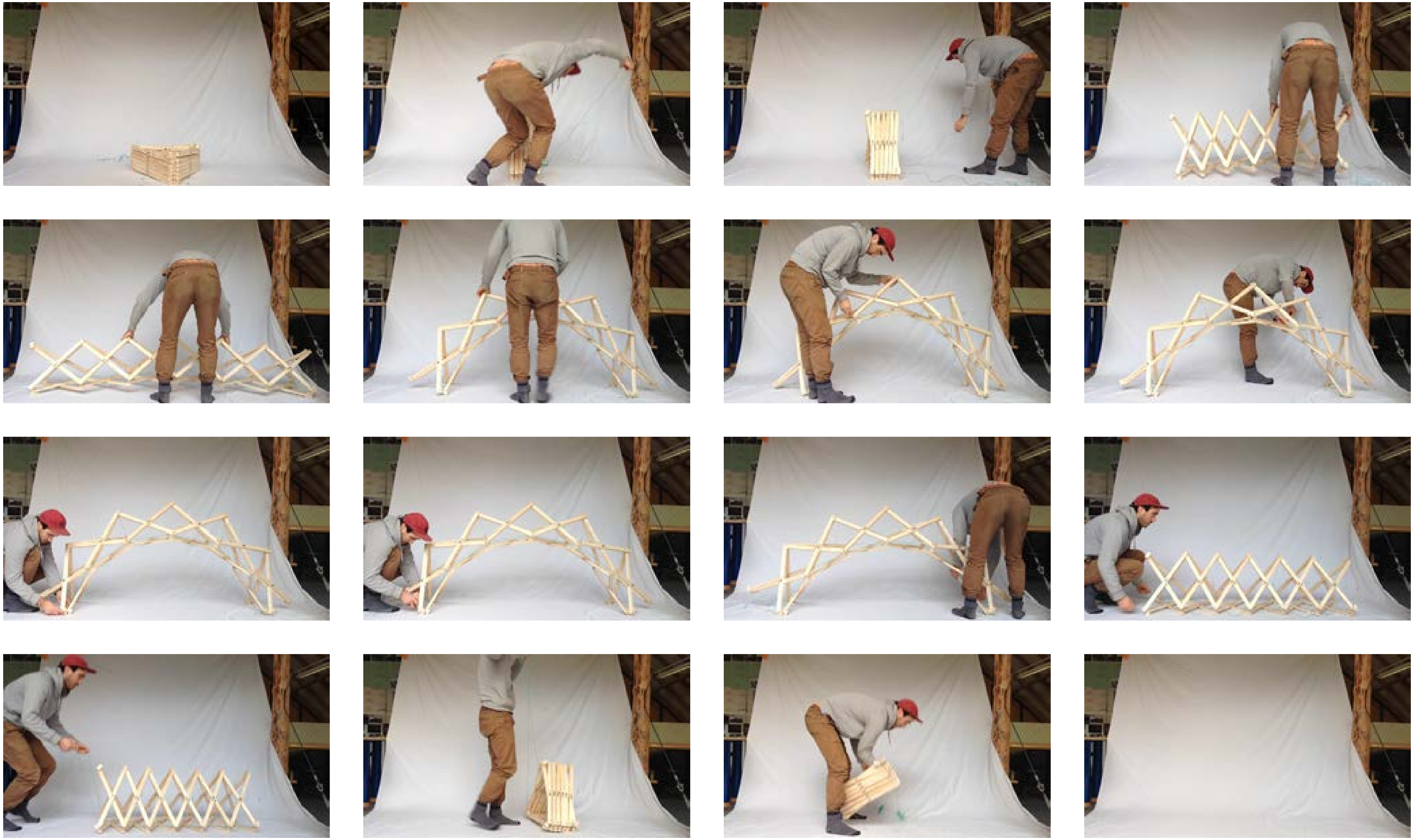


Tension member locations



In Use

ASSEMBLY AND DISASSEMBLY



LOAD TESTING

First test performed with structure extended in arched position. Load placed on lower members to simulate load on surface of a bridge.

Aim to support a person of 60 kg.

<u>Prediction</u>
Node connection seen as likely first point of failure in the system. Unlikely that steel cable will break, but rather will be pulled free from one of the screws holding it.

<u>Results</u>
Structure supported 45 kg, failing at 47 kg.

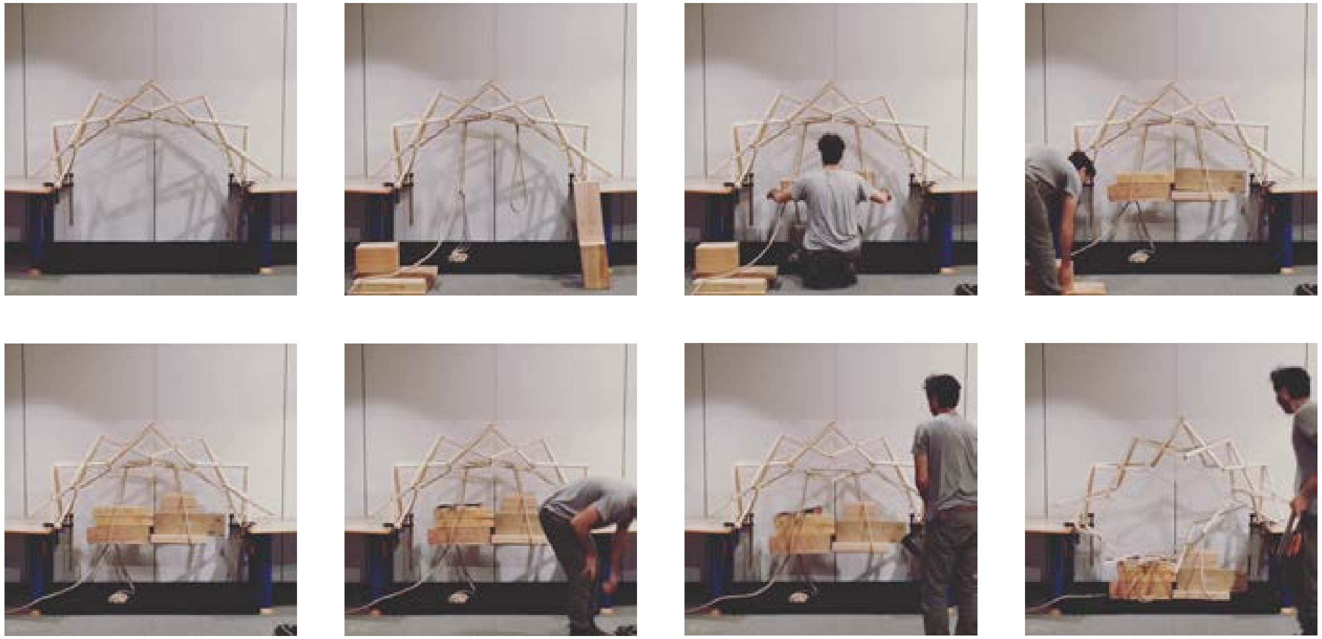
No wooden members are damaged. Consistent with prediction, steel cable is pulled as friction between screw and hydraulic cable is unable to resist force on cable.

Once middle two connections fail the rest of the bottom nodes fail in sequence.

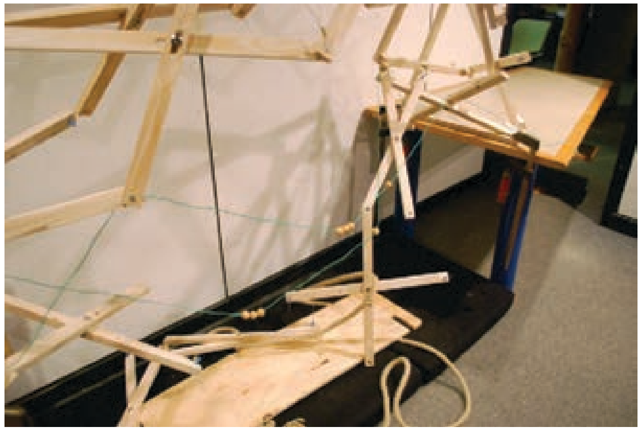
Suspect that loading solely on bottom members placed additional strain on nodes and prevented structure from transmitting forces properly causing early failure.

<u>Further test to be performed</u>

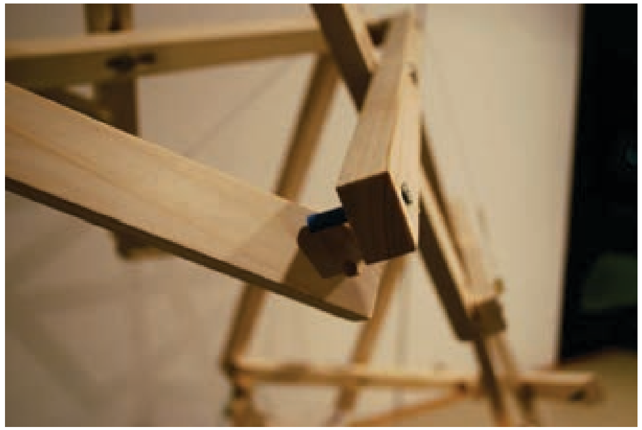
1. Different loading locations
2. New fasteners for holding steel cable
3. Load capacity in straight extended position



Stills taken from time-lapse during load testing



After one node fails, rest follow



Cable pulled from tubing and screw connection

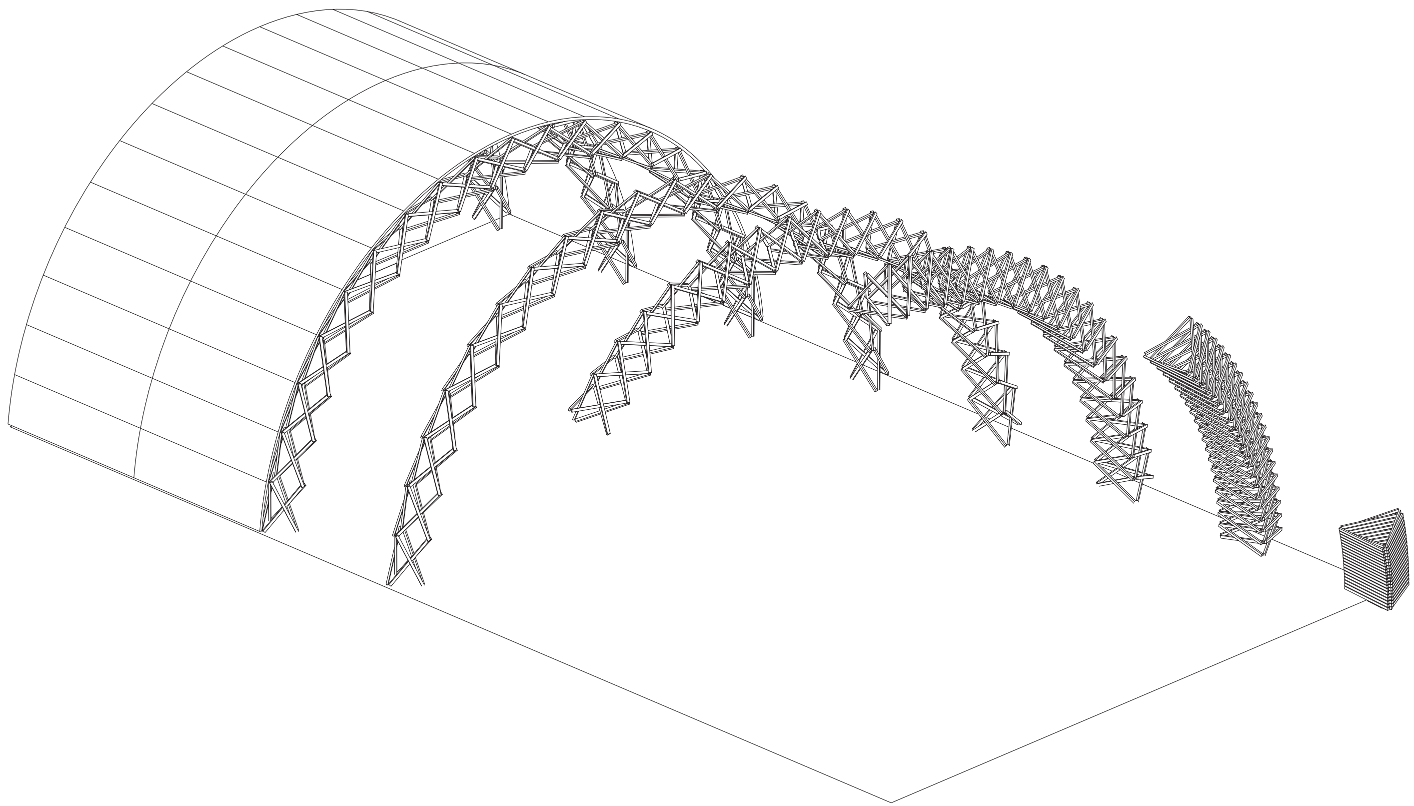
DEPLOYABLE BRIDGE

As project developed, prototype was imagined serving as a portable bridge. A trench was found in Hooke Park, and the system deployed.

SCALED UP

Scaled up, one use for the system would be as deployable structural elements for creating a large span space in a short time frame.

Could be delivered to a site collapsed before being erected and locked into position.



FURTHER DEVELOPMENT

Surfaces
Integrating flexible membranes between members (one surface or fully enclosed). Potential to look at these surfaces filling the role currently filled by additional tension elements.

Irregular Paths
A primary challenge throughout this project and in general for deployable structures is finding ways to achieve a structure capable of expanding along non linear or radial path while not compromising structural integrity.

In this prototype specifically, difficulty is posed by the way the triangular sections acts as expanding. Although collapsing in to an equilateral triangle, the section of the arch becomes an isosceles triangle making it difficult to transition from one path to another.

Rather than slots and two sides and the same slot pattern in each module, irregular paths will require a grasshopper model which is capable of calculating unique slot pattern for each member which adjusts to any curve.