bmcs course

brittle/matrix cementitious composite structures

oricrete*: Yoshimura vault, RWTH Aachen (2015)*

Jena, Germany, Dyckerhoff-Widmann (1922-1923)

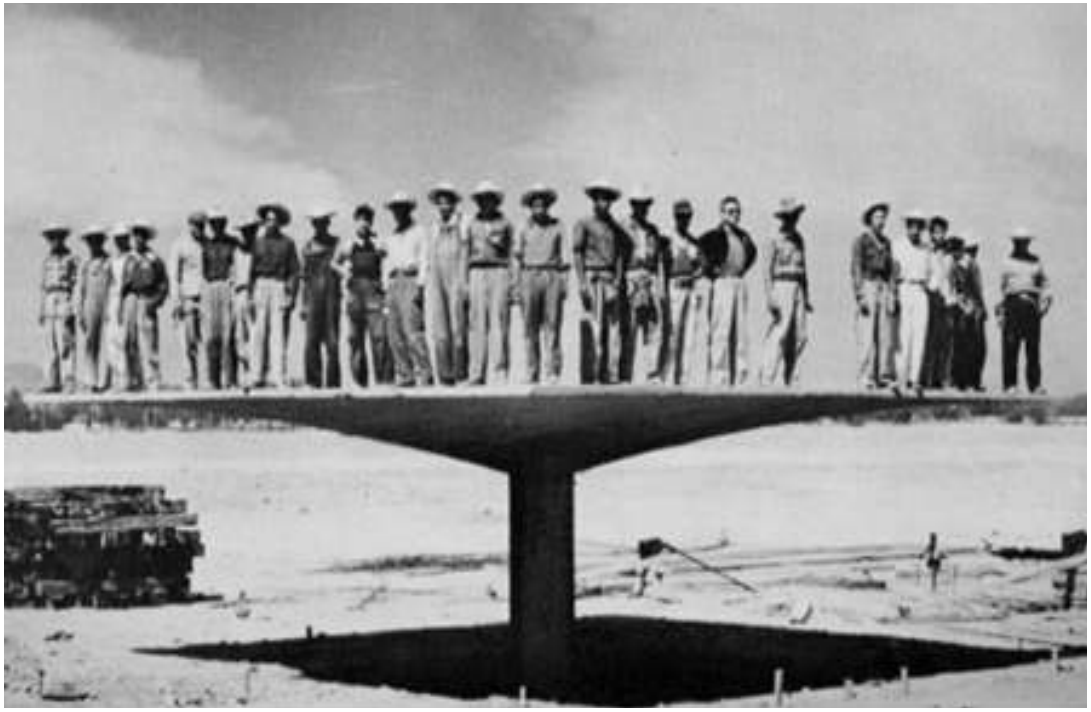
Rostislav Chudoba
Abedulgader Baktheer

Institute of Structural Concrete

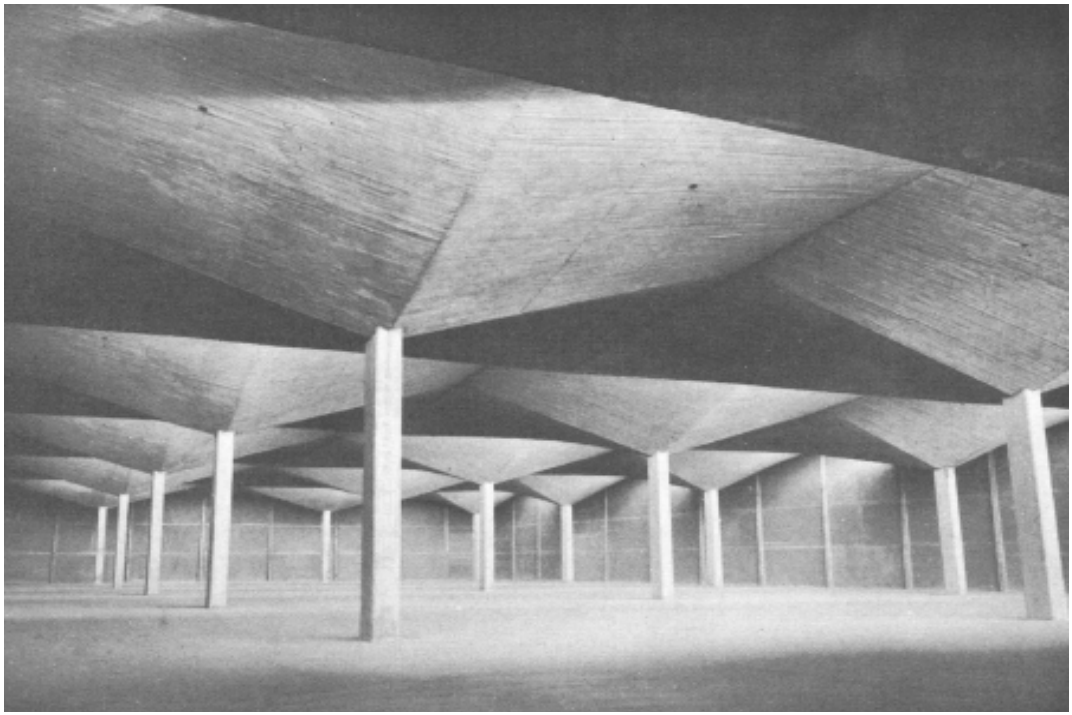
IMB RWTH AACHEN UNIVERSITY

... a bit of history ...

Félix Candela: HP shells (1)



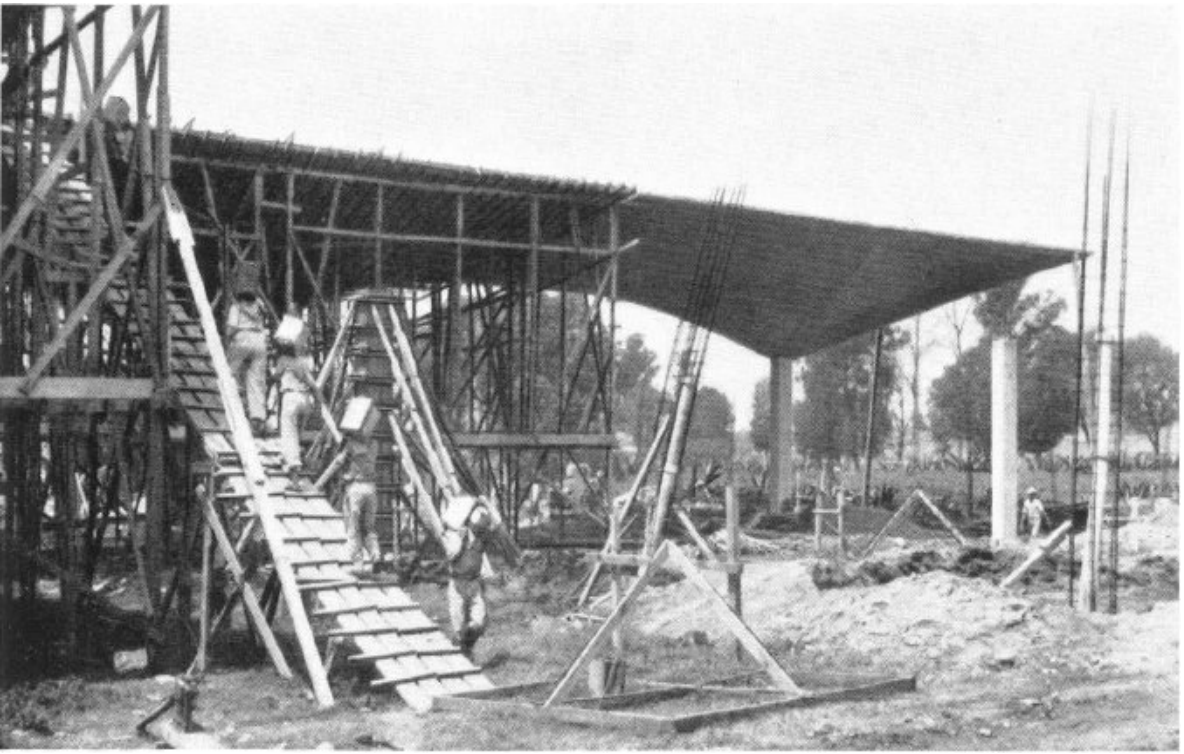
Félix Candela, Experimentalbau,
Las Aduanas, 1953



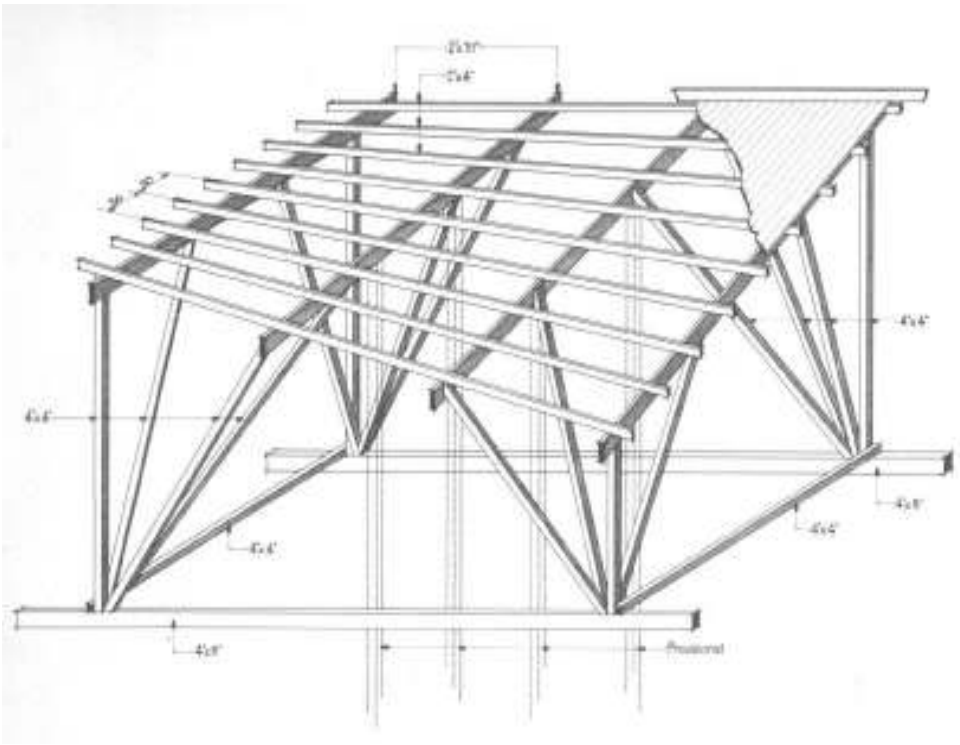
Lagerhaus Calestino, Vallejo,
Mexiko Stadt, 1956

Cassinello, P., Schlaich, M., Torroja, J.A.:
Félix Candela. In memoriam (1910-1997). From thin concrete shells to 21st century lightweight structures.

Félix Candela: HP shells (2)



continuous concreting



formwork

Félix Candela: HP – shells (3)

reinforcement

concreting

Félix Candela: HP – shells (4)

designed

dimensioned

built

around 800 RC shells

spanned up to 30 m

thickness 3 cm

Félix Candela: HP – shells (4)

designed

dimensioned

built

around 800 RC shells

spanned up to 30 m

thickness 3 cm

[1] "As a matter of fact, I am as lost and disorientated as you are. I am around 60 years old and 20 of them I spent as contractor and designer of structures, I know the trade of the traditional architect reasonably well and I neither find market nor use for some capabilities that cost me so much to achieve. I am out of place in today's world and I do not know what to do nor if I am worth anything."

Universidad Nacional Autónoma de México (1969)

Why?

concrete shells are (Cassinelo, Schlaich Torroja):

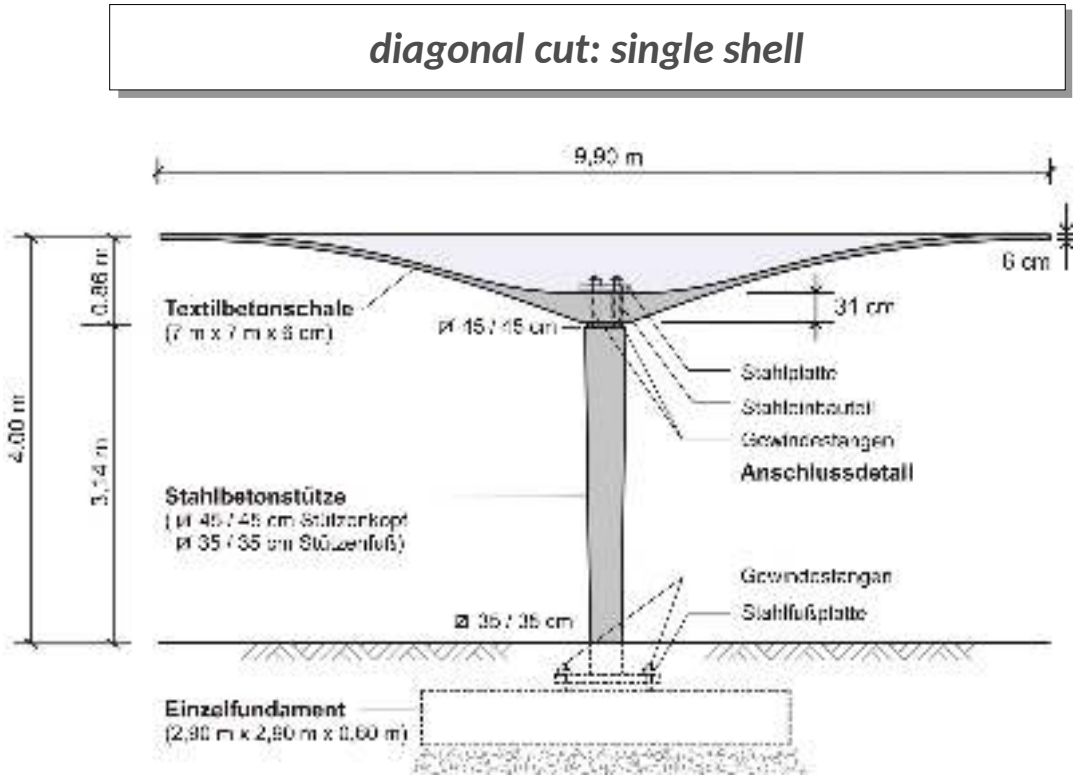
- out of fashion
- expensive
- not practical
- difficult to analyze
- dark
- not compatible with modern building physics
- not covered by building codes

…. it was NOT in vain!

T3 Pavilion, Aachen 2014

T3 pavilion: structure

SFB 532 – demonstrator,
RWTH Aachen

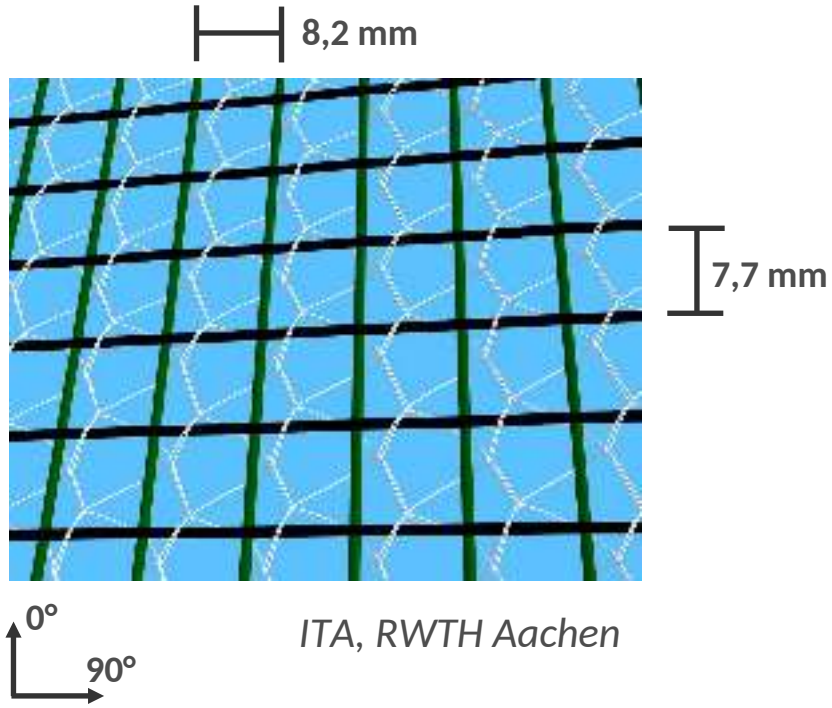


Scholzen, A.; Chudoba, R.; Hegger, J.: Dünnwandiges Schalentragwerk aus textilbewehrtem Beton: Entwurf, Bemessung und baupraktische Umsetzung, Beton- und Stahlbeton, Heft 11, 2012.

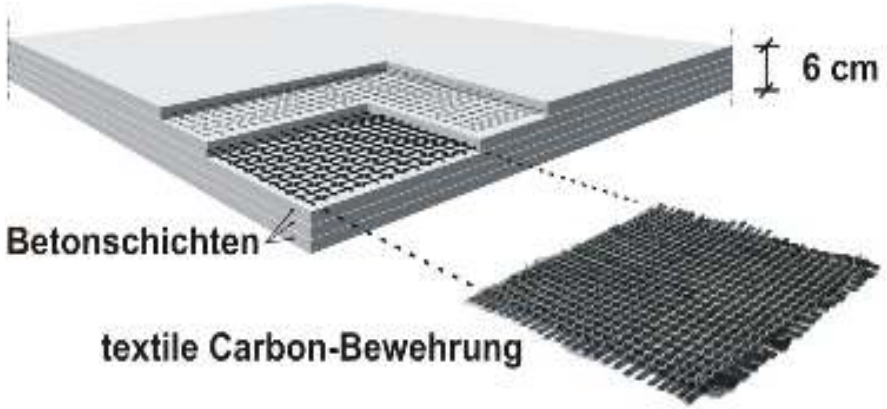
TRC shell cross section

carbon fabrics„ 2D-05-11“
non-penetrated carbon yarns: 800 tex

layout of the
TRC cross section:



ITA, RWTH Aachen



D – day: 14.12.2011

formwork

bauko2

manufacturing: alternating shotcrete and carbon fabrics layers

manufacturing: lamination and cutting

… exactly one century ago: 14.12.1911 at the south pole

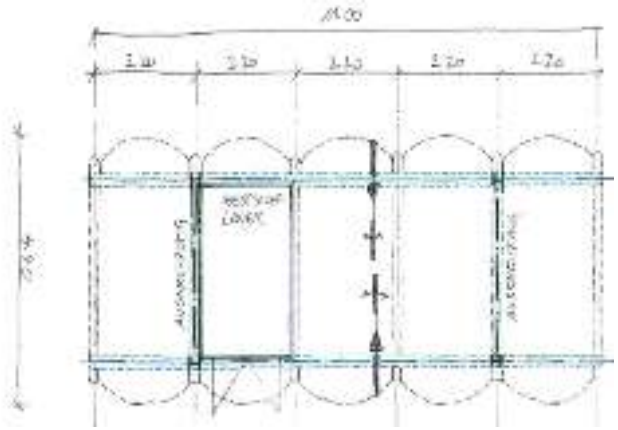
manufacturing: treatment

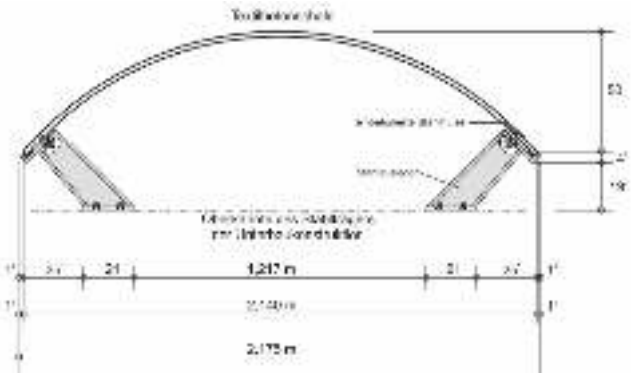
transport and mounting




another one

media and mobility module

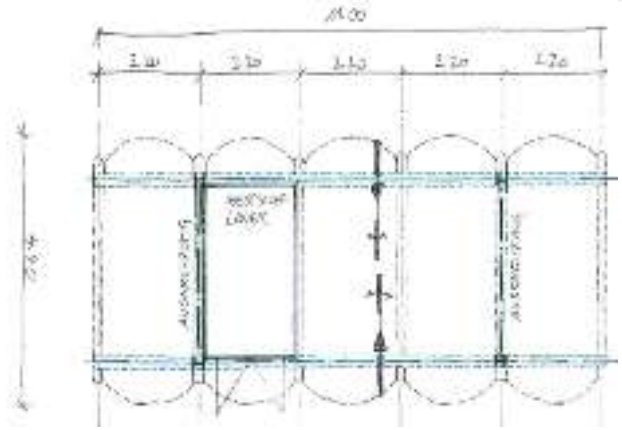


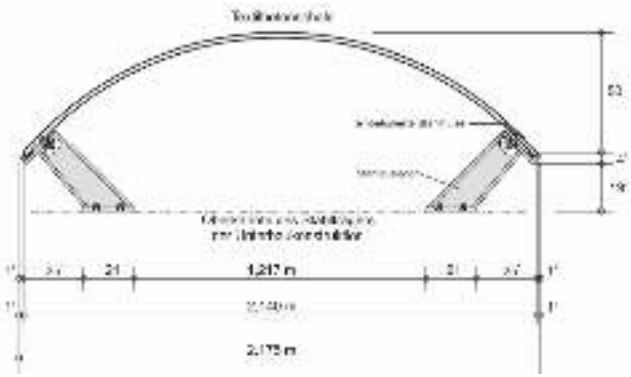


durapact Düsseldorf

IMB & ITA, RWTH Aachen

media and mobility module






IMB
ITA
DuraPact
ITA

But, … how to get simultaneously …

… high shaping flexibility
… high manufacturing efficiency
… high structural performance?

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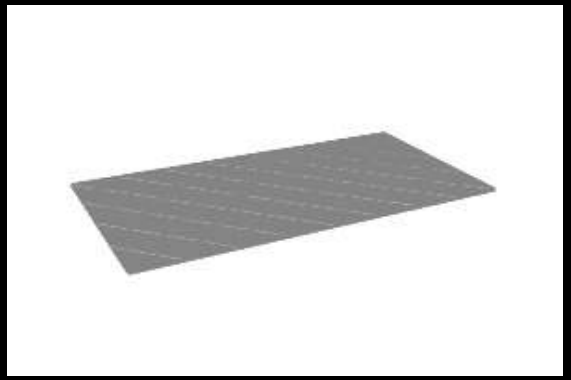
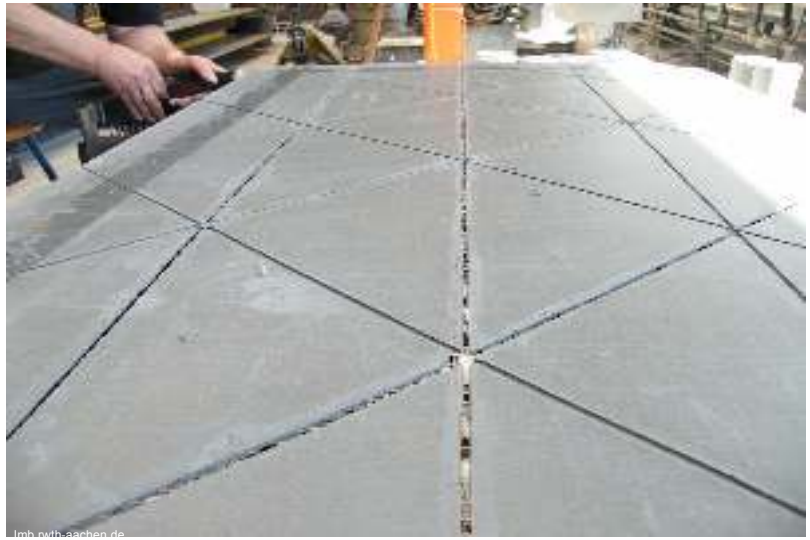


FOLD IT … ?!!

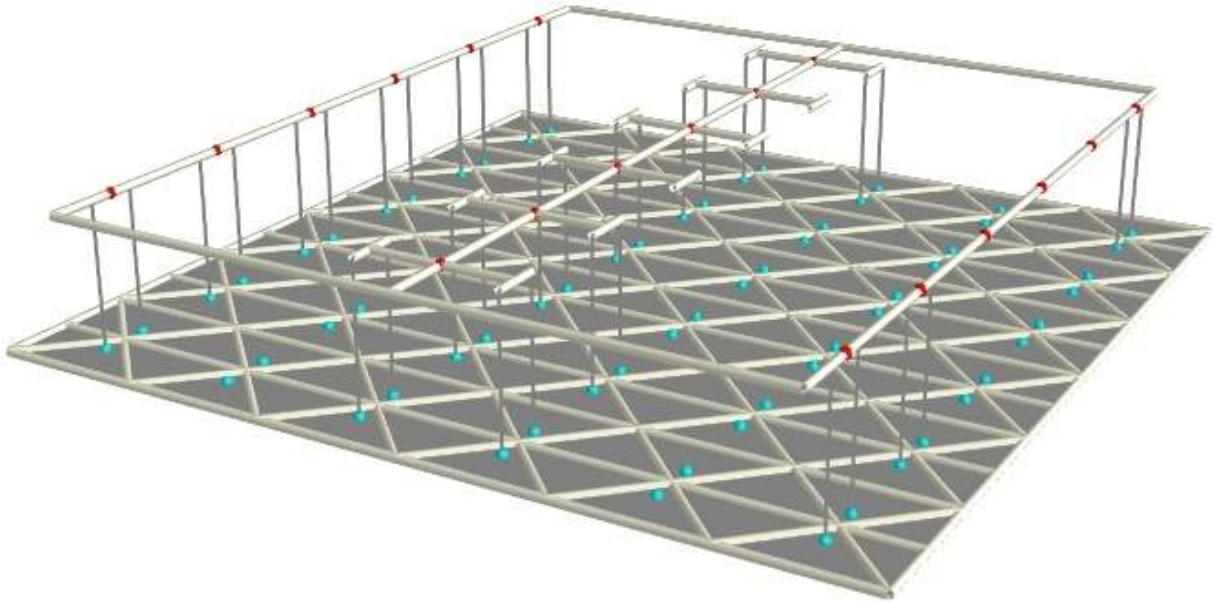
Yoshimura vault



Yoshimura vault

September 2009

efficient manufacturing ???



barrel vault I

- complex kinematics: shell with 100 facets
- form finding based on geometric relationships
- folding procedure using steel ropes and contact with scaffolding
- crease lines fixed by filling the creases with grout

van der Woerd, J.D.; Chudoba R.; Hegger, J.: *Design and construction of a thin barrel vault by folding*, IASS Symposium 2015, Amsterdam, 17. – 20. August 2015.

barrel vault II

- sequential folding
- no scaffolding
- folding into target shape
  by fixing the fold angles using
  profiled steel sheets
- injection of grout into
  the fold lines

bike shell-ter

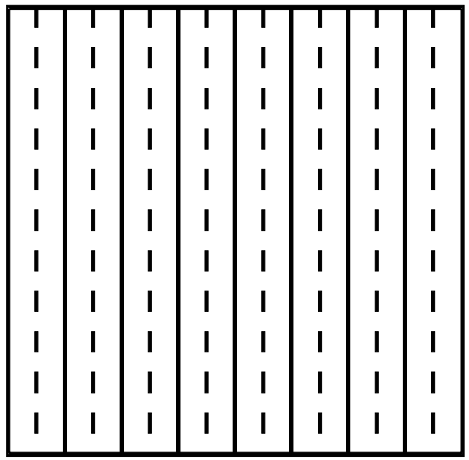
- larger fold angles
- combination of folding strategies
- steel ropes, scaffolding, force of gravity
- boundary with profiled steel sheets

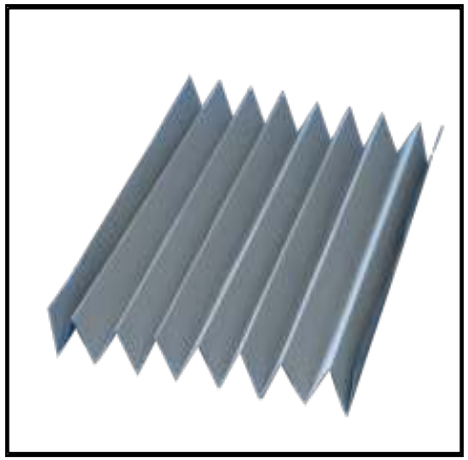
van der Woerd, J.D.; Chudoba R.; Hegger, J.: *Folded bike shell-ter: Application of oricrete design and manufacturing method*, IASS Symposium 2016, Tokyo, 26. – 30. September 2016.

shaping flexibility?

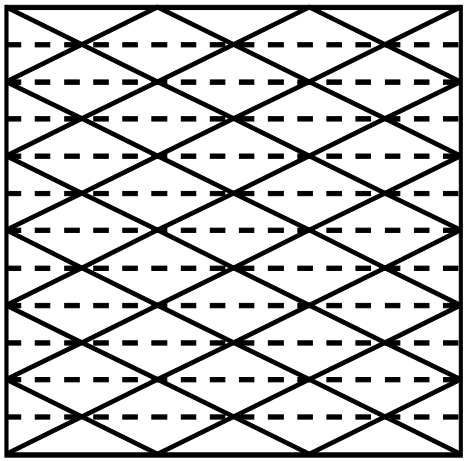
examples of crease patterns / tessellations

accordion

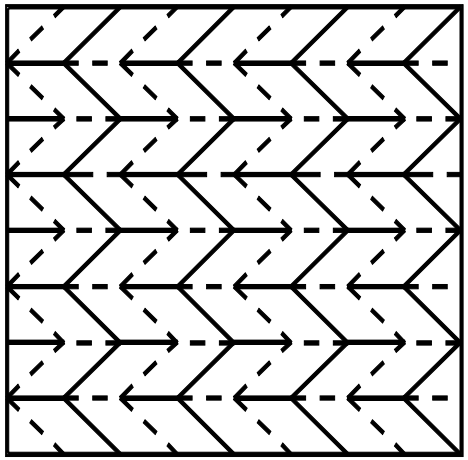


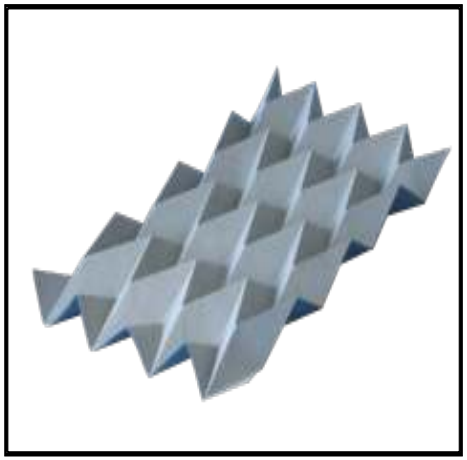


yoshimura

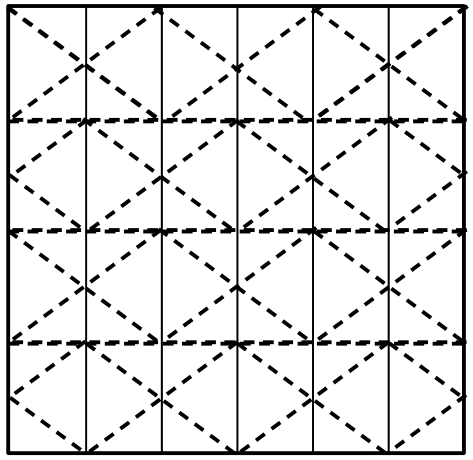


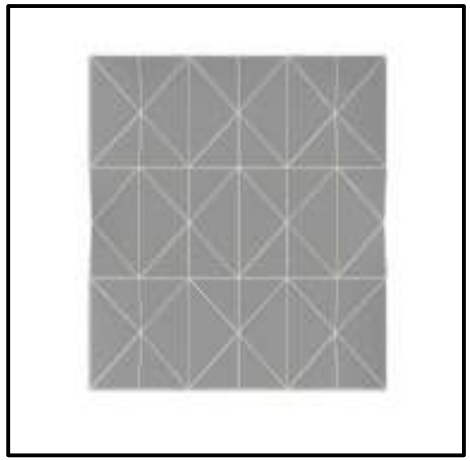
miura ori



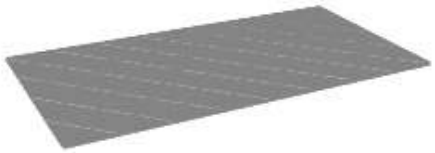


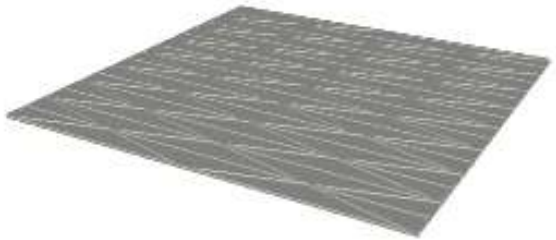
waterbomb





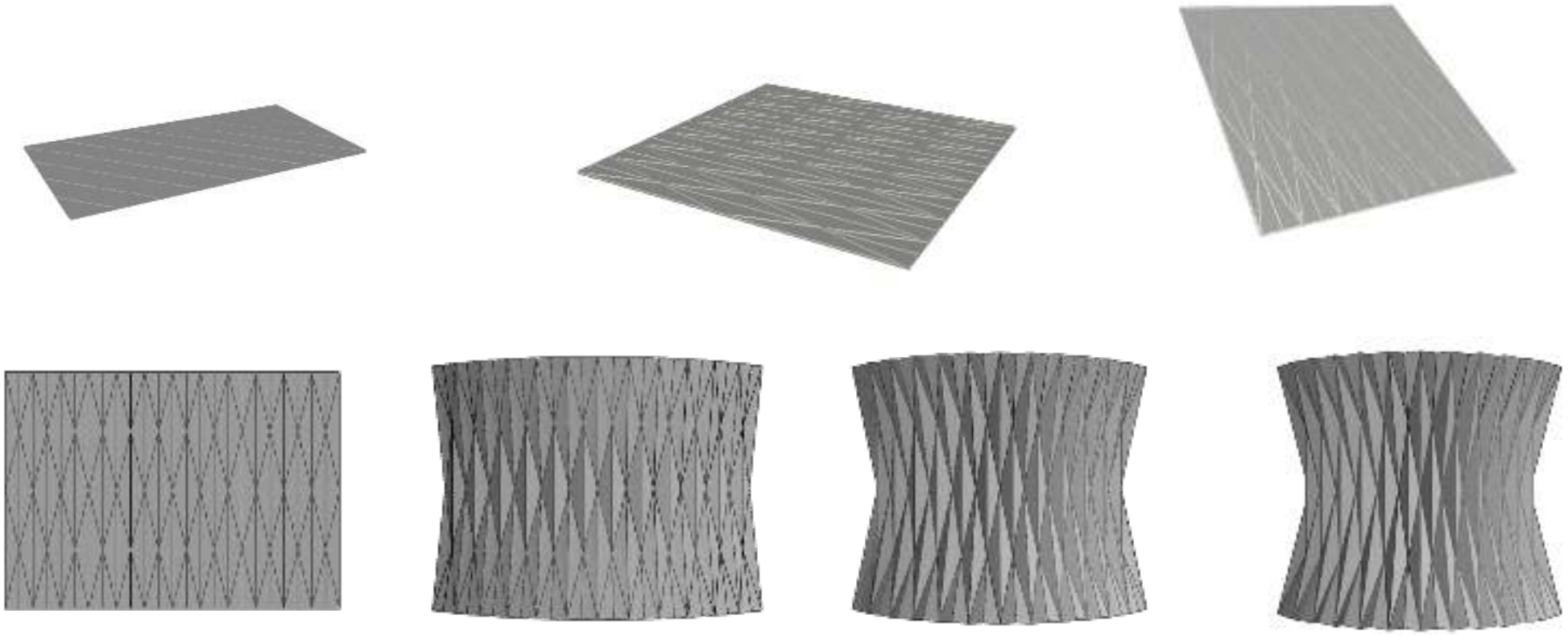
design space around yoshimura crease pattern





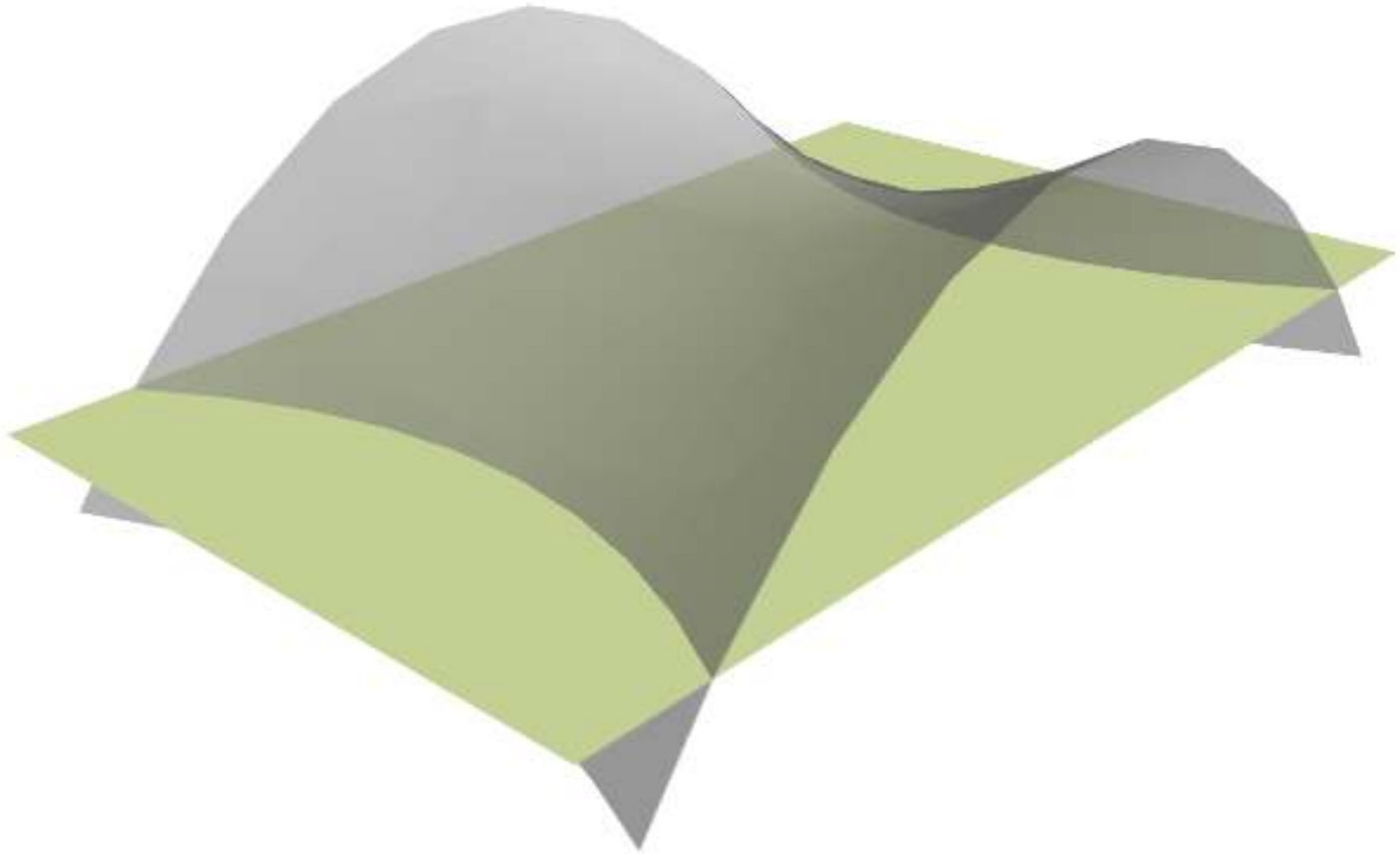
- rigid folding kinematics → rigid origami

design space around yoshimura crease pattern



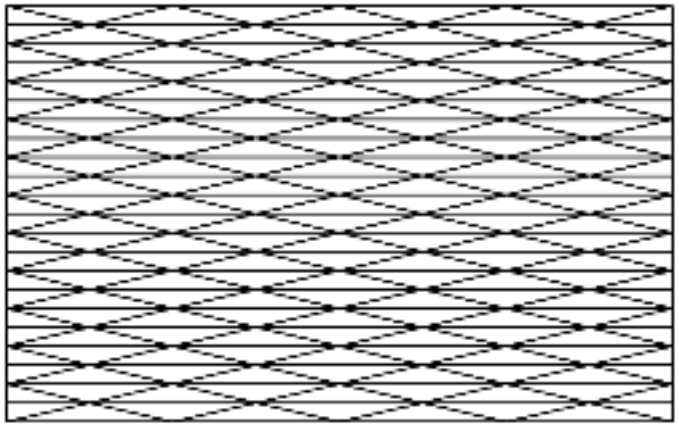
- non-uniform distribution of fold angles offers a limited shape flexibility

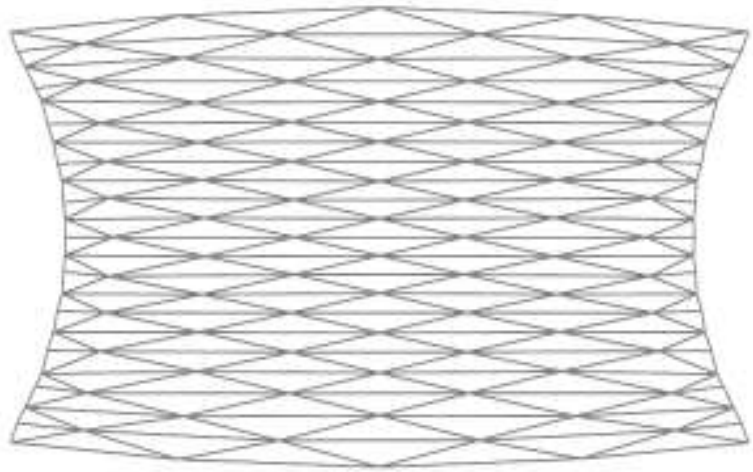
enhanced design space



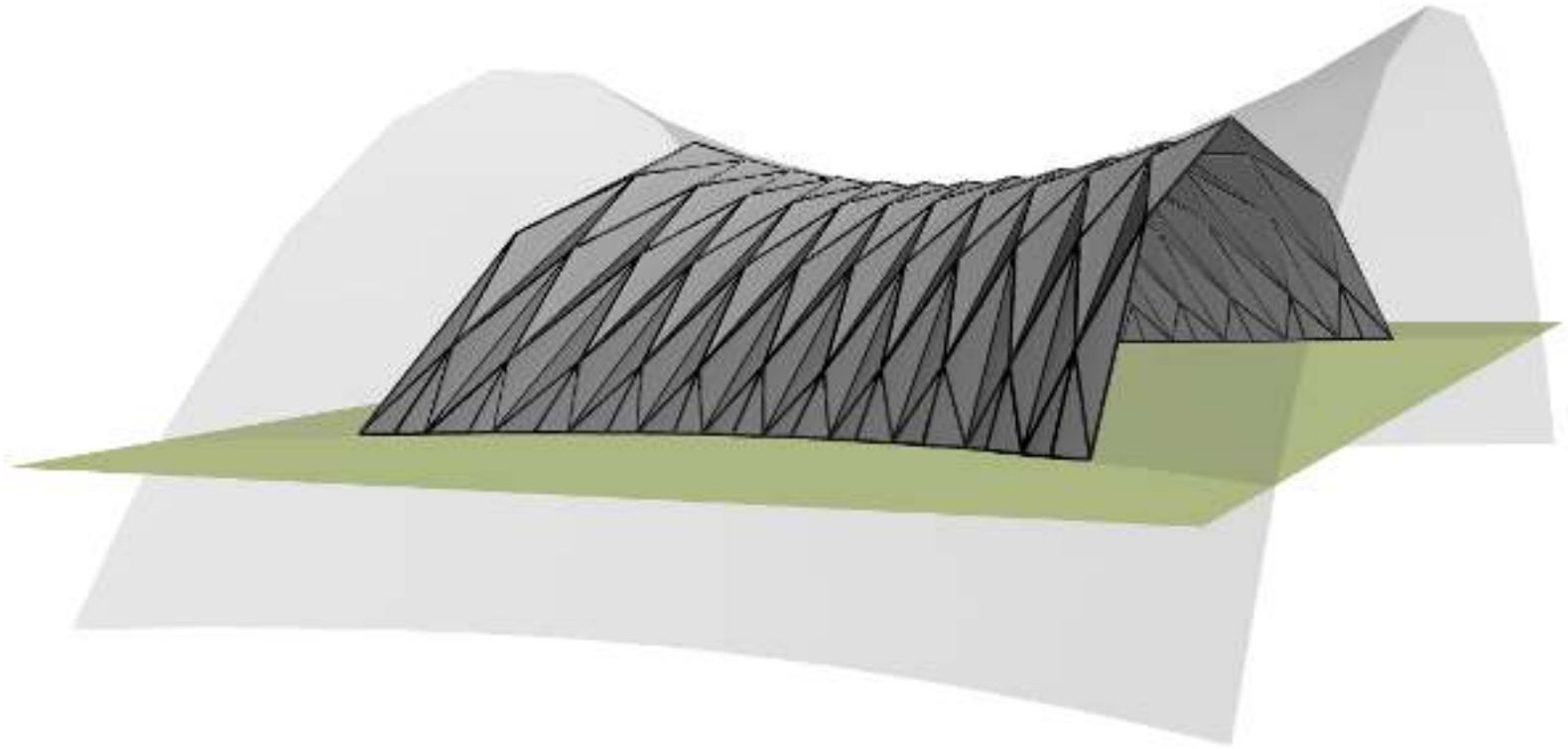
- modify a crease pattern to match the desired surface

form-finding: adapted crease pattern



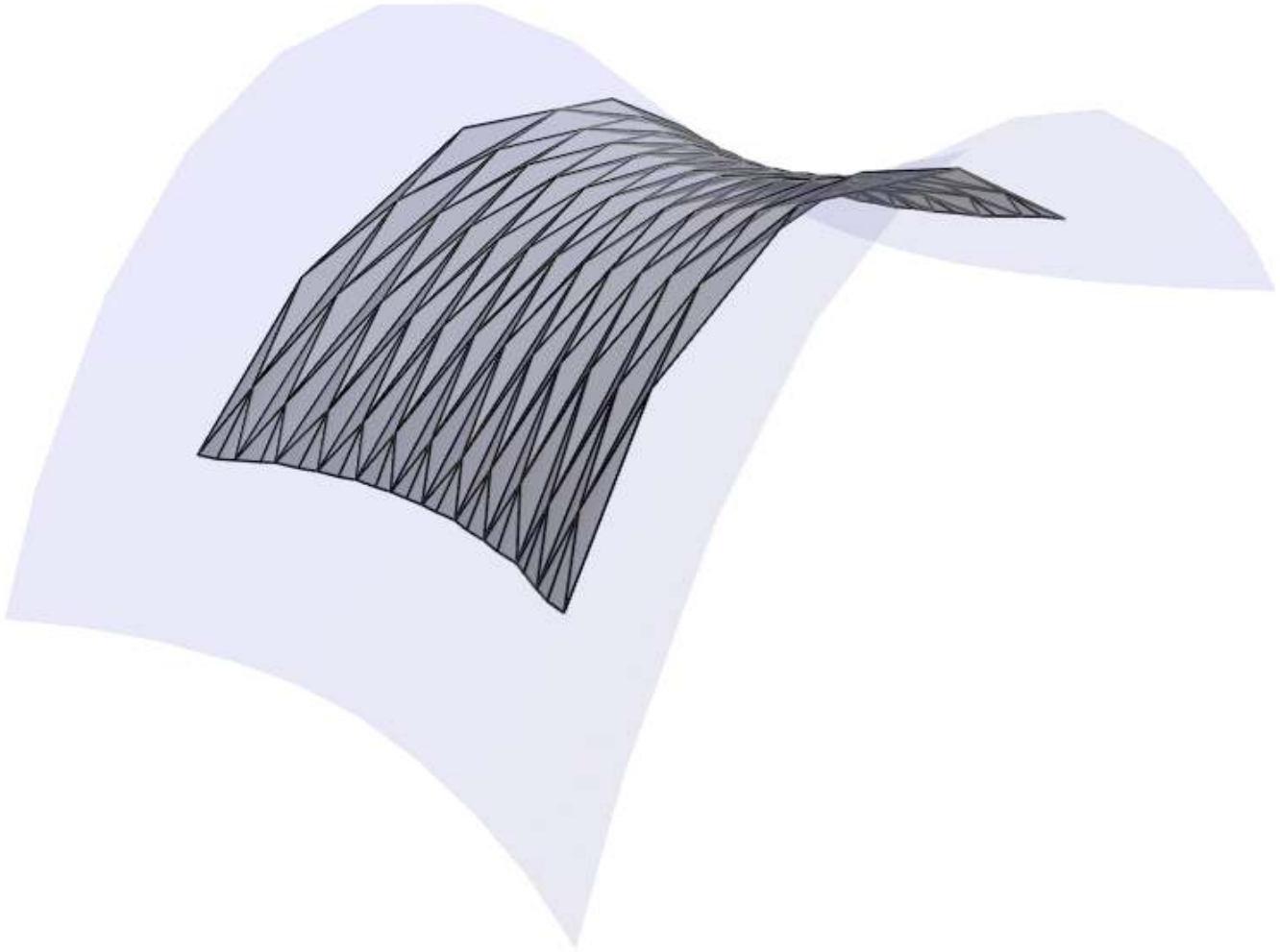


form-finding: target configuration

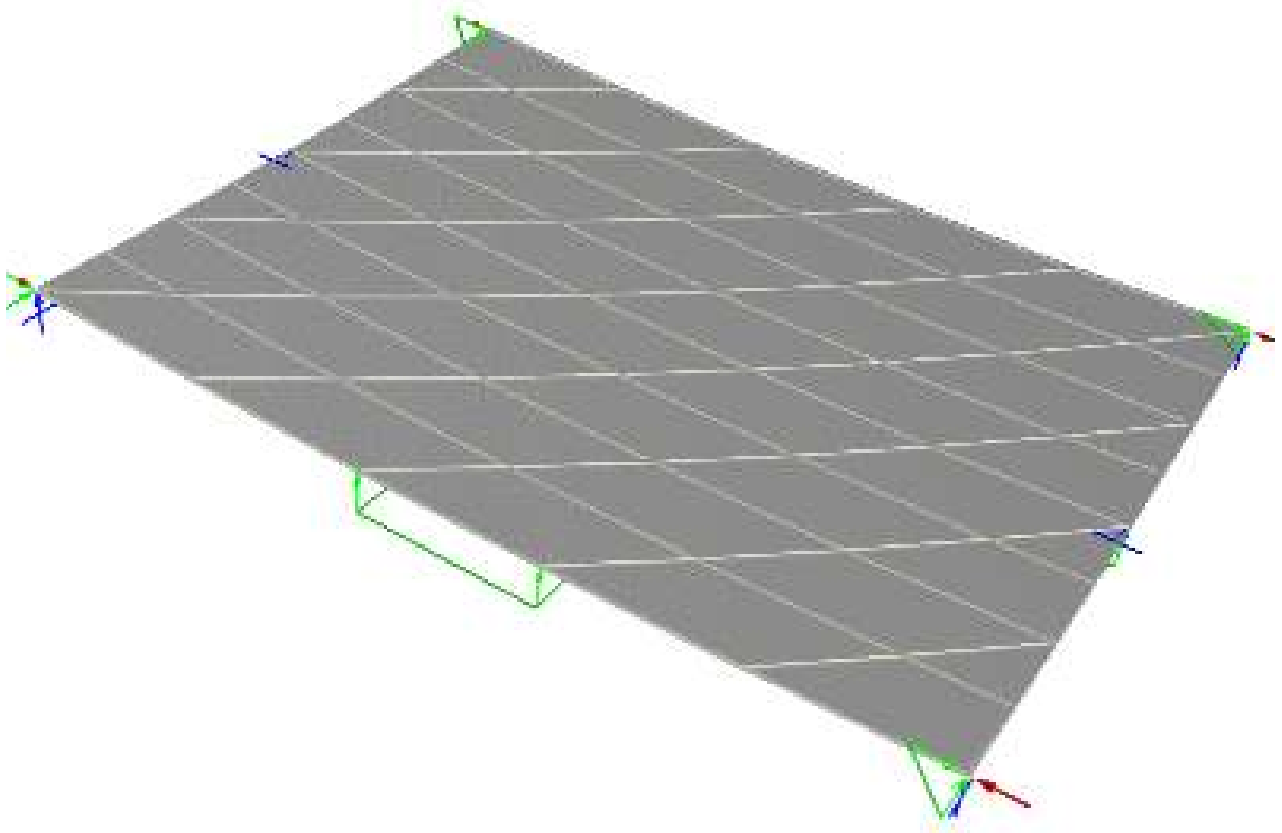


Chudoba R.; van der Woerd, J.D.; Hegger, J.: Oricreate*: modeling framework for design and manufacturing of folded-plate structures*, Origami6, 2015

developability: verification



shape induced by force-flow



- hanging-cloth …, or better hanging-crease pattern reversed
- identification of shapes with prevailing membrane forces

canopy shell

- doubly-curved shell
- hanging-cloth-reversed principle for form-finding and manufacturing
- consideration of force flow within the design

van der Woerd, J.D.; Chudoba R.; Hegger, J.: *Canopy – Doubly curved folded plate structure, Fib*-Symposium 2017, Maastricht,The Netherlands,12. – 14. June 2017.

segmentation / modularization

- large structures divided into small segments
- adaptation of crease pattern to segment geometry
- small scale study oridome assembled out of 20 segments

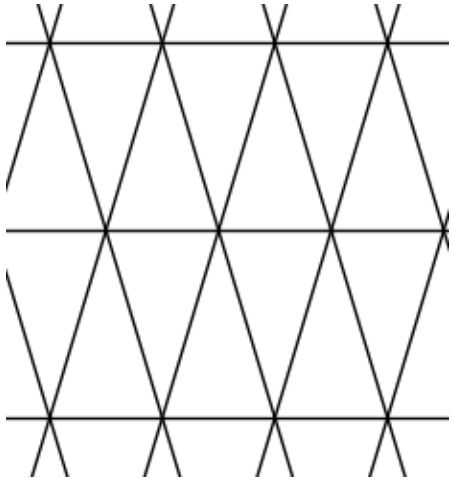
van der Woerd, J.D.; Chudoba R.; Hegger, J.: *Construction of a dome by folding*, IASS-SLTE Symposium 2014, Brasilia, 15. – 19. September 2014.

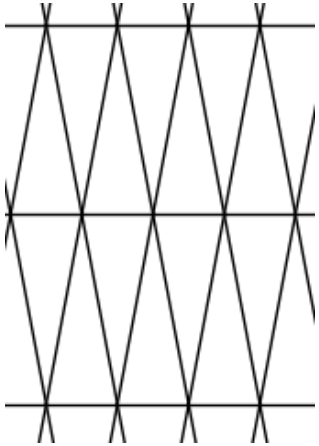
Folding principles provide the potential to balance the inherent trade-off between

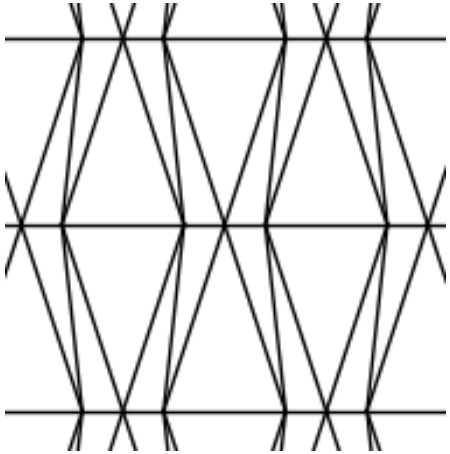
- complexity of forms – shell & spatial
- distribution of material in space leading to high structural performance
- manufacturing efficiency / mass customization

… but isn’t yoshimura crease pattern somewhat boring?

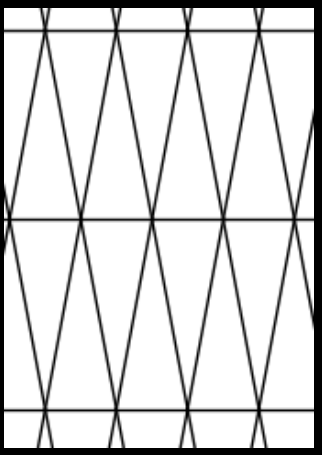
Tessellations with six-crease waterbomb base

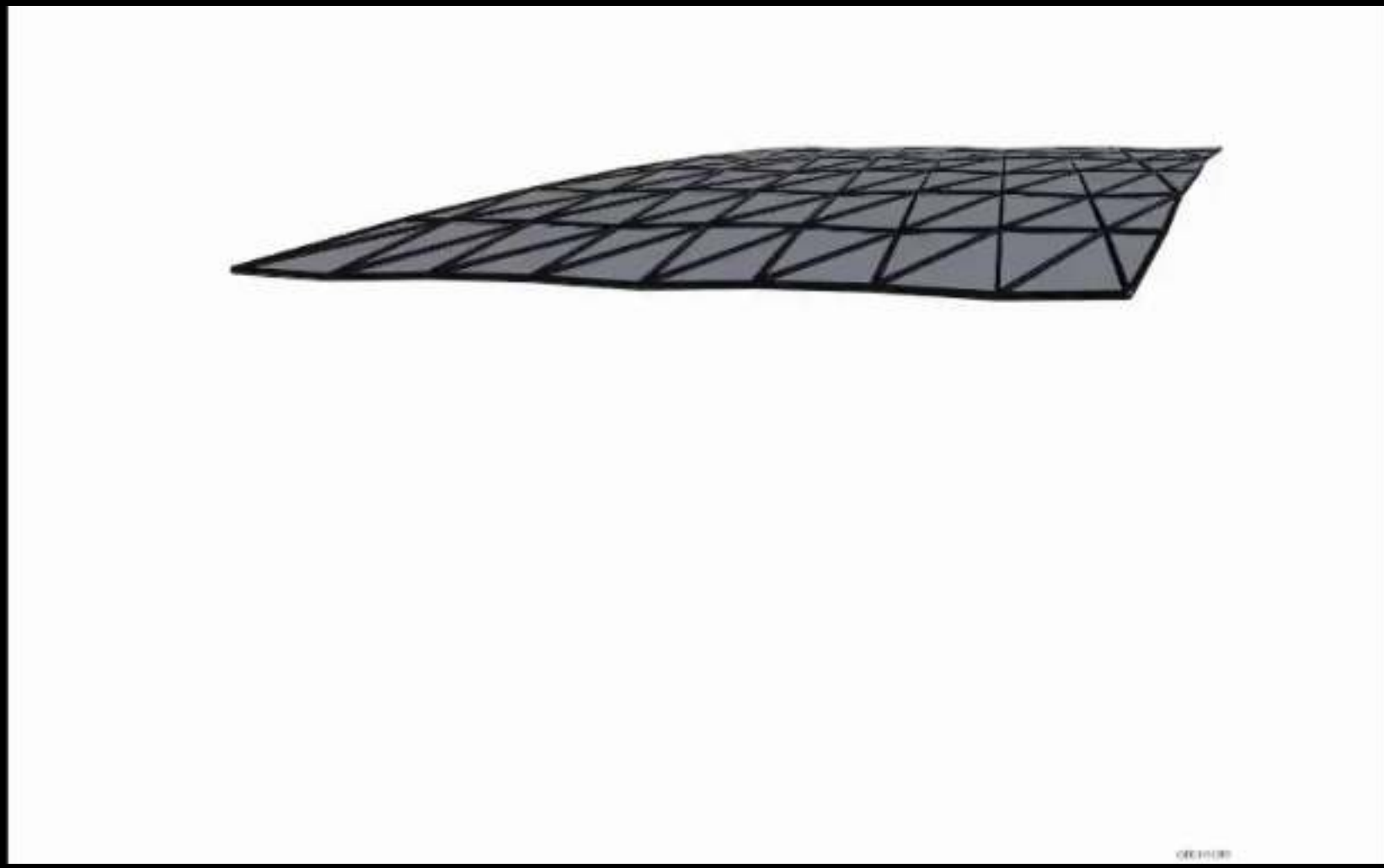




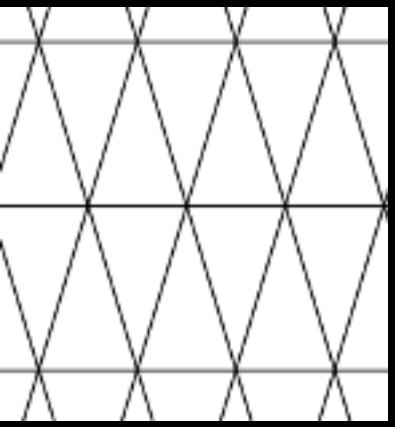


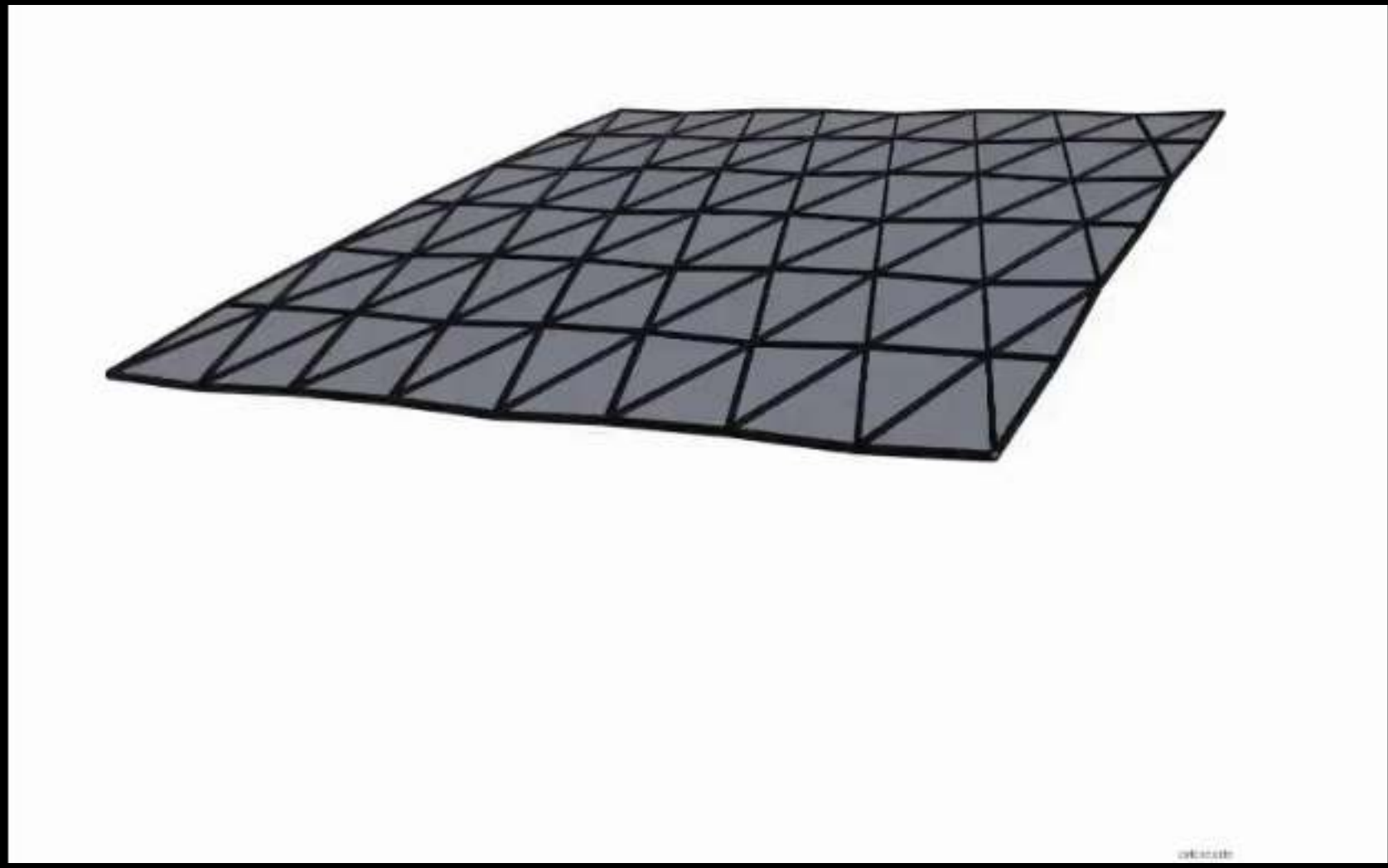
Tessellations with six-crease waterbomb base



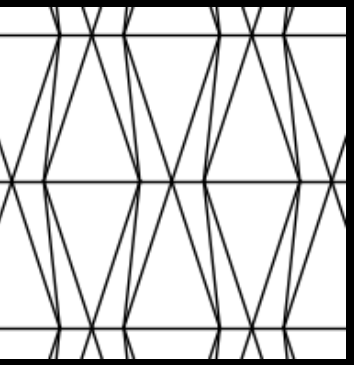


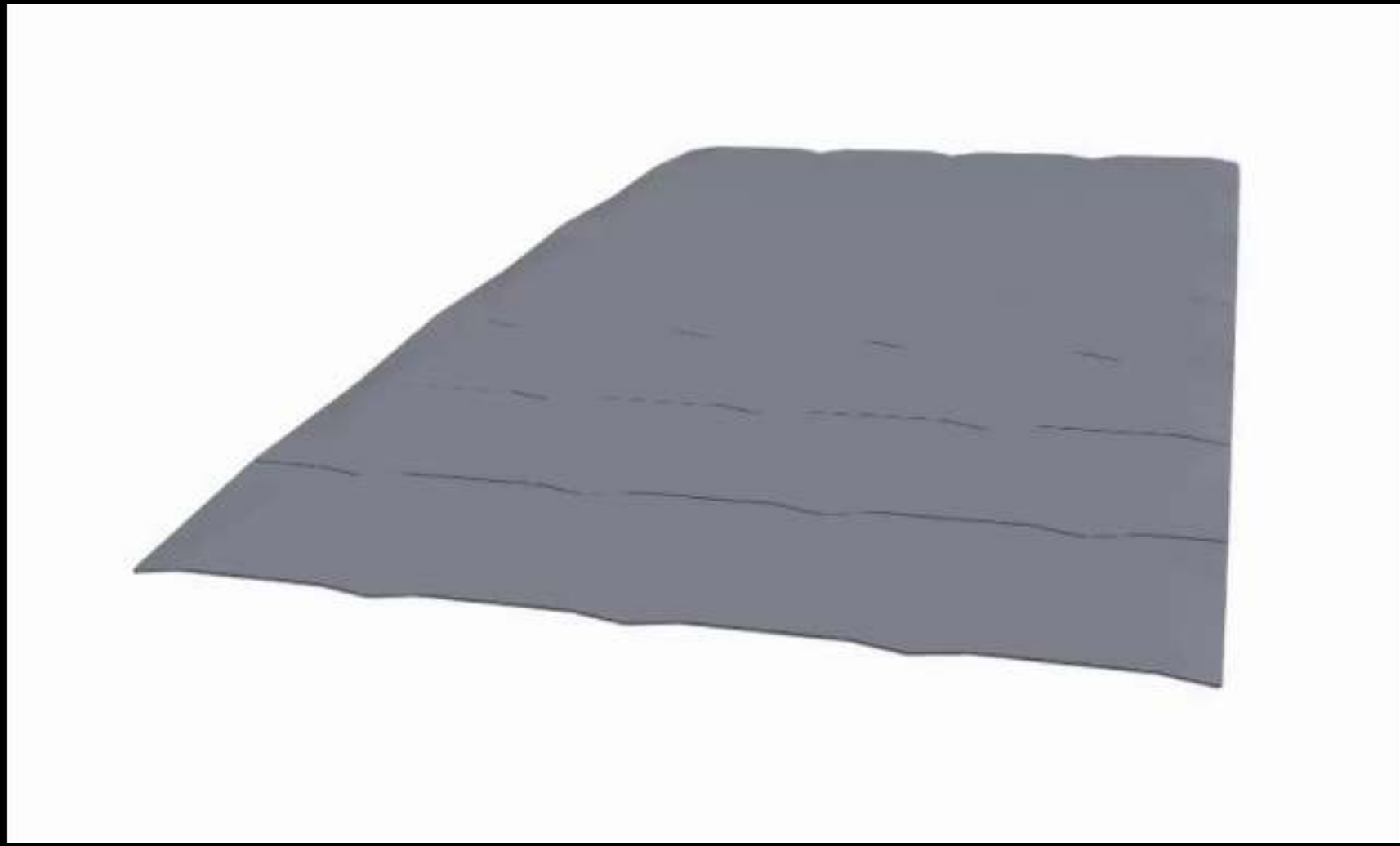
Tessellations with six-crease waterbomb base





Tessellations with six-crease waterbomb base





ORICRETE PROTOTYPES

Waterbomb Shell IV

Rostislav Chudoba
Jan Dirk van der Woerd
IMB RWTH Aachen University

02/2018

... thank you for your attention!