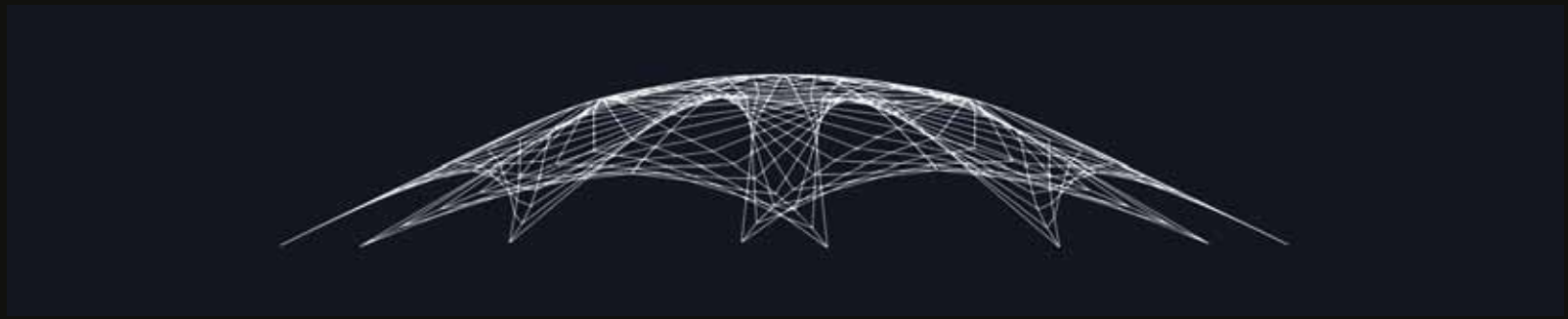


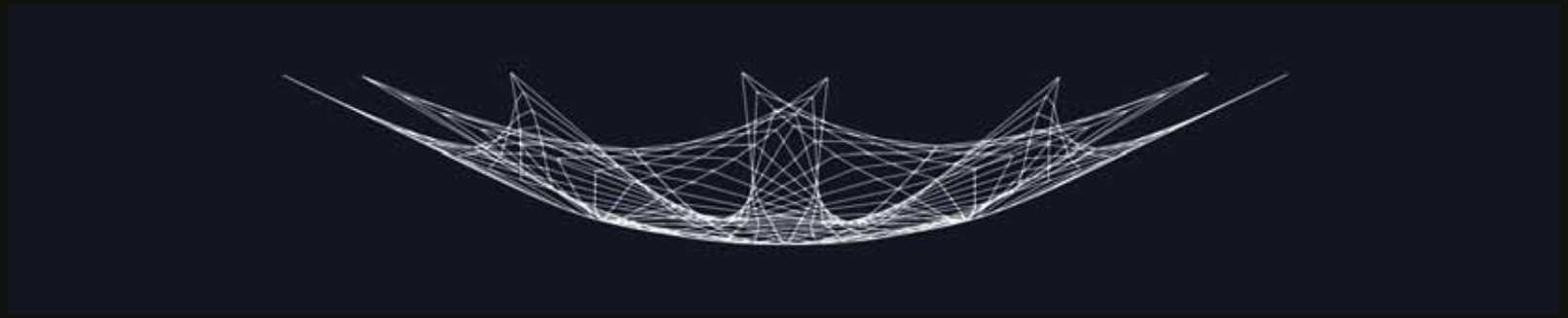
Reimagine Steel: Efficient Design and Beautiful Structures
Finding Steel Forms and Topologies

Chalmers University

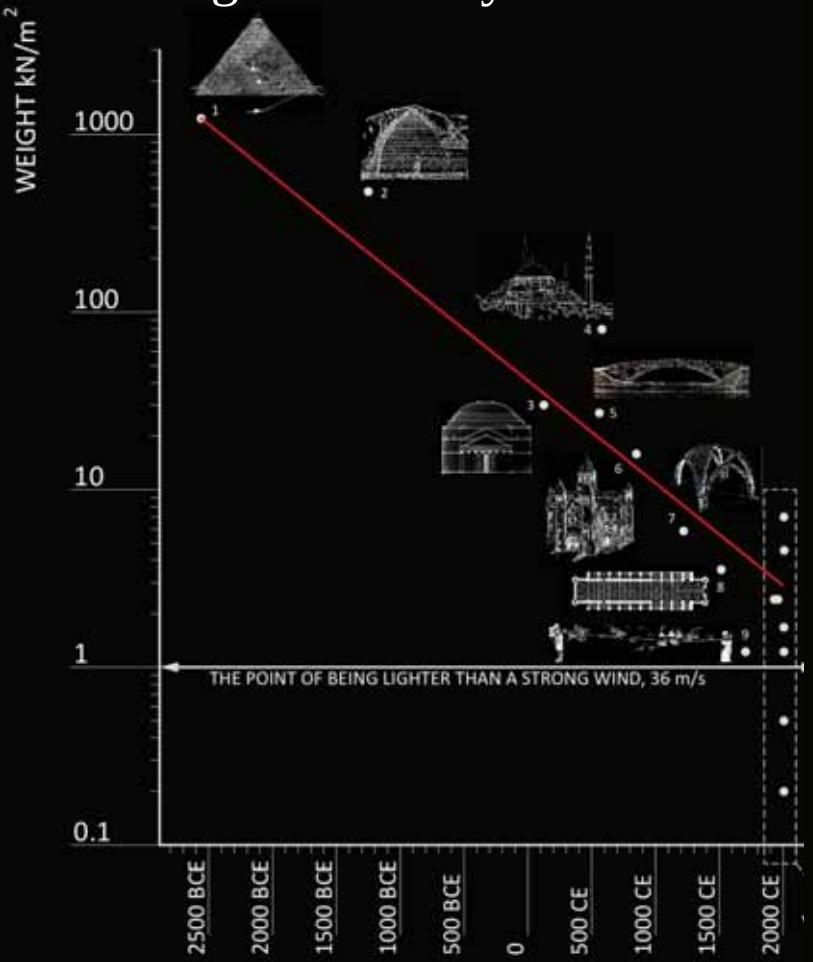
Form Finding Lab

Sigrid Adriaenssens

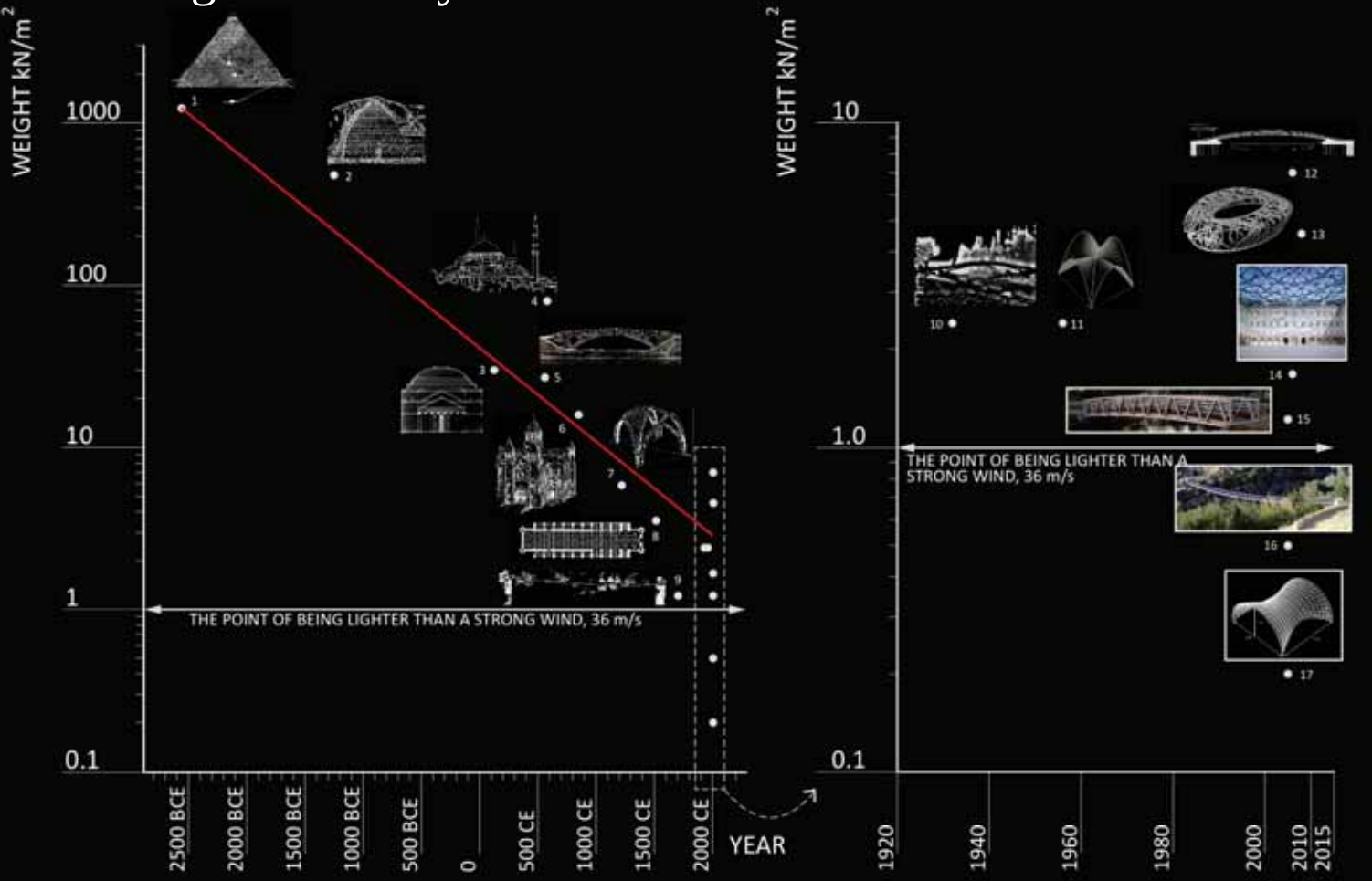
Princeton University



Structural forms throughout history



Structural forms throughout history



Finding Steel Forms

Dutch Marine Museum, Amsterdam, Netherlands.
17th century gunpowder warehouse with inner courtyard.
Source: Form Finding Lab

Invited Design Competition

Historical context

Symbolical context

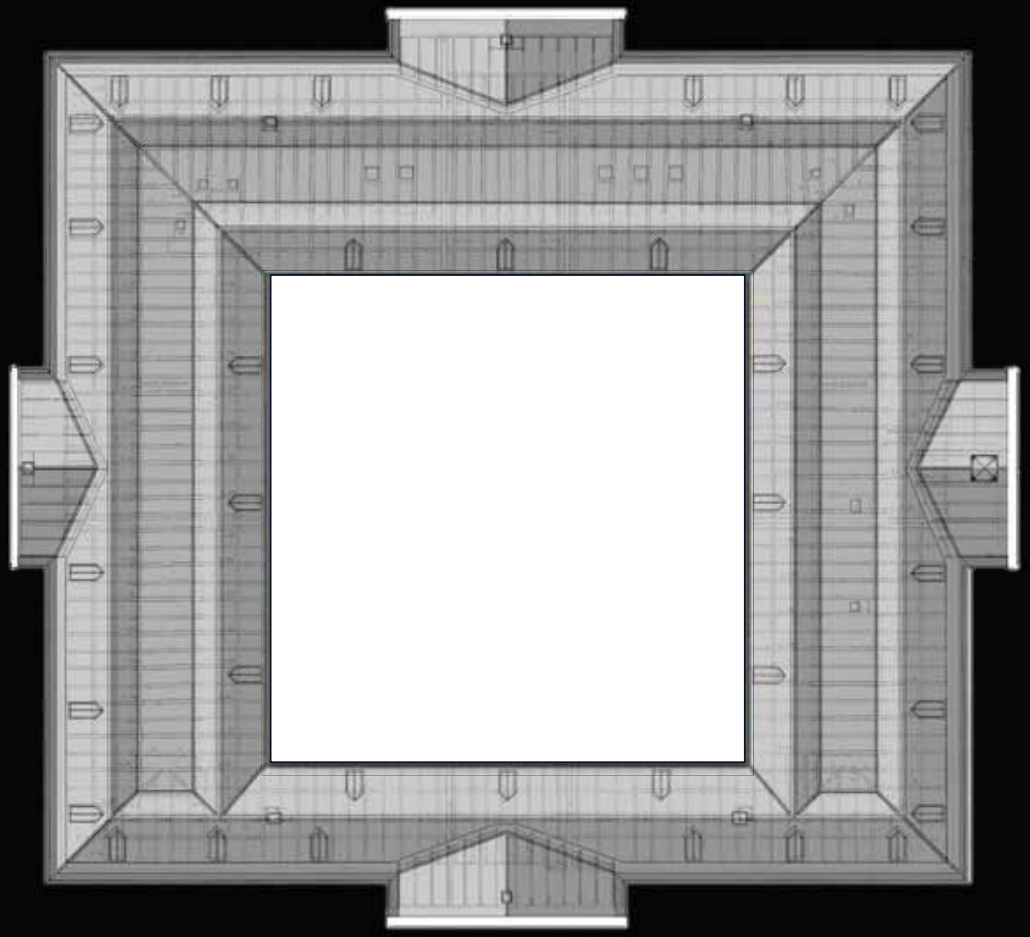
Existing protected building

Boundary Conditions

Prefab structure

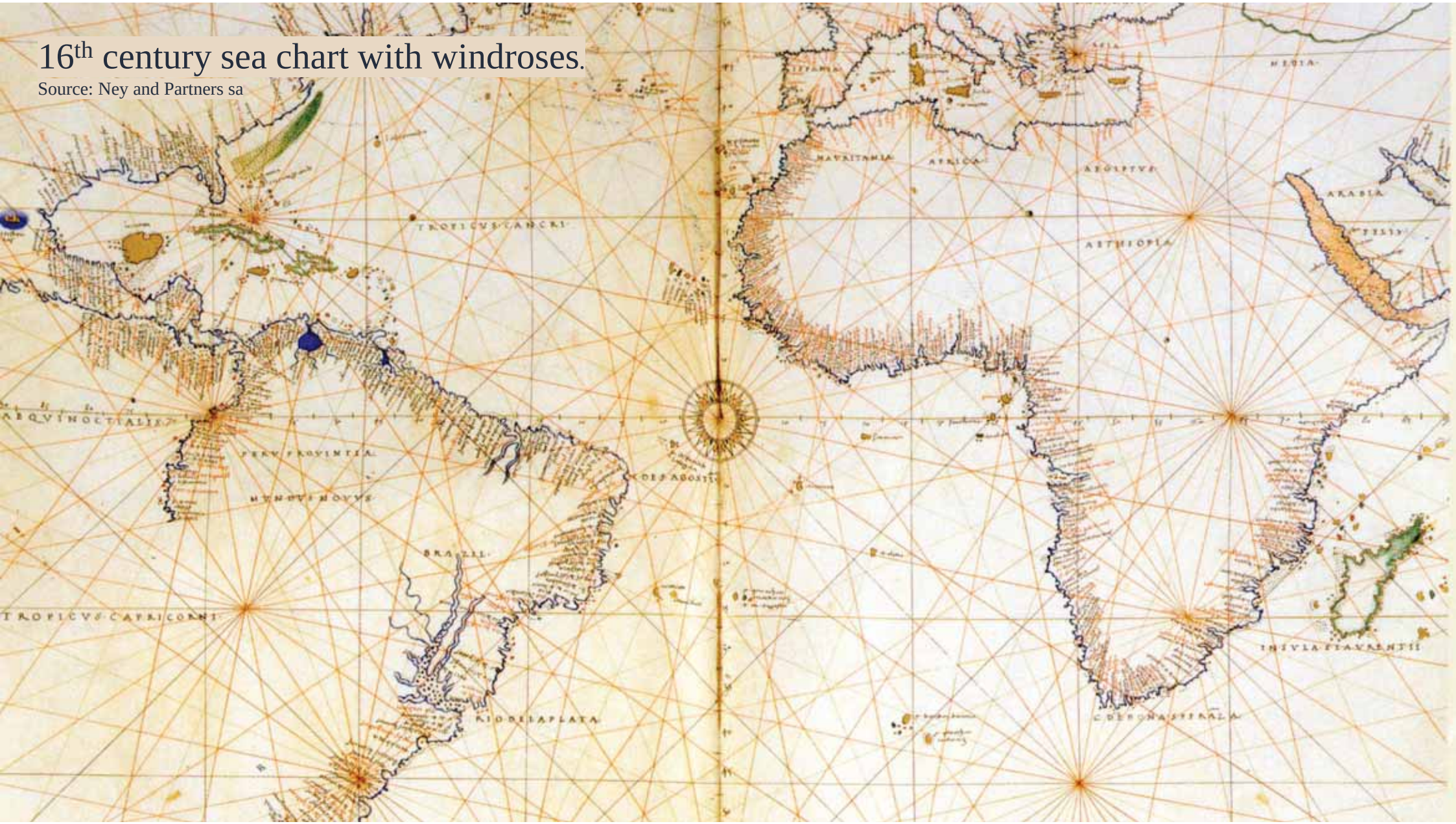
Plan of Dutch Marine Museum showing courtyard.

Source: Ney and Partners sa



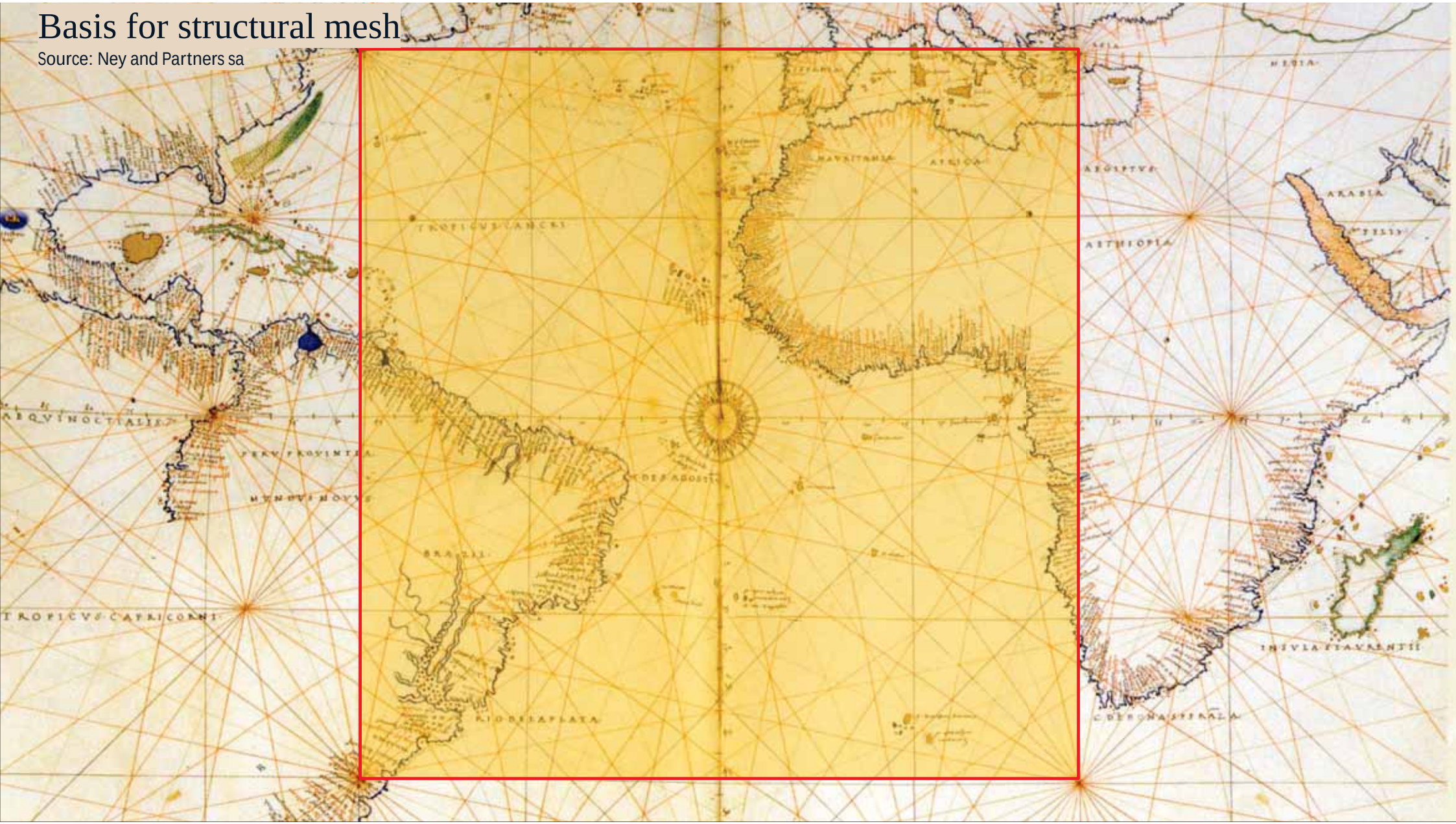
16th century sea chart with windroses.

Source: Ney and Partners sa



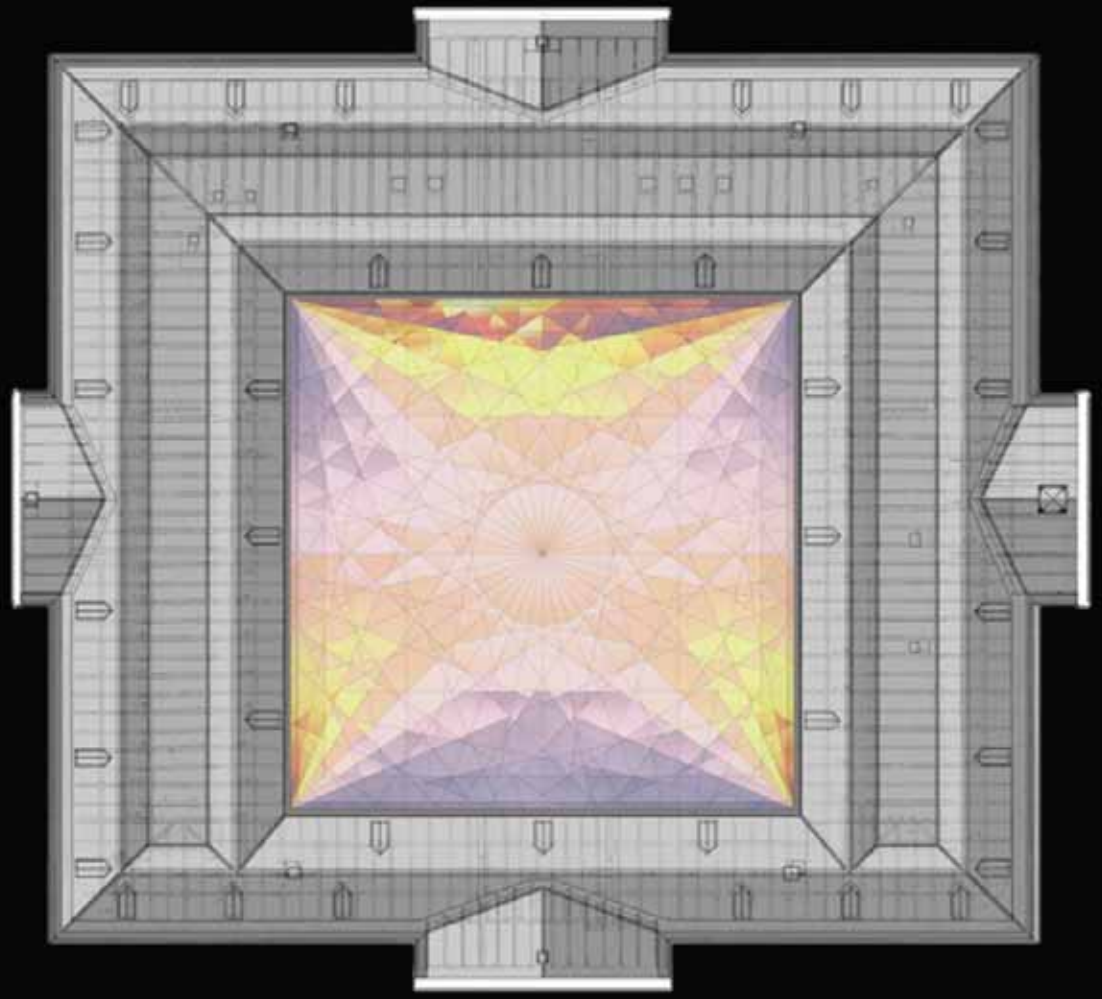
Basis for structural mesh

Source: Ney and Partners sa

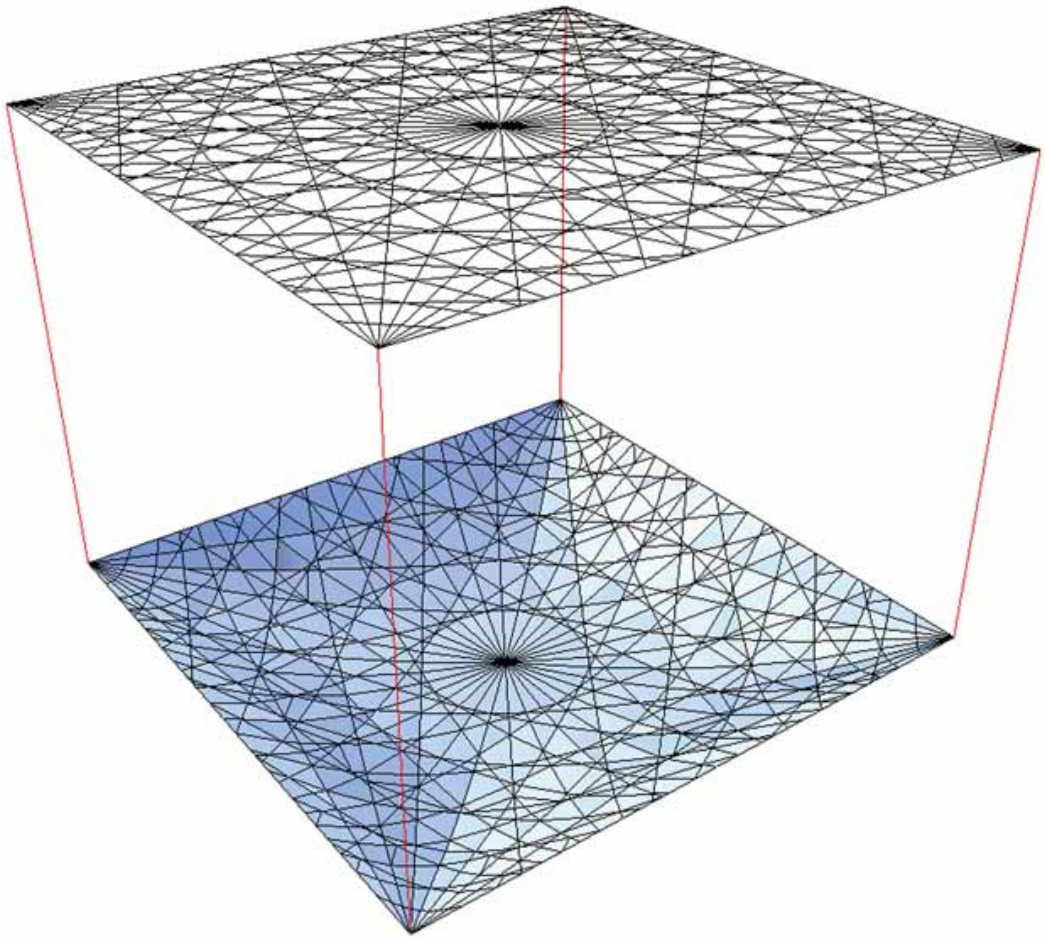


Plan of new gridshell roof structure

Source: Ney and Partners sa



Form Finding from 2D to 3D



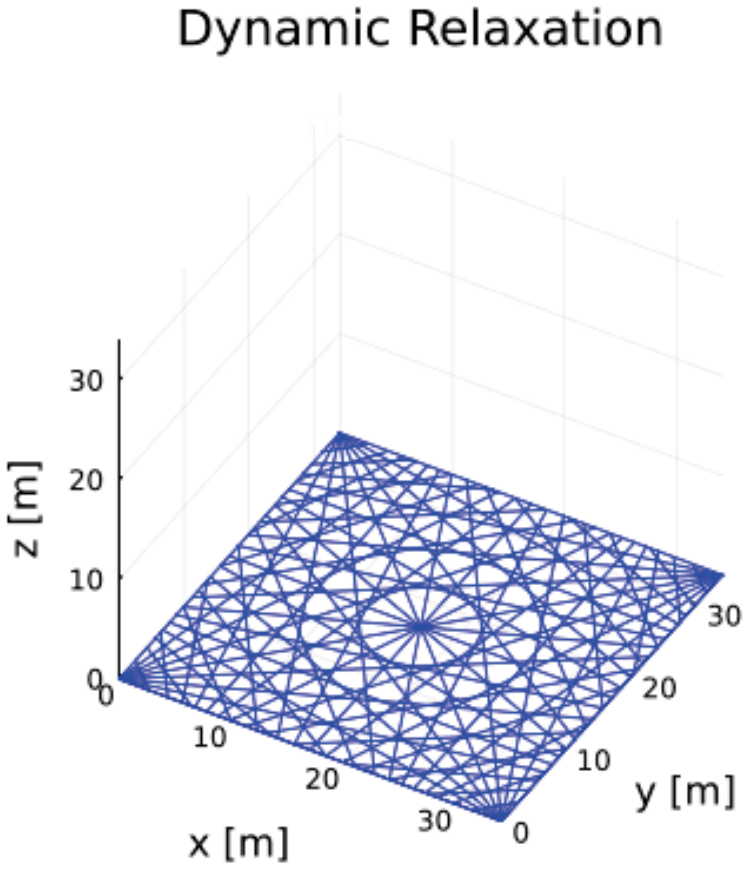
Numerical hanging net model generates form

Efficient shape

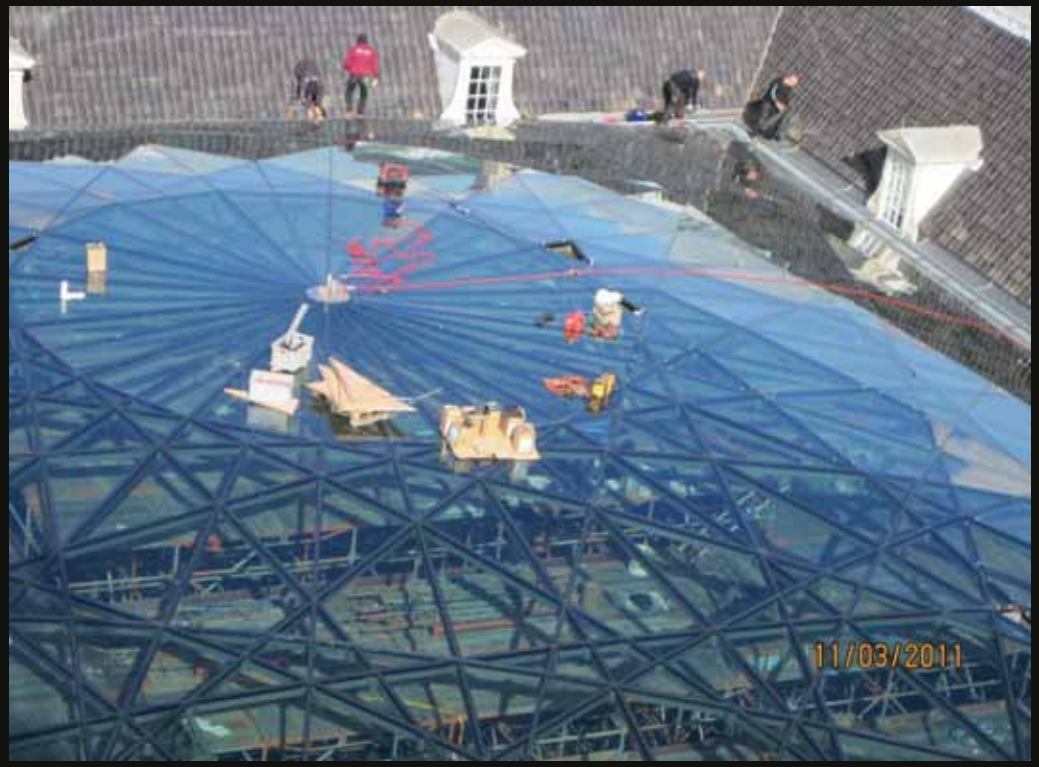
Minimal Use of Materials

Adriaenssens, S., Ney, L., Bodarwe, E., & **Williams, C.** (2012). Finding the form of an irregular meshed steel and glass shell based on construction constraints. *Journal of Architectural Engineering*, *18*(3), 206-213.

Source: Ney and Partners sa



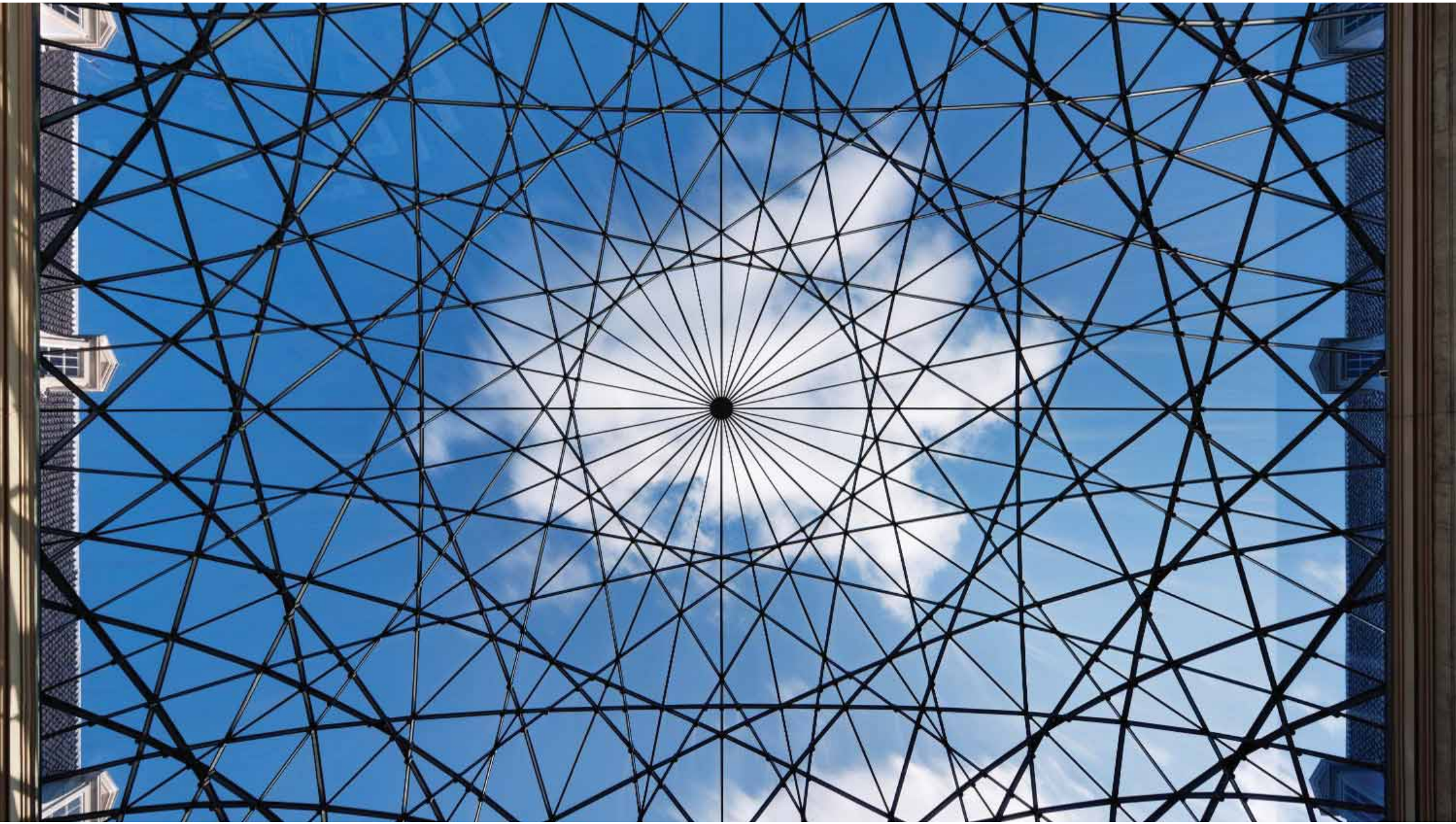
Reproduced by Axel Larsson, then Chalmers University, now PhD student at Form Finding Lab

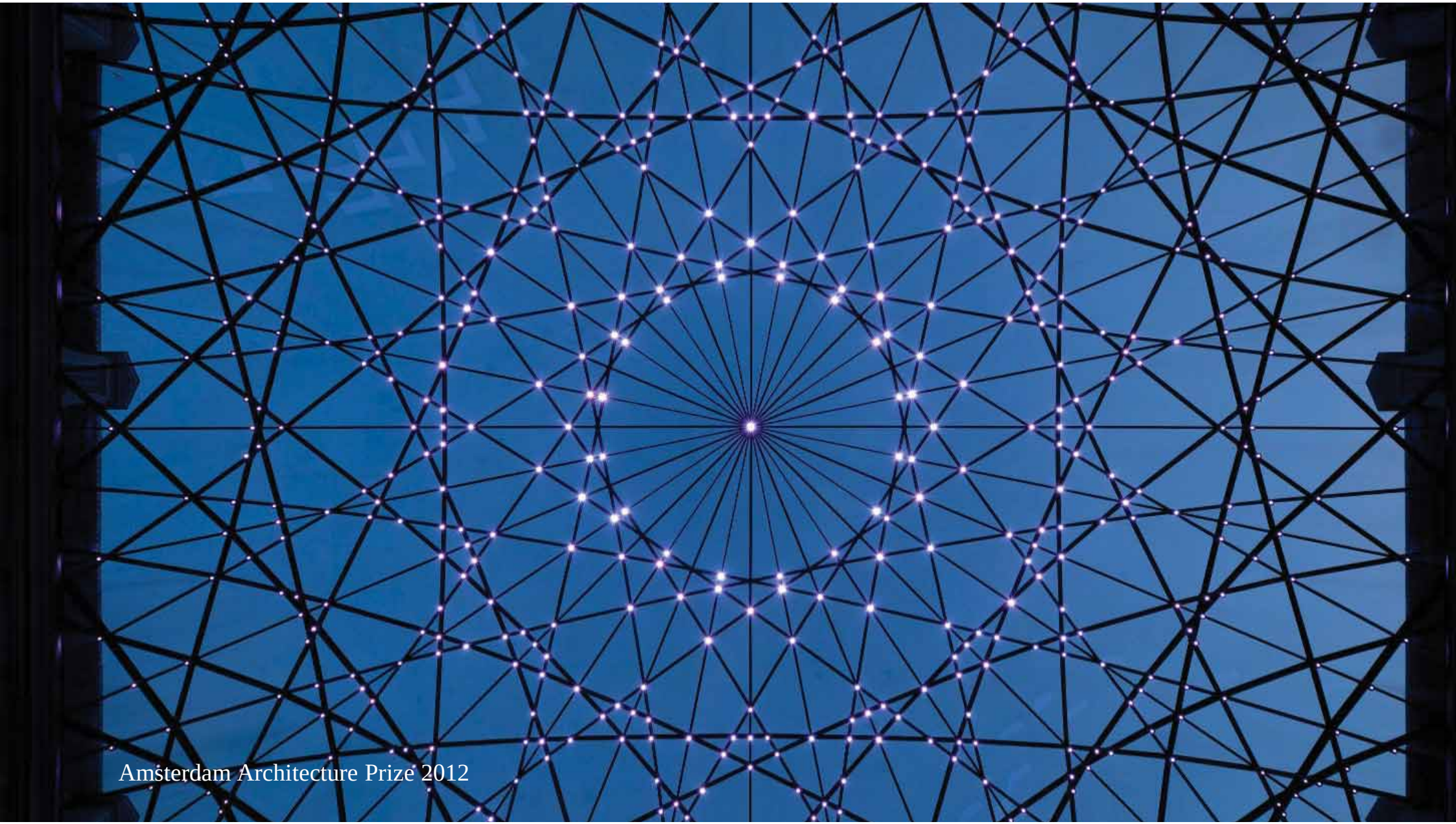

11/03/2011


11/03/2011

Realised gridshell over courtyard, Dutch Marine Museum.

Source: Ney and Partners sa





Amsterdam Architecture Prize 2012

Finding Steel Topologies

Inspiration IKEA flat pack.

Social context

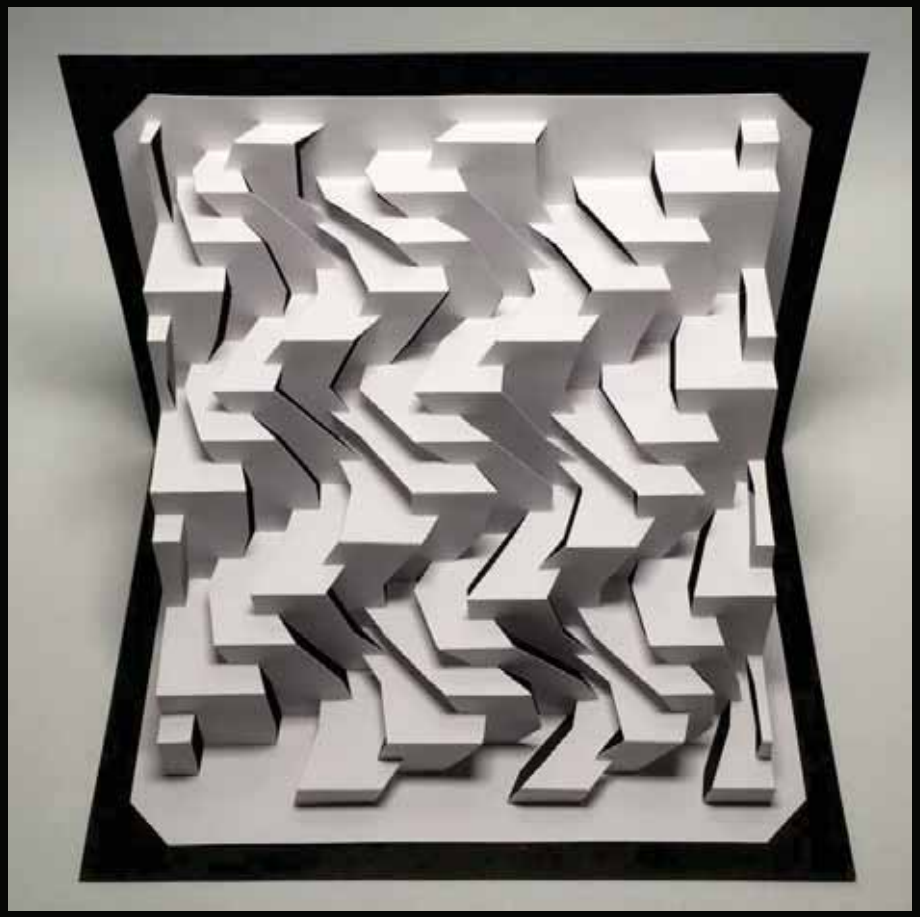
Transportation, different parts, and coordination

Inspiration Ikea: smart transportation and manuals

Innovation: assembly intelligence in system itself

Finding Steel Topologies

Inspiration Pop-up cards.



Design and Construct

Structure, topology, nodes, assembly embedded in one flat pack design

No manufacturing waste

Efficient transportation

Kirigami craft at the large scale

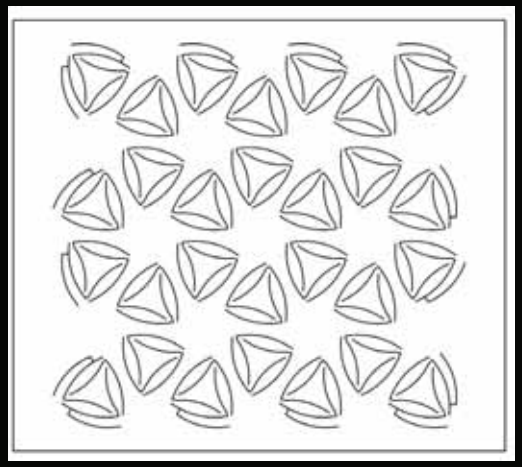
Rotational Kirigami System

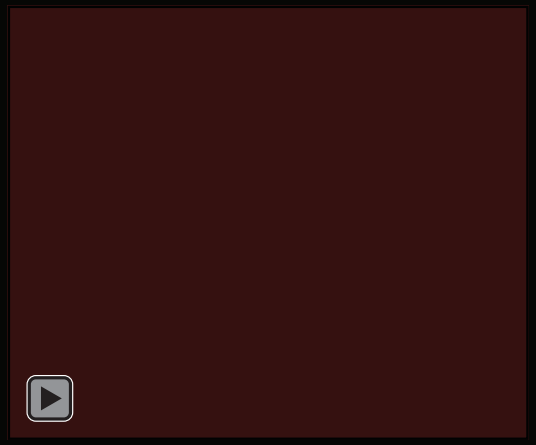
E. Baker

From 2D sheets to 3D space-frames

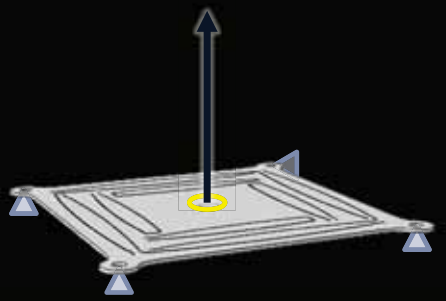
Few fabrication steps:

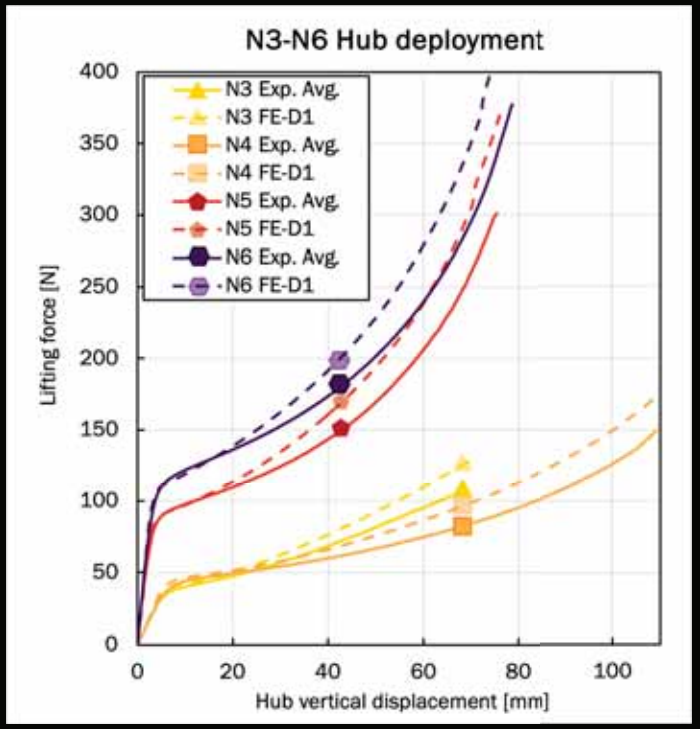
- Cut
- Deploy & Connect



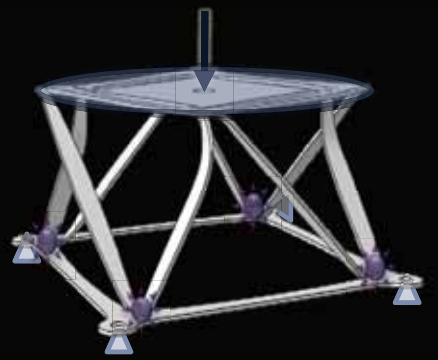


Mechanics of a Kirigami Unit



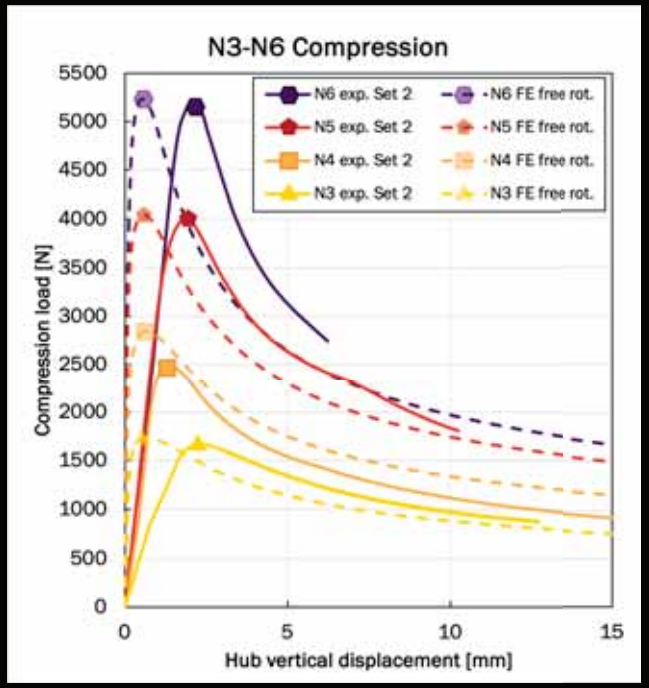


Mechanics of a Kirigami Unit



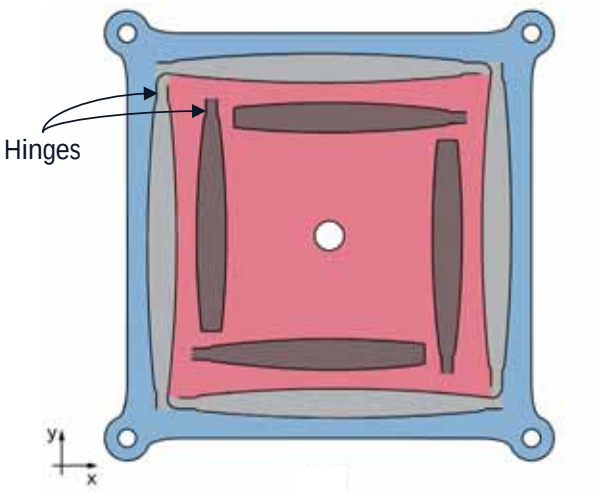
Kirigami units 20 cm scale, 2 mm thick steel

- P_{cr} = up to 1400 * self-weight
- P_{cr} = up to 20 * deployment load
- Withstands loads of up to ~5 adults



Experimental and numerical investigation of a rotational kirigami system. *Thin-Walled Structures*, *192*, 111123.

Numerical Model of a Kirigami Unit



Cut pattern

Simulations

- Scale: **20 cm** (7 ½ in.)
- Geometry software: Rhinoceros 3D
- FE software: Abaqus/Standard
- **Shell elements**, linear interpolation (S3, S4)
- Connector elements: axial and weld (CONN3D2)
- Material: **Carbon Steel** A1008
- E = 200 GPa, ν = 0.3, σ_Y = 186 MPa
- Steel sheet **gauge 14** (thickness t = 1.89 mm)
- Steps 1-5: **Nonlinear static general**
- Step 6: **Nonlinear Riks**

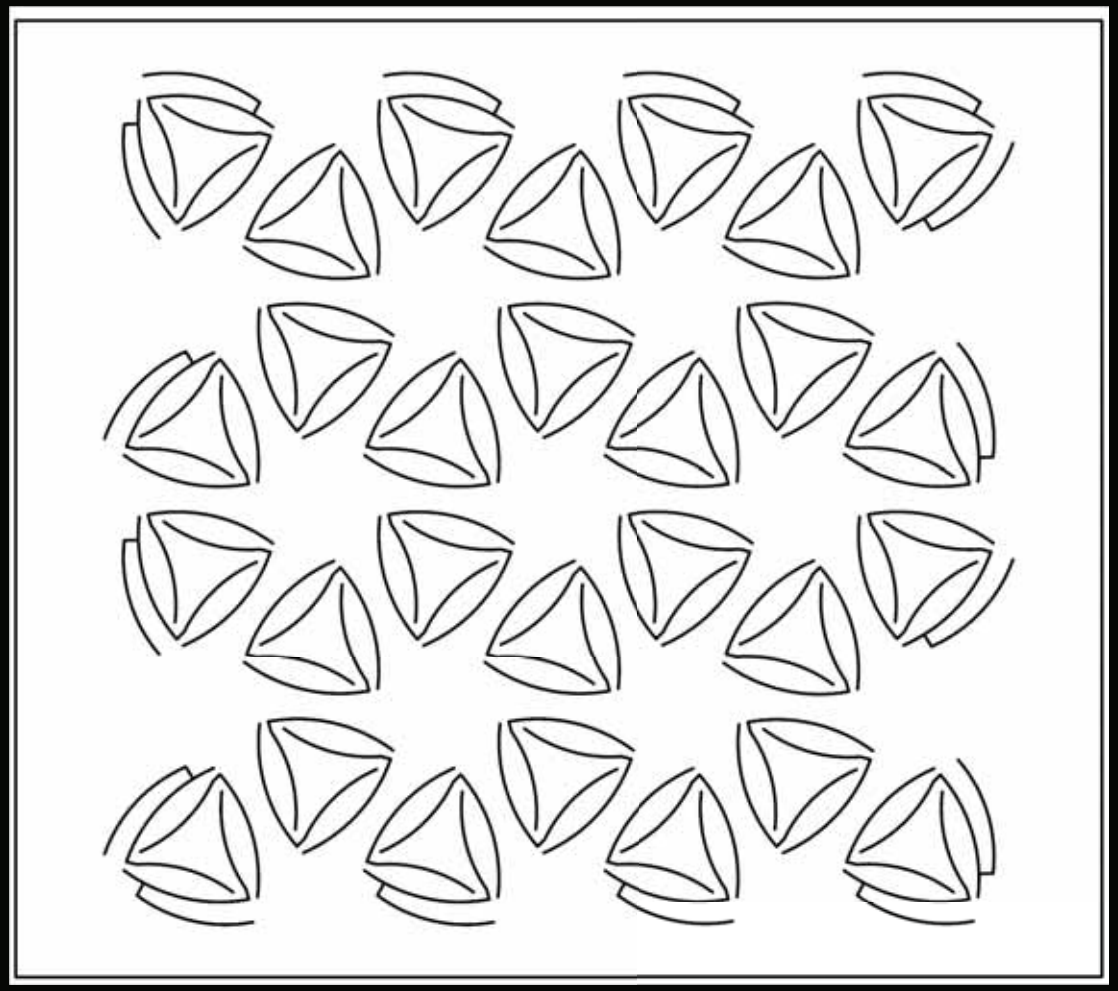
Designing from a unit with embedded intelligence to a space frame

Unit → **Space frame**

(multi-unit system)

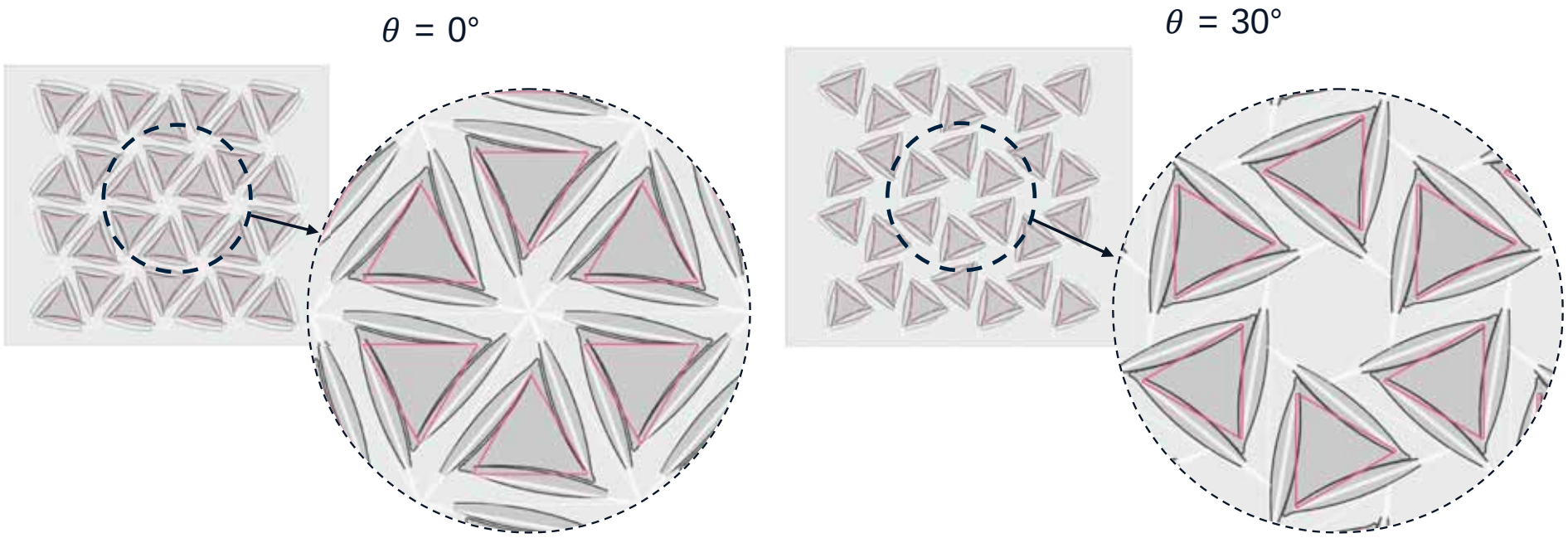
E. Baker, 2017

Kirigami Steel Sheet Cut Pattern



Different Cut Pattern, different deployed state

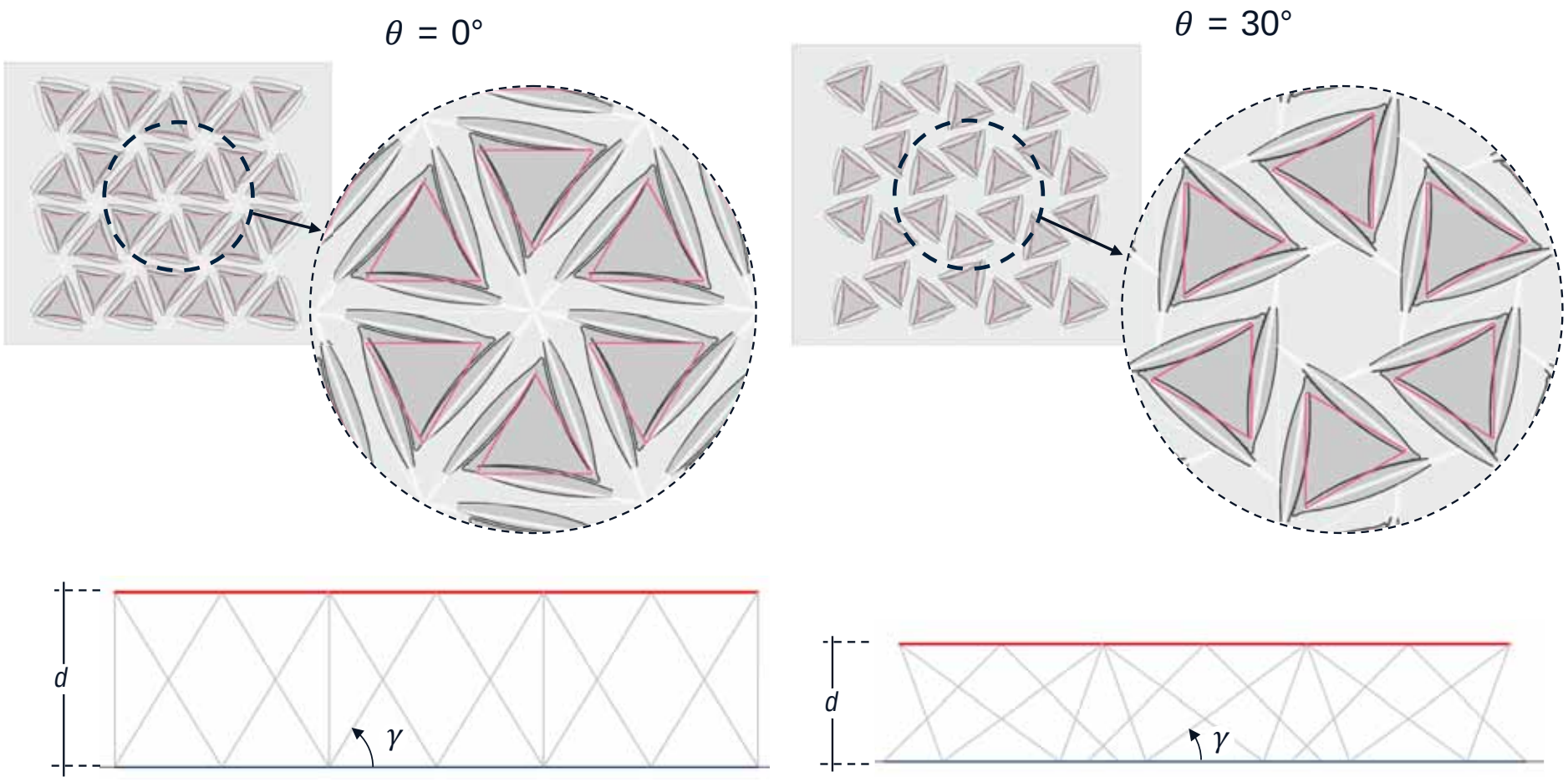
Cut pattern



Different Cut Pattern, different deployed state

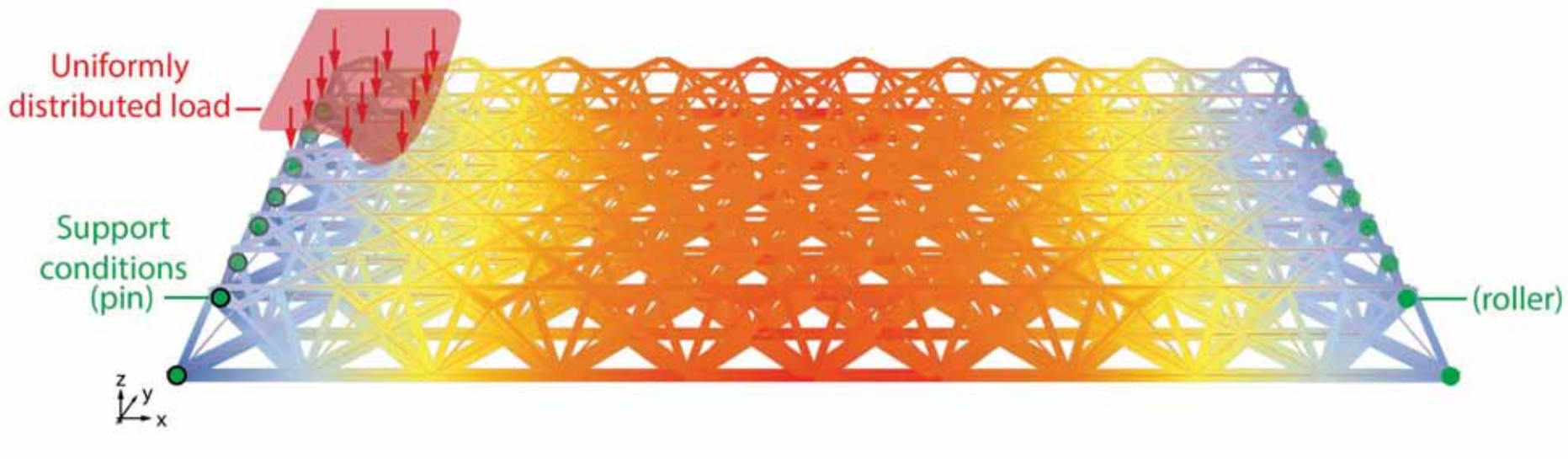
Cut pattern

Deployed frame

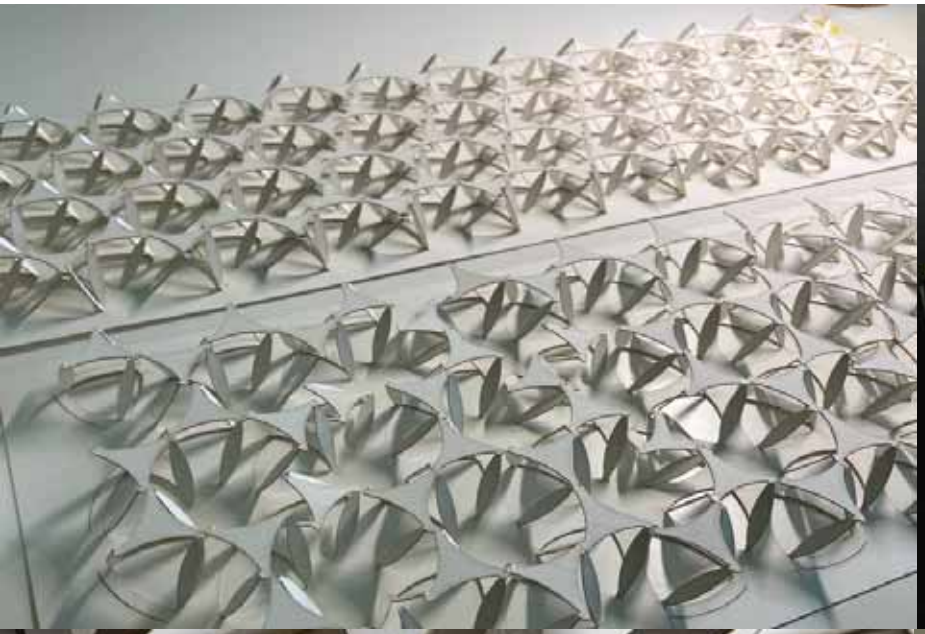


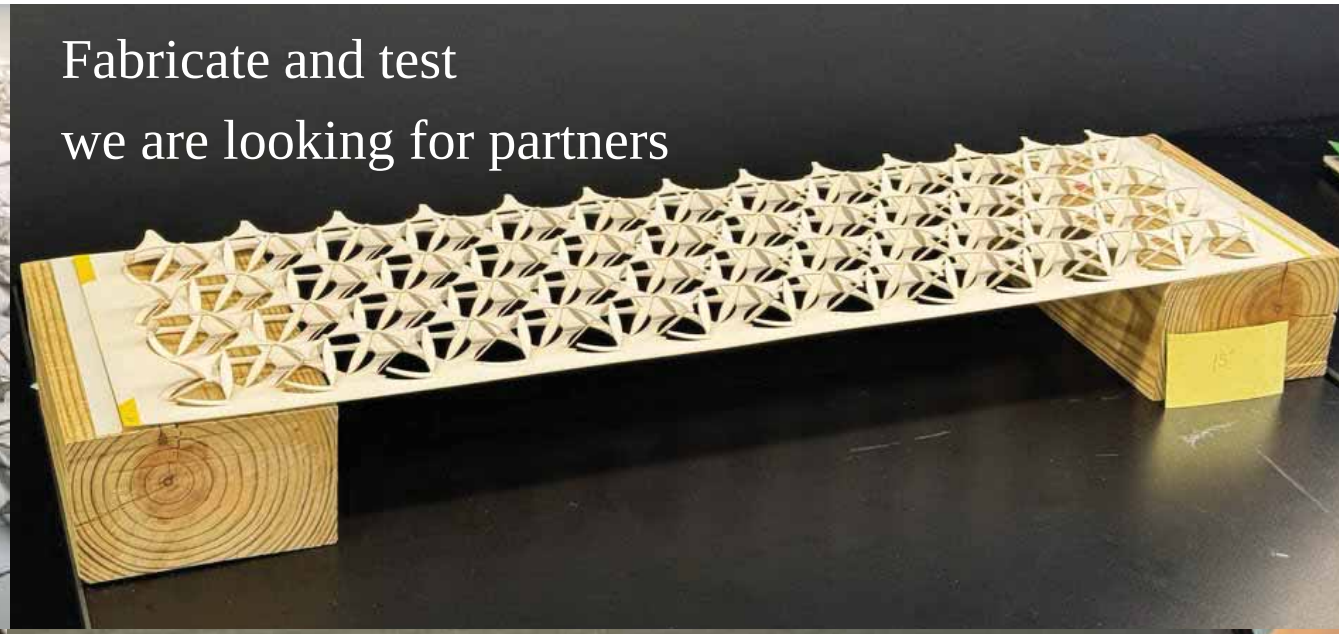
Structural behavior in a one-way spanning condition

What is the maximum deflection at midspan for different rotations?



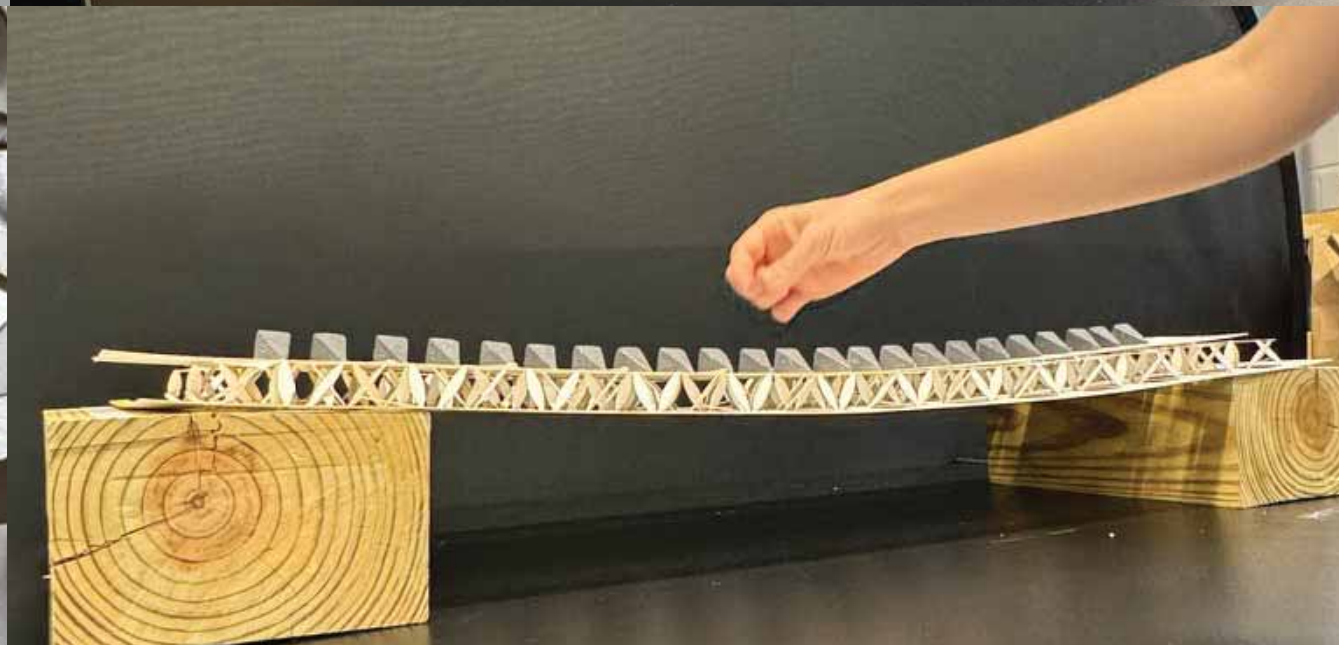
- Beam elements
- Linear elastic regime
- Simply supported, UDL
- Continuous beams at top and bottom chords
- Hinged diagonal endpoints
- Software: Karamba3D





Fabricate and test

we are looking for partners



Innovate with variable units

MILE ZERO PROJECT

Team

- Emily Baker, Vincent Edwards, and Edmund Harris (University of Arkansas)
- Isabel Moreira de Oliveira (Princeton University's Form Finding Lab)
- Eduardo M. Sosa (West Virginia University)
- Reilly Dickens-Hoffman (Fayetteville, Ark.-based artist)
- Caleb Rothell helped with visuals

Thank you for being a wonderful audience and let me know if you would like to collaborate (sadriaen@princeton.edu)