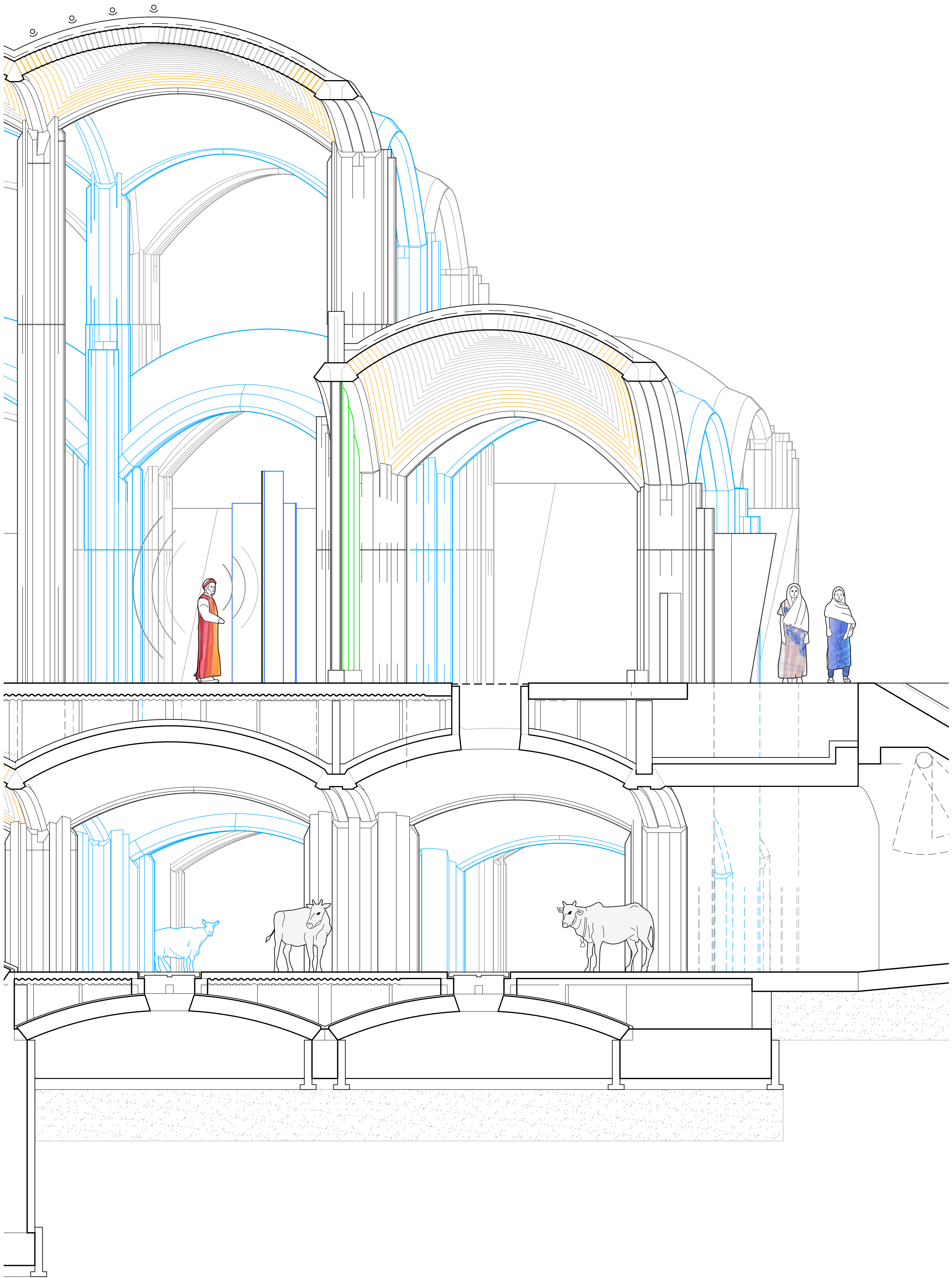
J F C Lemay



A Cyclone Shelter For Coastal Bangladesh

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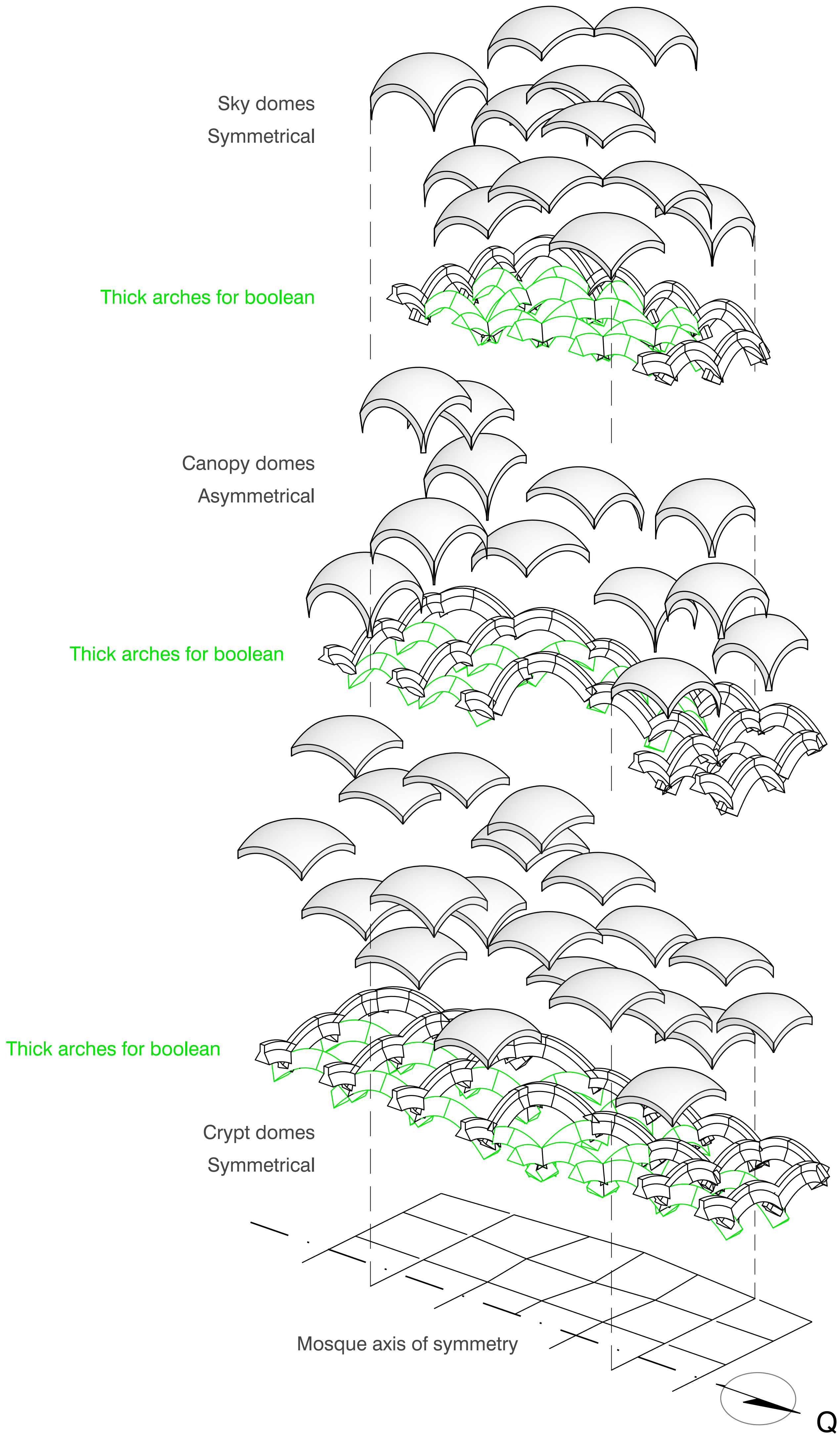

Jean-François C. Lemay

A Cyclone Shelter For Coastal Bangladesh

A 4th year student project at the Architectural Association School, London, UK

Teachers Simon Beames and Kenneth Fraser, Diploma 7

2007 – 08

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A 4th year student project at the Architectural Association School, London, UK

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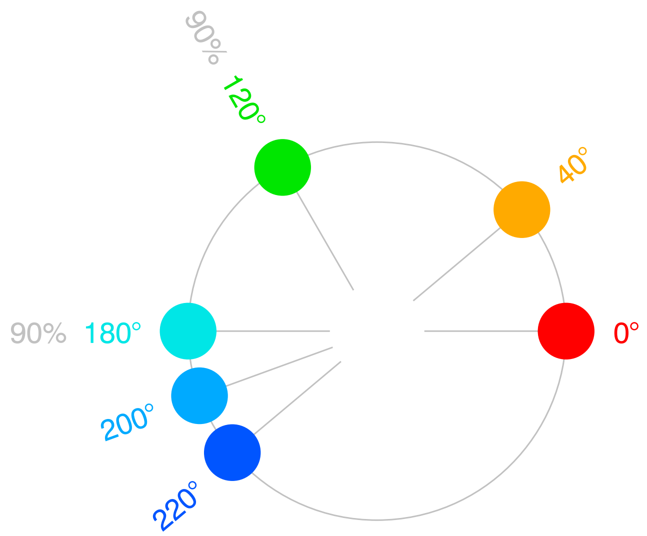

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Timeline

1 October 2007
Start of AA academic year

Chapter 1
1 Oct - 28 Nov

15 November 2007
Cyclone Sidr strikes the coastal areas of Bangladesh, killing 3200 persons and 460 000 livestock, affecting 8.4 million people.

Bangladesh

1 January 2008

Chapter 2
13 Dec - 28 Jan

28 January 2008
Life After Cyclone Sidr, an exhibition by Diploma 7, opens in the AA bar.

Chapter 3
29 Jan - 16 June

16 June 2008
Final presentation (4th year students)

4 July 2008
End of AA academic year
Projects review exhibition opens

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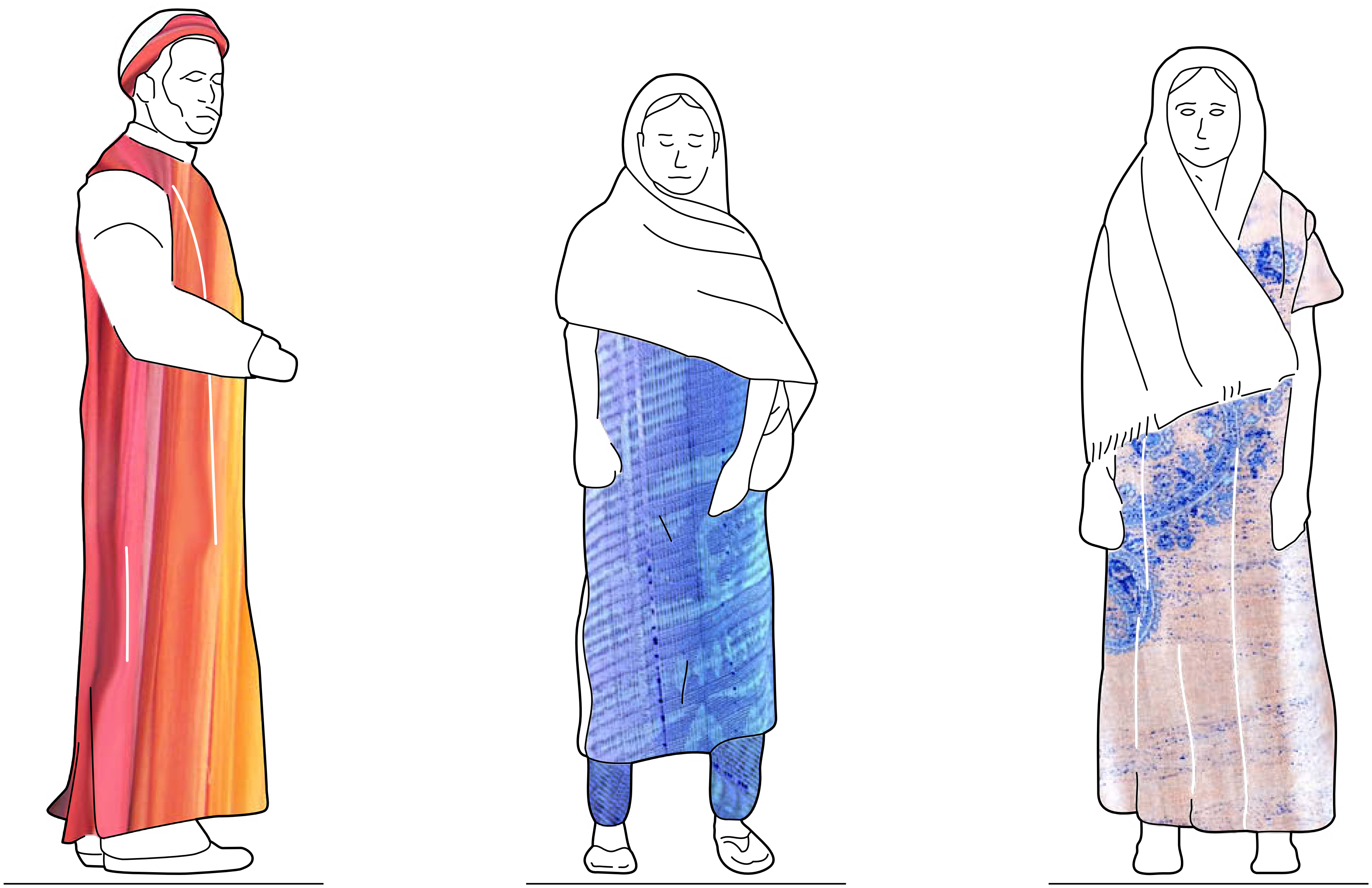
Moshe Safdie and Associates



I would also like to thank my teachers at the AA, Simon Beames and Kenneth Fraser; and in Dhaka, the faculty of the BRAC University Department of Architecture, for their great assistance.

À mon ami Vincent Giard.

DIPLOMA UNIT 7

Simon Beames, Kenneth Fraser

There are fast-growing numbers of people who can no longer gain a secure livelihood in their homelands because of drought, soil erosion, desertification, deforestation and other environmental problems. In their desperation, these 'environmental refugees' … feel they have no alternative but to seek sanctuary elsewhere, however hazardous the attempt.

Norman Myers, *Environmental Exdous: An Emergent Crisis in the Global Arena*, 1995

Political conflict and geographical phenomena are displacing unprecedented numbers of people. Last year's unit project, 'One-year house', was stimulated by the question of political migration. A 1:1 prototype house was constructed at the Maela refugee camp on the Thai–Burma border, and assessments of its performance are ongoing. In a context where the population is denied a permanent base, the concept of 'temporary housing' has begun to be challenged.

In 2007/08 this research will be extended to Burma's neighbour, Bangladesh, and specifically to the Ganges Delta. Home to 100 million people, this is the most densely populated place on earth. It also experiences some of the most extreme climatic conditions, ranging from long periods of drought to violent storms and monsoon floods. Here, communities survive through tactical, environmental migration. Diploma Unit 7 will explore the philosophical, social, political and technical responses to the provision of long-term settlements in this environment, working with a research group that includes technologists and theorists as well as NGOs responsible for live-field projects – the emergent strategy will be applied in response to their requirements.

The year's programme will develop from component to urban strategy. Investigating solutions of increasing scale from rapid prototype to rapid manufacture, Diploma Unit 7 will assemble a logical argument based on the critical evaluation of component-based systems, as follows:

Organisational Network: operating successfully in extraordinary contexts requires the formation of diffuse contact networks.

Social: appropriate application of technology and energy; development of tactics though interview and interaction.

Environmental: extended component systems developed into a socio-economic taxonomic structure.

Structural: constructional strategies tested through extensive research and development.

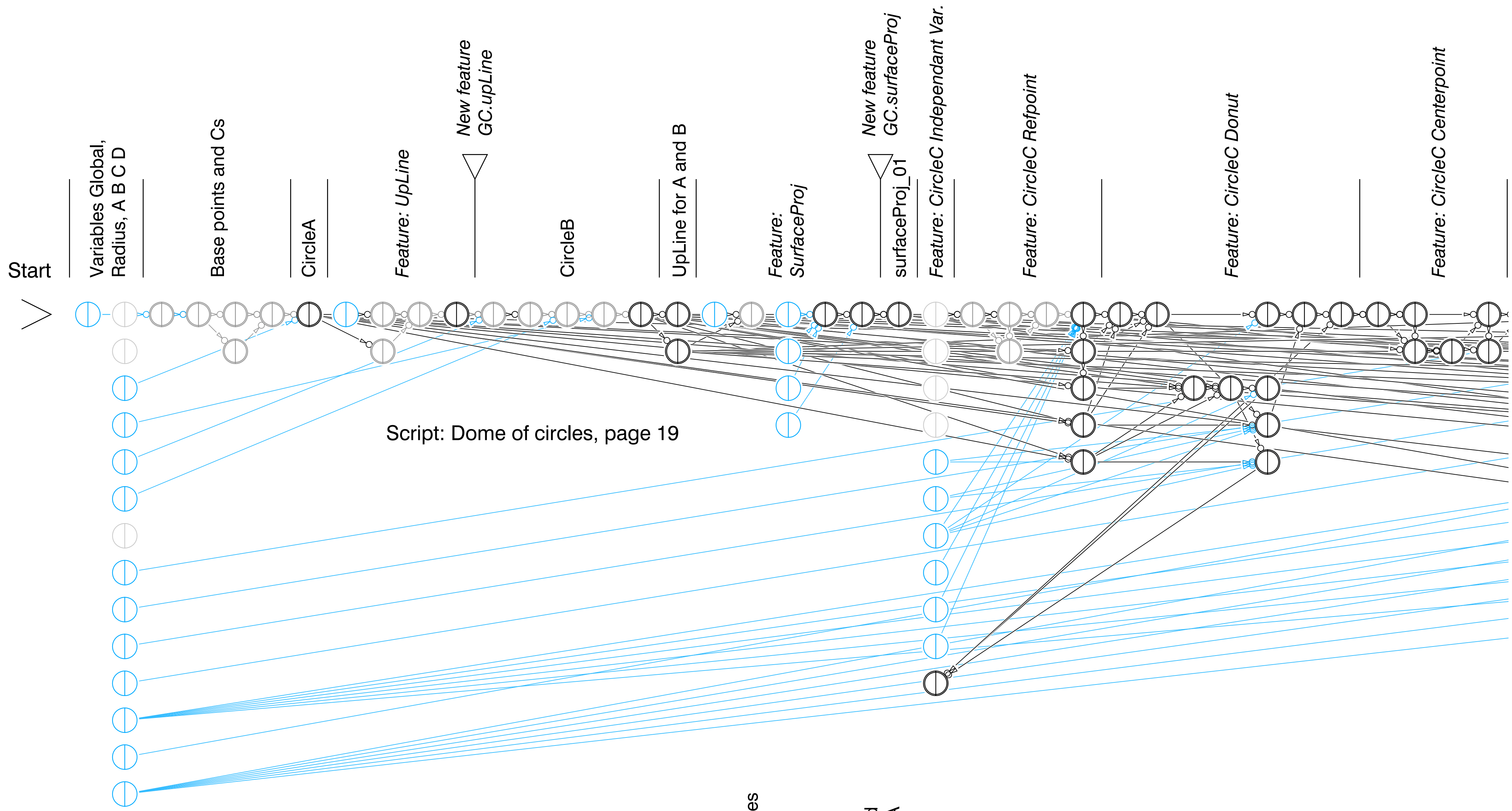
Economic: human self-interest, global ecology, sustainability and fair trade feature in the resolution of live projects.

Application: output from analysis will be a construction manual applied to production information used for manufacturing.

Material Systems: development of a material system based on local technological context, knowledge transfer, renewable resources and hybridity.

Simon Beames is director of YOUMEHESHE (youmeheshe.com) and architect for COTE, an NGO involved in construction and re-socialisation following conflict and disaster. At Grimshaw he led projects including Battersea Power Station and Rensselaer Electronic Media and Performing Arts Building.
Kenneth Fraser is a principal of Kirkland Fraser Moor (k-f-m.com). He previously worked with Renzo Piano Building Workshop, where he was project leader for the Rome Auditorium and the Padre Pio Pilgrimage Church.

Image: Detail of one-year house developed by Asif Khan and Julia King for the Maela refugee camp, June 2007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CircleB
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New feature GC.surfaceProj
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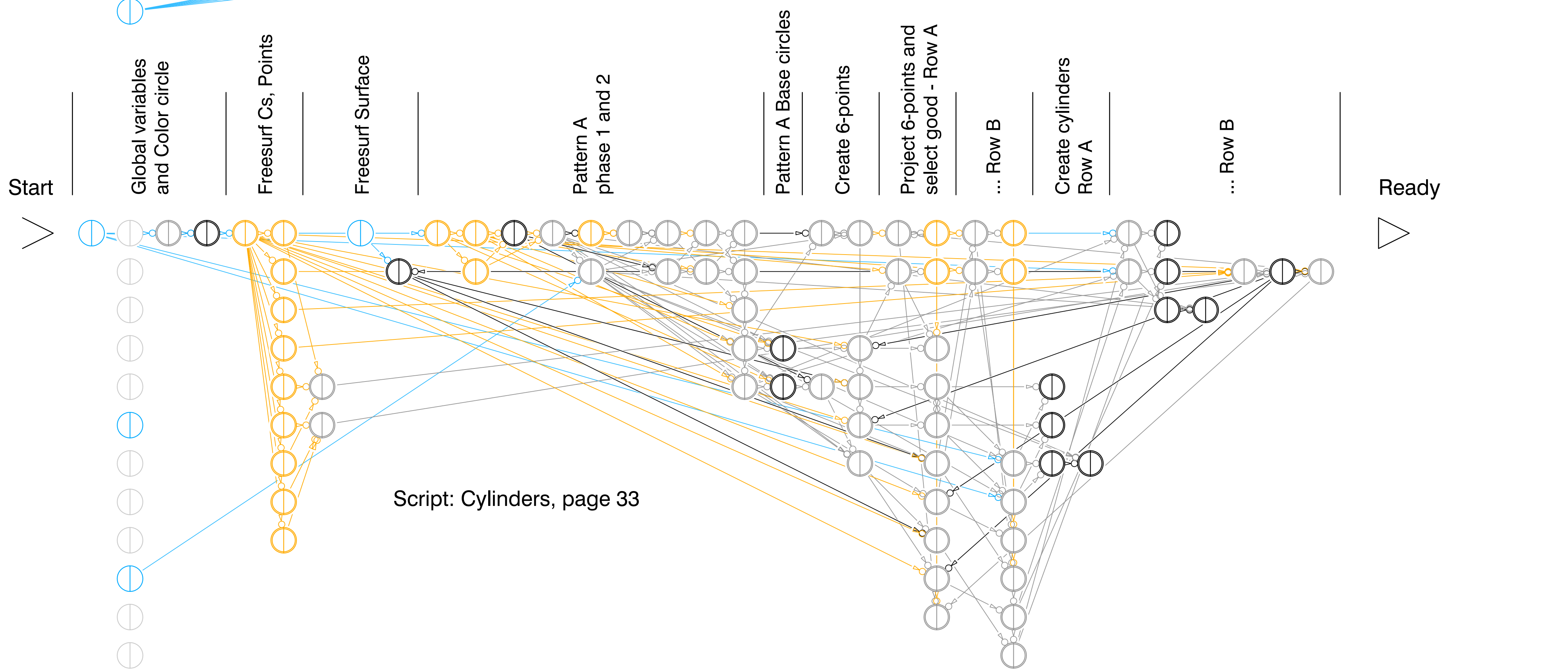
Feature: CircleC Refpoint
Feature: CircleC Donut
Feature: CircleC Centerpoint
Script: Dome of circles, page 19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... Row B
Create cylinders Row A
... Row B
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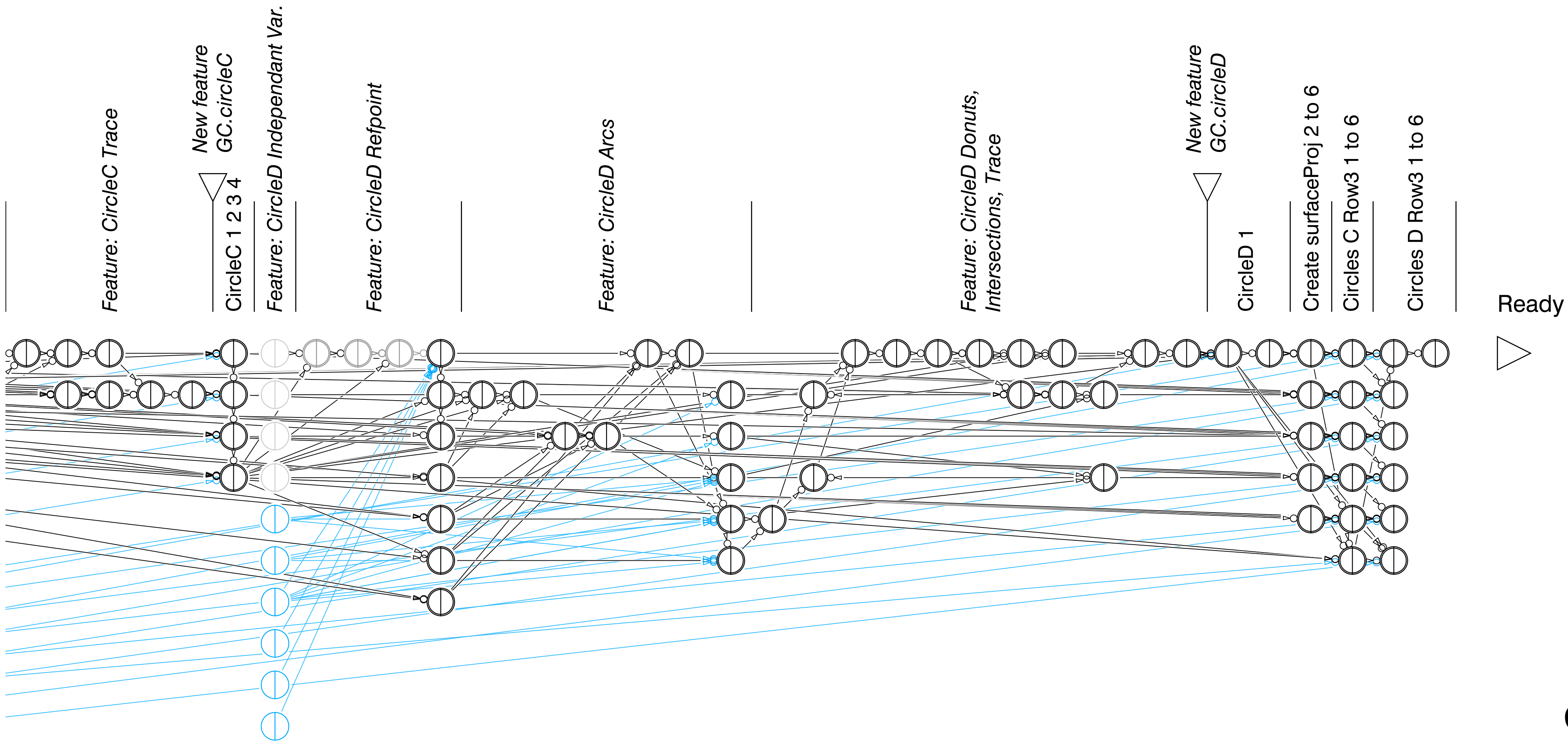
Script: Cylinders, page 33

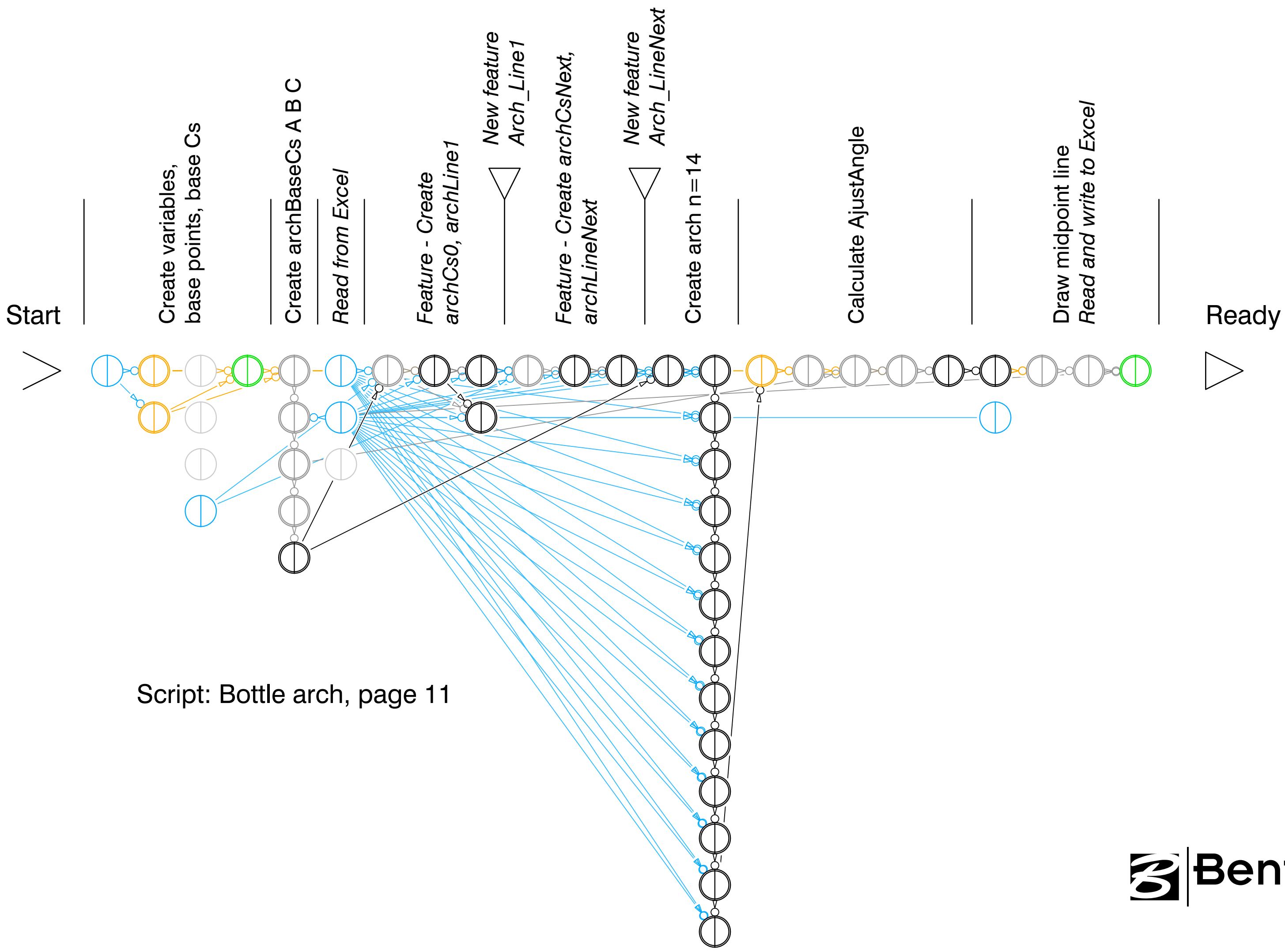


Chapter 1

Components and shelter

Although we knew that, later in the year, our sites would be in Bangladesh, we began the year with an exercise: to draft ideas of shelters which could work in many contexts (not just Bangladesh). Bentley provided the studio with Generative Components (GC), a software for parametric design, and we tried to see where it could take us. At the end of the semester, we were each asked to arrive at a shelter design made of repetitive (not necessarily identical) parts or components.

The graphs on the left are the symbolic diagrams of the GC scripts contained in this chapter. They are indicators of the scripts' respective complexity.



Script: Bottle arch, page 11

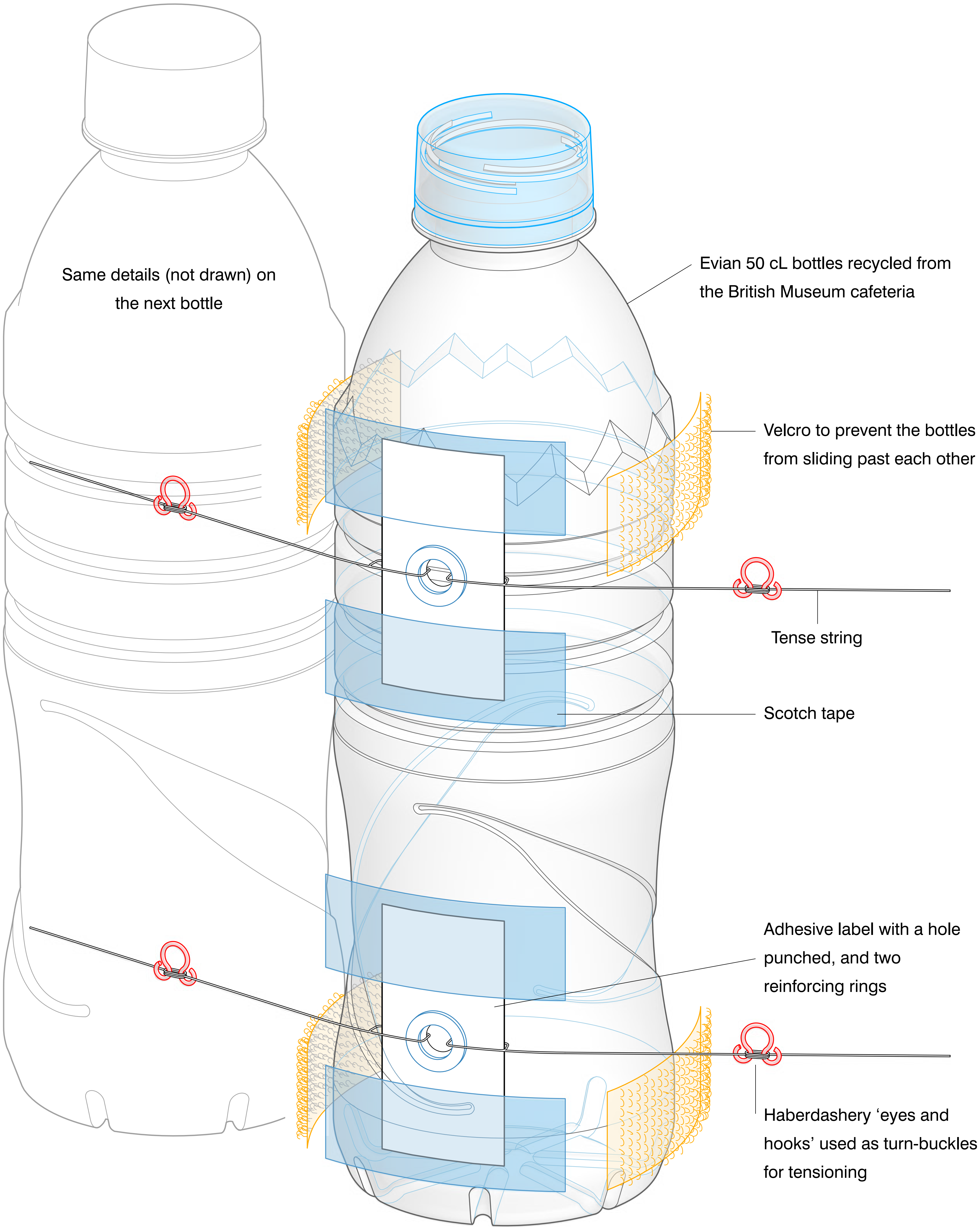
Bentley GENERATIVE COMPONENTS

1.1 An arch made of bottles

Although it uses water bottles, this one-week exercise really looked at the possibility of using cylindrical objects to make an arch. It is challenging to make a structure with cylinders side by side, since they barely touch and tend to slip past each other. However, many cylindrical objects exist (stronger water bottles, barrels, drums, woven baskets) which it would be fascinating to turn into canopies.

The 36 water bottles were collected from the British Museum cafeteria (in 2007, they would otherwise have been sent as garbage, since the cafeteria didn't recycle). String was used to create tension between the bottles. Haberdashery 'eyes' were used to increase the tension; these were advantageous, since they could be inserted on a string already tied at both ends.

The teachers asked to translate this idea to double curvature, hence I began to think about a cone dome (see p 12).

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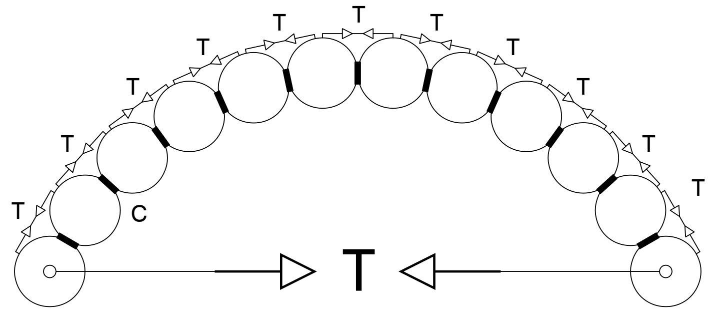
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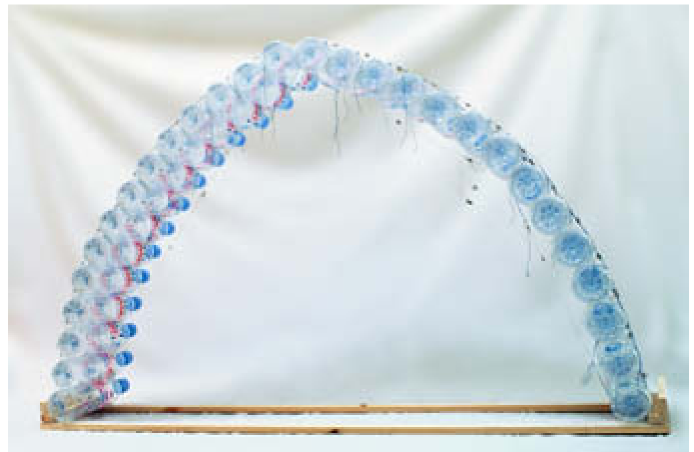
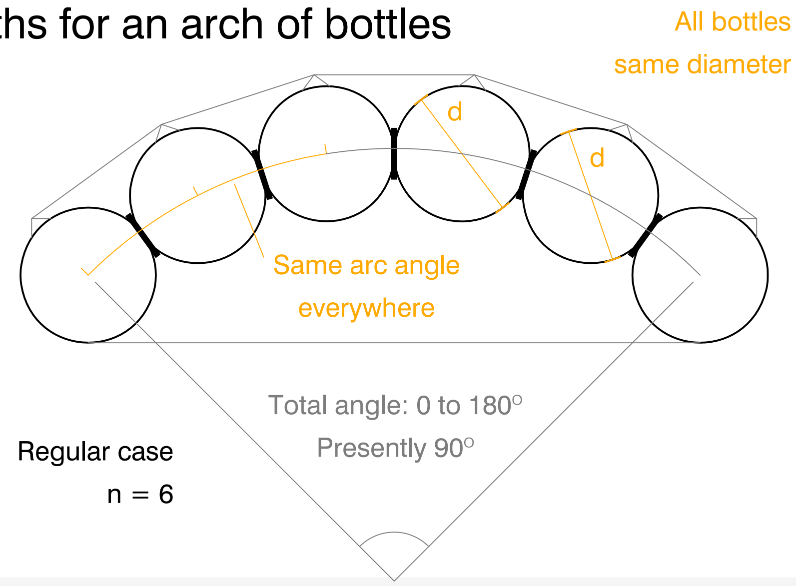


Script maths for an arch of bottles

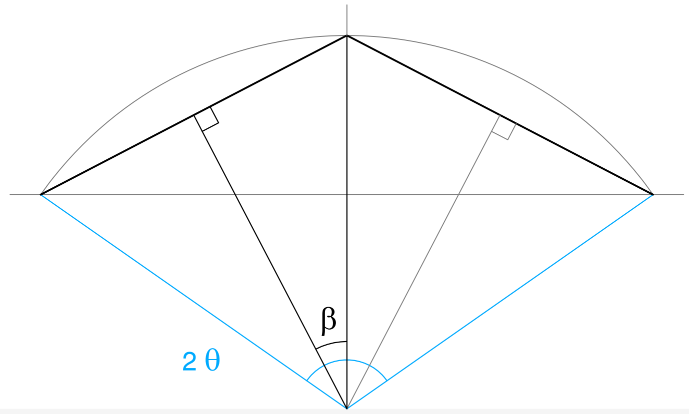


1

Finding properties of regular polygons inscribed in a circle

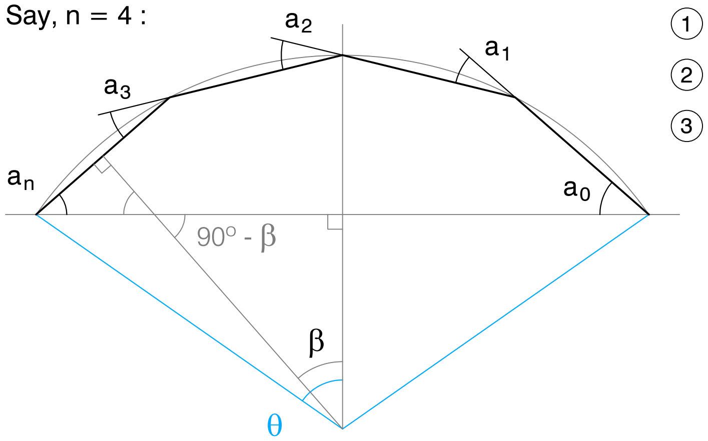
Say, n = 2,
we can find that: $\beta = \dfrac{2\cdot\theta - \dfrac{2\cdot\theta}{n}}{2} = \theta\cdot\left(1-\dfrac{1}{n}\right)$

This is true for all "n" number of sides.



2

Relating β to a_0
Say, n = 4 :



We know:

① $a_1 + a_2 + a_3 = a_0 + a_n$

② $a_0 = a_n$

③ $\beta = \theta \cdot (1 - 1/n)$

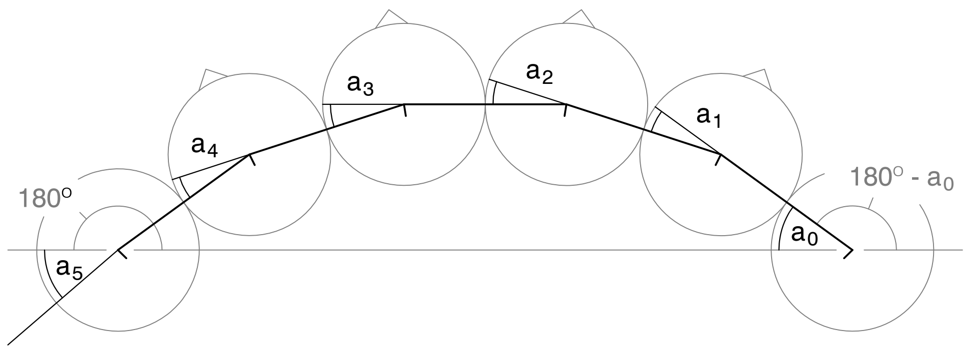
From this diagram,

$180° = a_n + 90° + 90° - \beta$

Thus $\beta = a_n = a_0$

Thus $a_0 = \theta \cdot (1 - 1/n)$

3



From basic geometry of polygons, we can find:
$(180° - a_0) + a_1 + a_2 + a_3 + a_4 = 180° + a_5$
... For a regular convex polygon,
regardless of the number of bottles (a_7, a_8...).

Since $a_0 = a_5$, generally:

$(n - 1) \cdot a_1 = 2 \cdot a_0$

4

5

Meanwhile, we notice that
$a_1 + a_2 + a_3 + a_4 =$ Some value

We can decide that, if (say) angle a_2 is doubled,
$a_1 + 2 \cdot a_2 + a_3 + a_4 =$ The same value

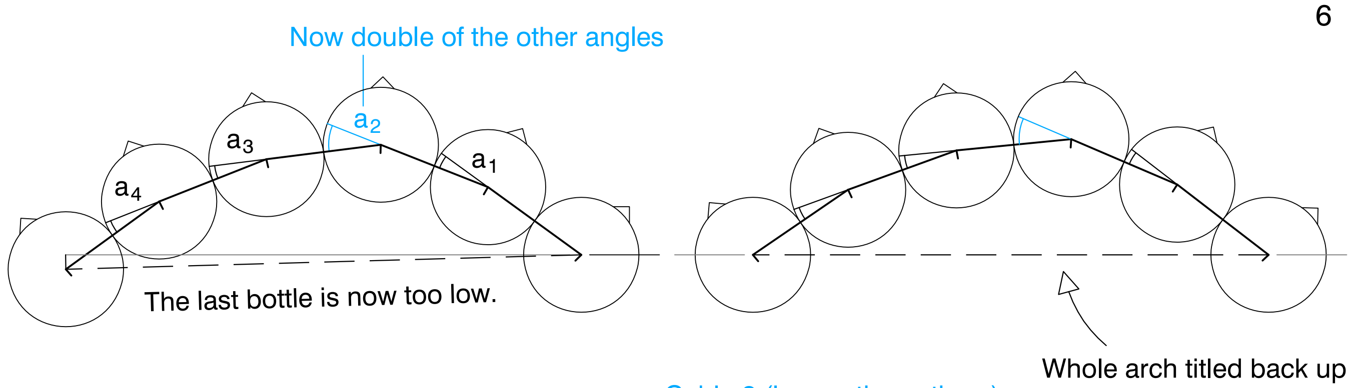
↑

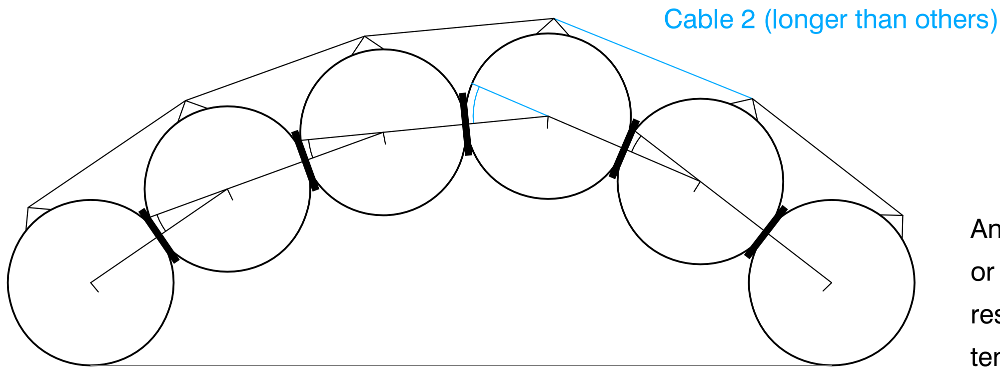
... must be ...

The angles must thus be ponderated:
1 + 2 + 1 +1 = 5
Angles concerned: 4 thus p = 4/5
$p \cdot a_1 + p \cdot 2 \cdot a_2 + p \cdot a_3 + p \cdot a_4 =$ Same value

If before 18° + 18° + 18° + 18° = 72°
Then after doubling a_3, 14.4° + 28.8° + 14.4° + 14.4° = 72°

6





Angle a2 is now double of a1, a3 or a4. The resulting drawing resembles what occurs when the tension in cable 2 is lowered.

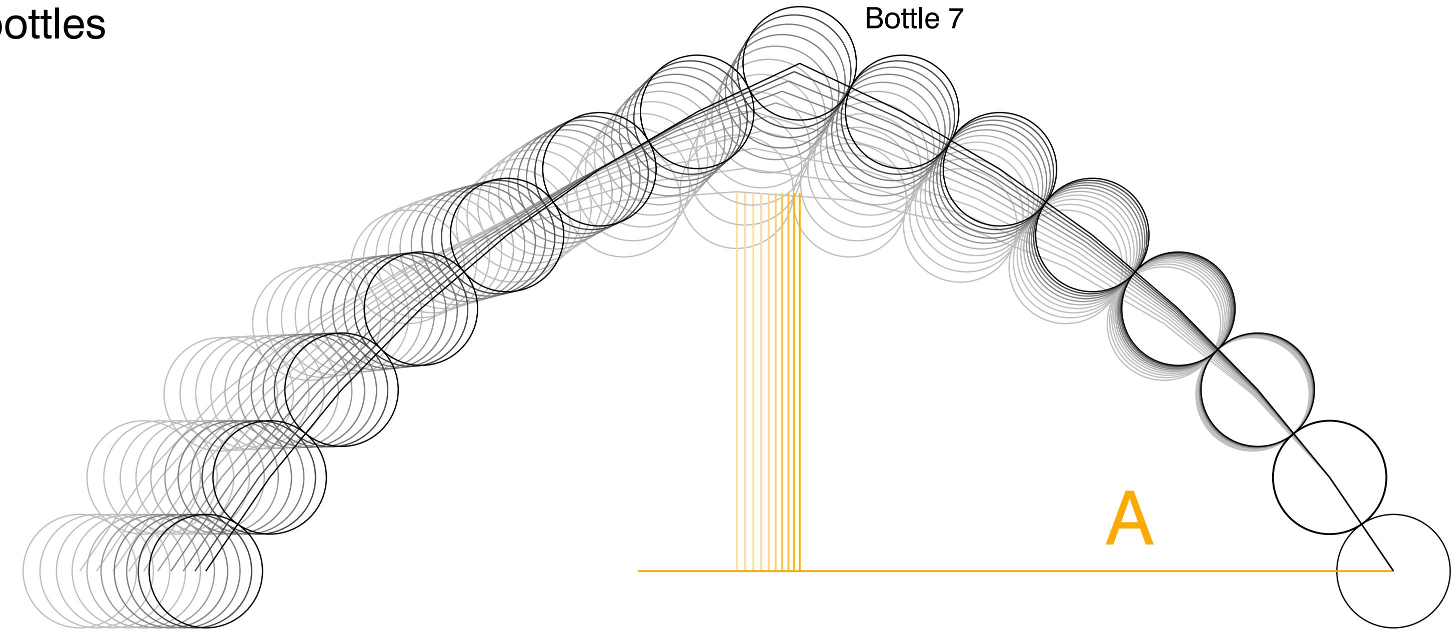
Varying the parameters of an arch of bottles

These examples were generated using GenerativeComponents, linked to Excel.

Example A

The total angle, $2 \cdot \theta$ is fixed at 120°.

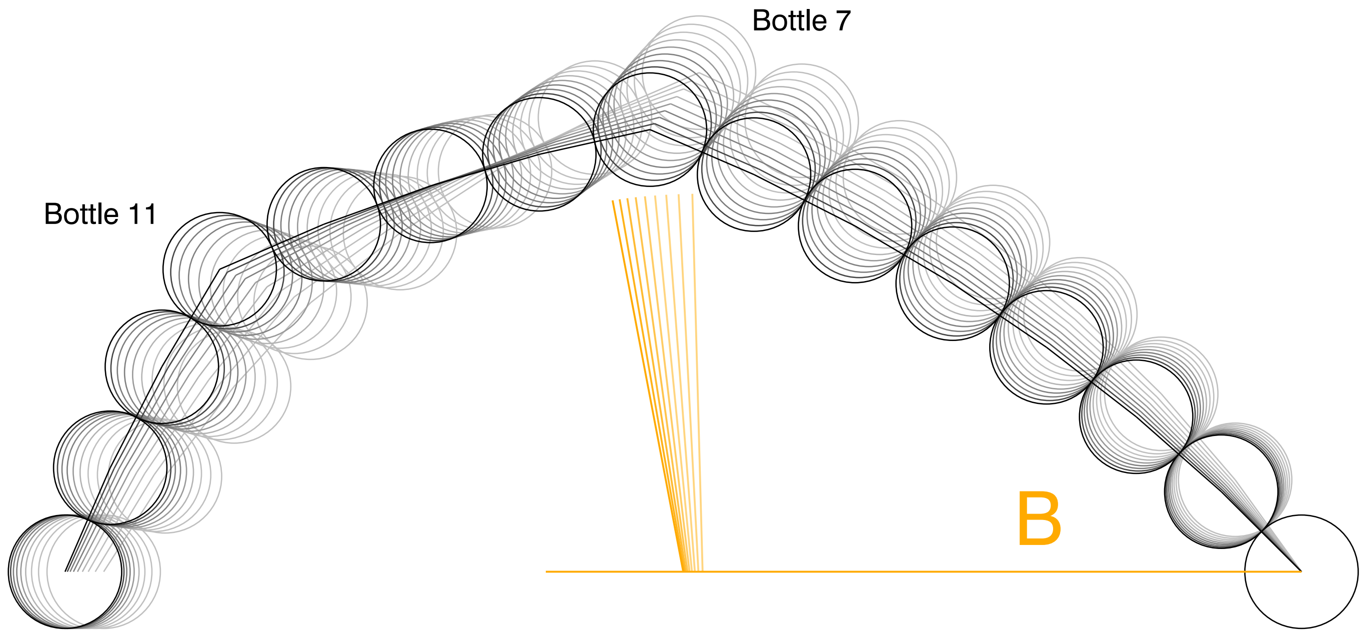
Bottle	Tension coefficient p
1	1
2	1
3	1
4	1
5	1
6	1
7	Varies from 1 to 10
8	1
9	1
10	1
11	1
12	1
13	1



Example B

The total angle, $2 \cdot \theta$ is fixed at 120°.

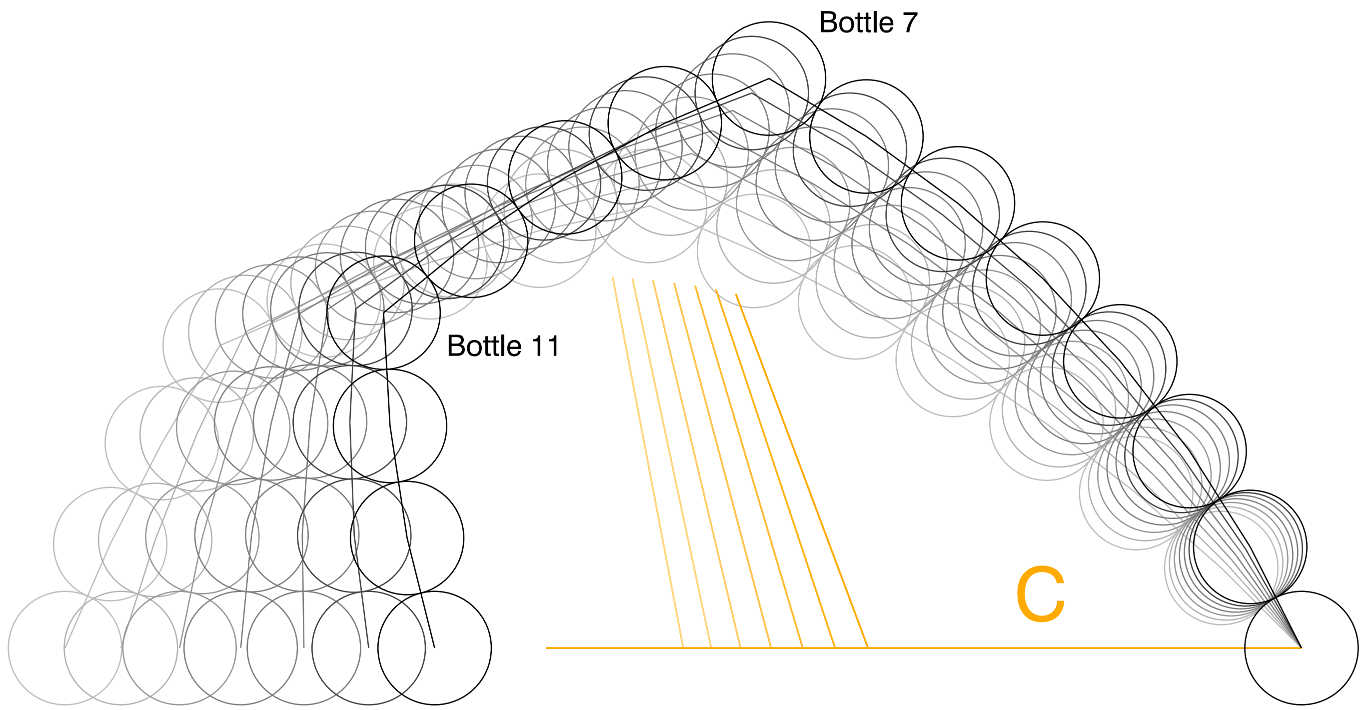
Bottle	Tension coefficient p
All others	1
7	10
11	Varies from 1 to 10



Example C

The total angle, $2 \cdot \theta$ varies from 120° to 180°.

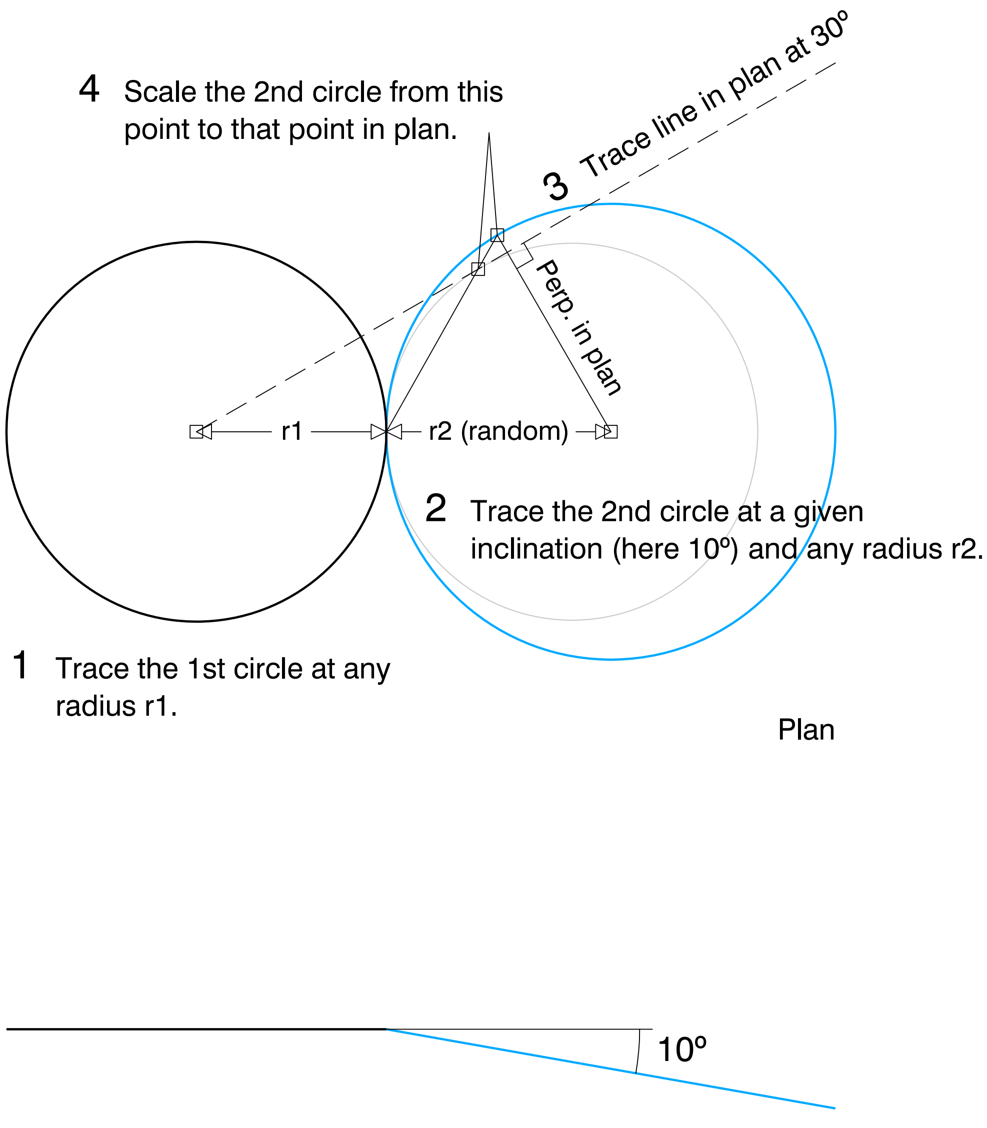
Bottle	Tension coefficient p
All others	1
7	10
11	10

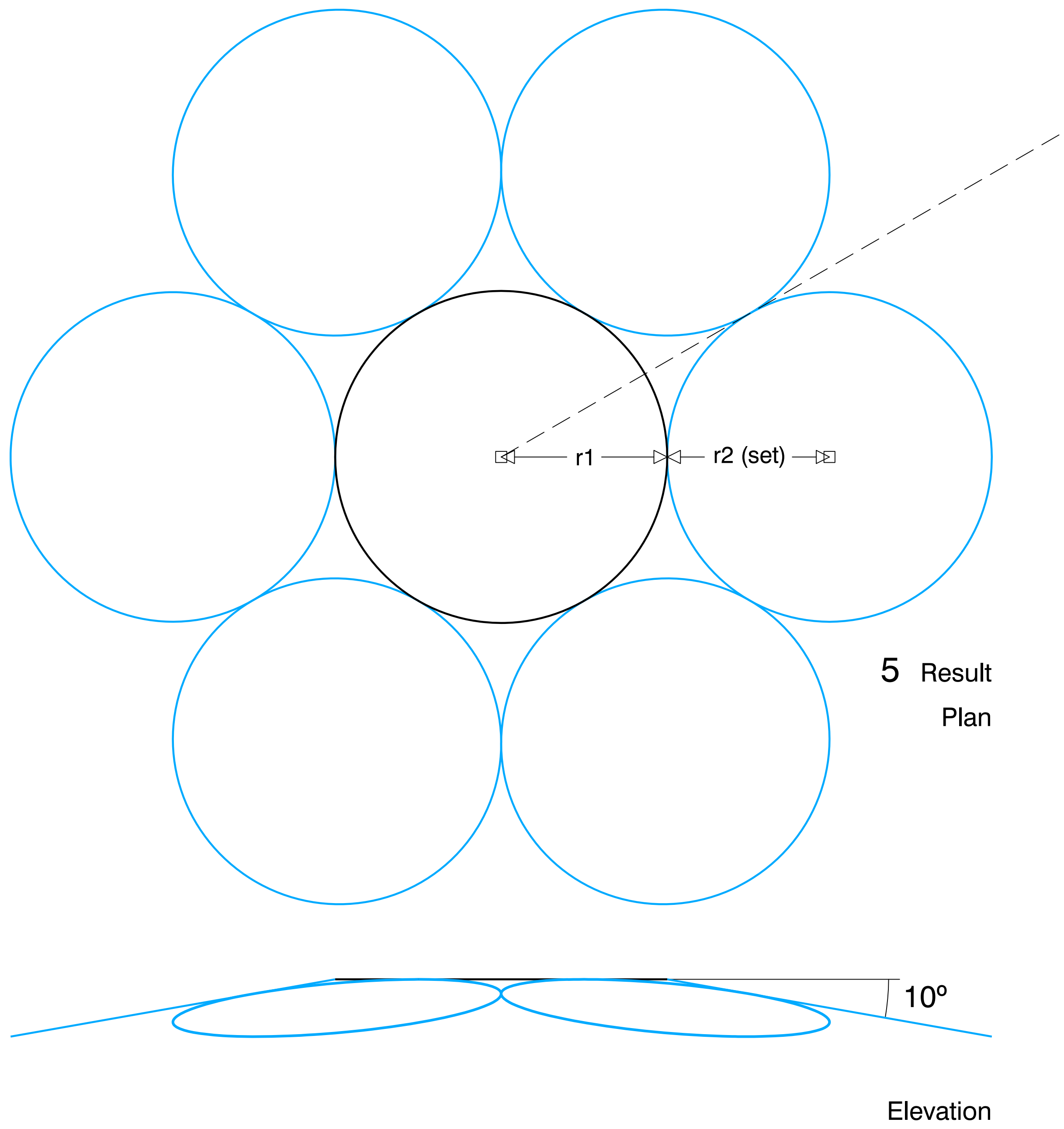


1.2 A dome made of circles

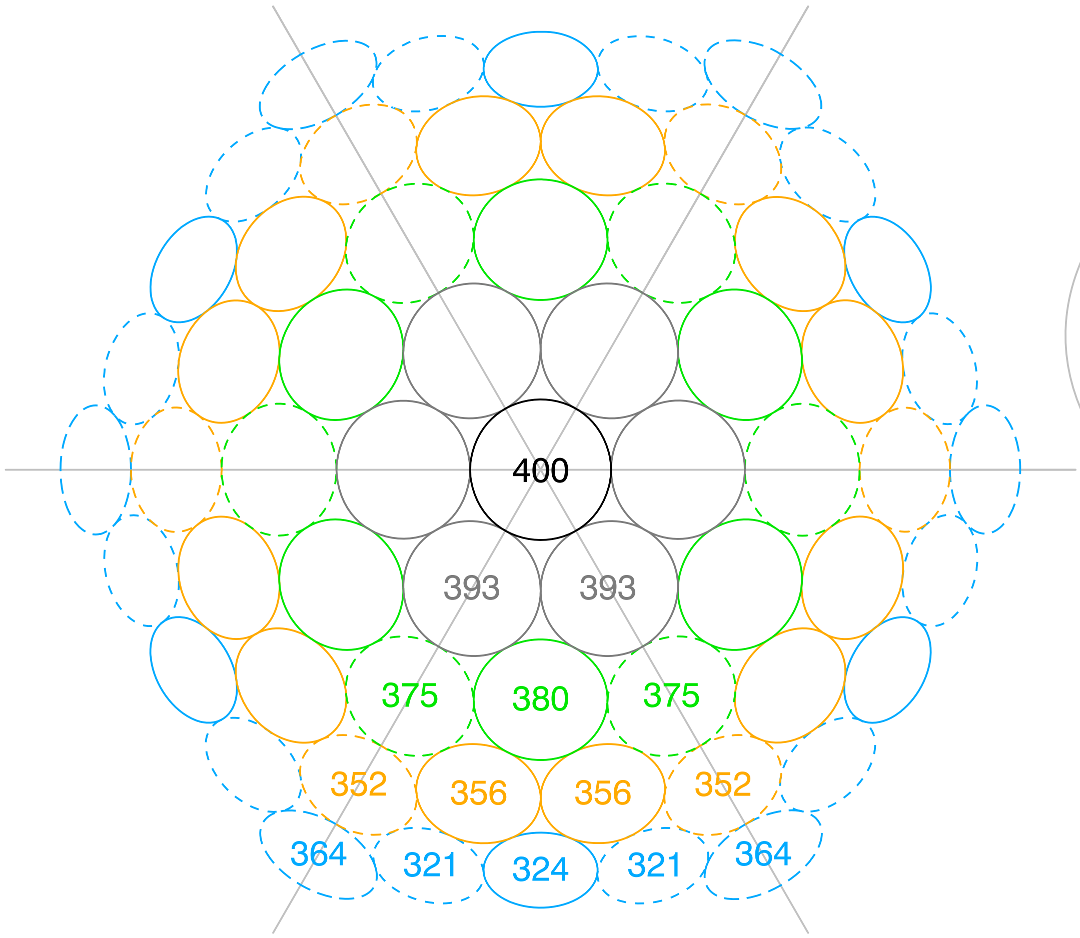
Around the year 1620, the Polish geometer Jan Brozek found that of all regular patterns, a pattern of hexagons covered the greatest area with the least length of line. This economical pattern is here translated to the architectural space frame, in a novel way: by replacing the hexagons with circles.

Around a circle, one can fit up to six circles of the same radius. But if the radii of the six circles are smaller, can they still all touch? They can, by inclining the circles in the third dimension. This is the start of this reflection.

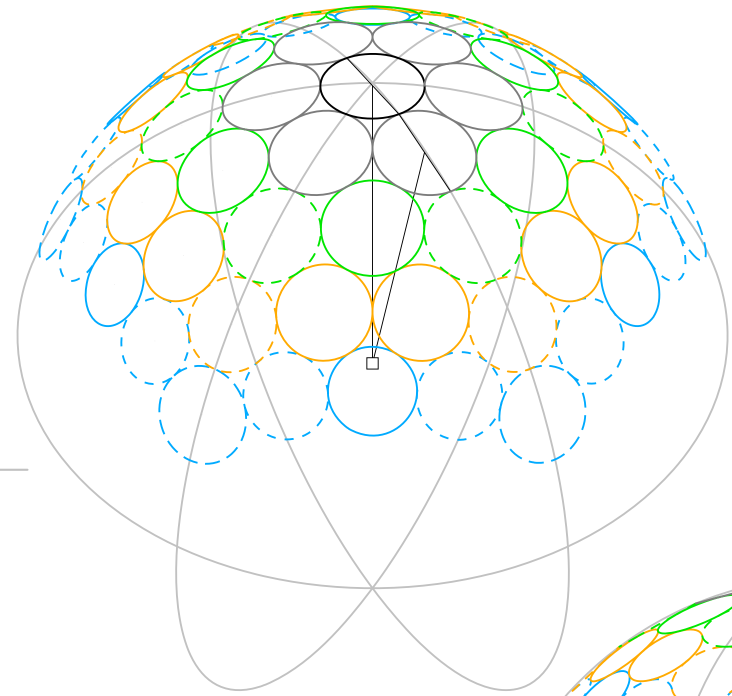




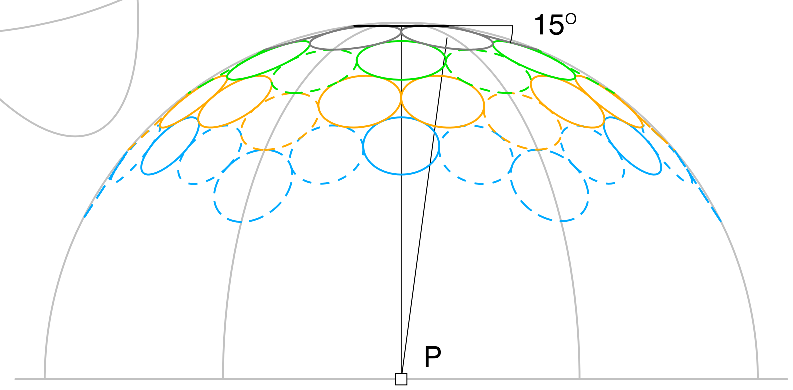
How to find the first row manually

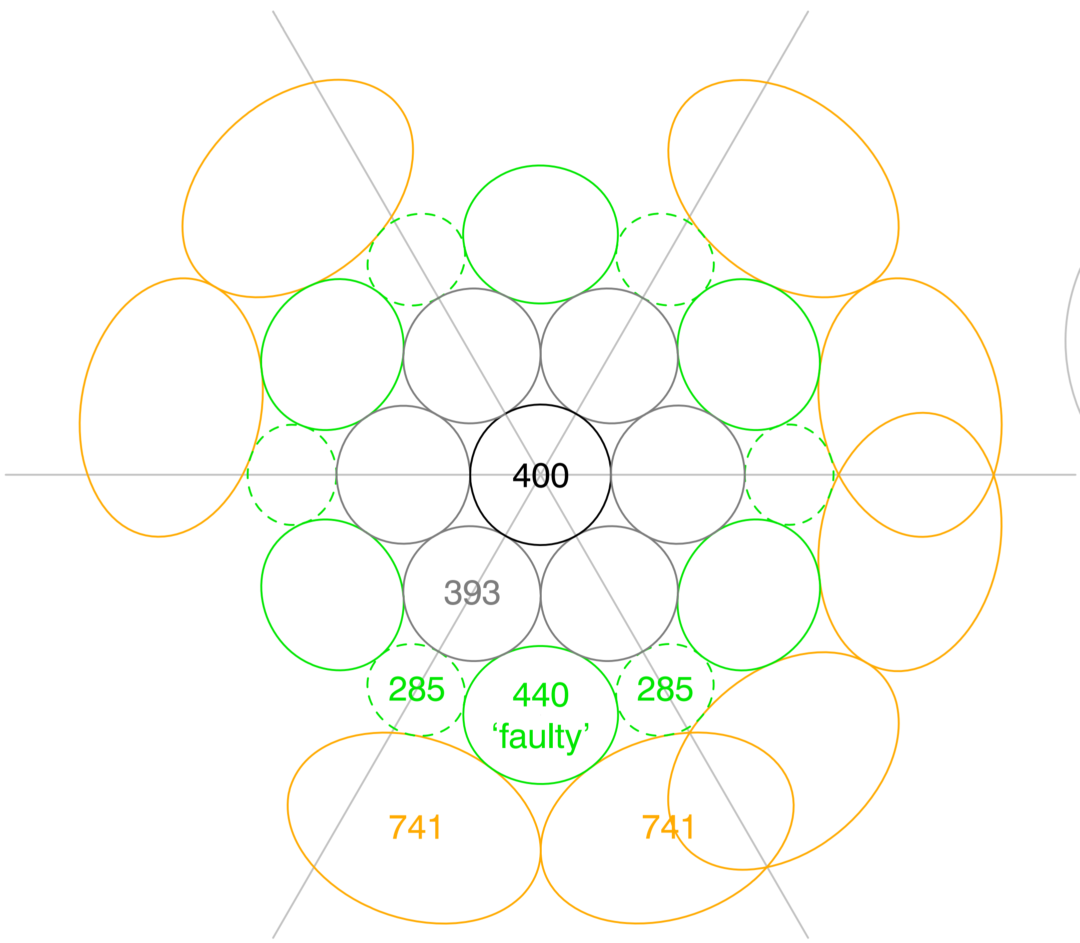


With balanced radii, it is possible to keep adding rows.

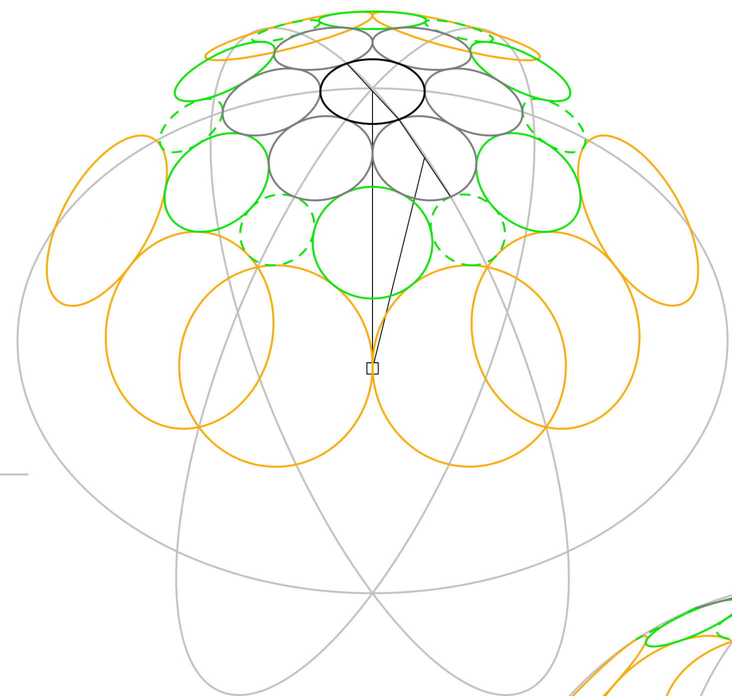


Incidentally, the circles end up approximating a sphere: all their *connection points* are equidistant to a center point P.

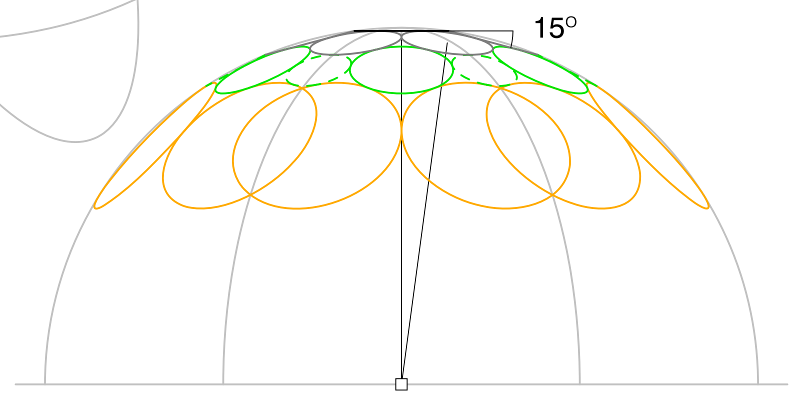




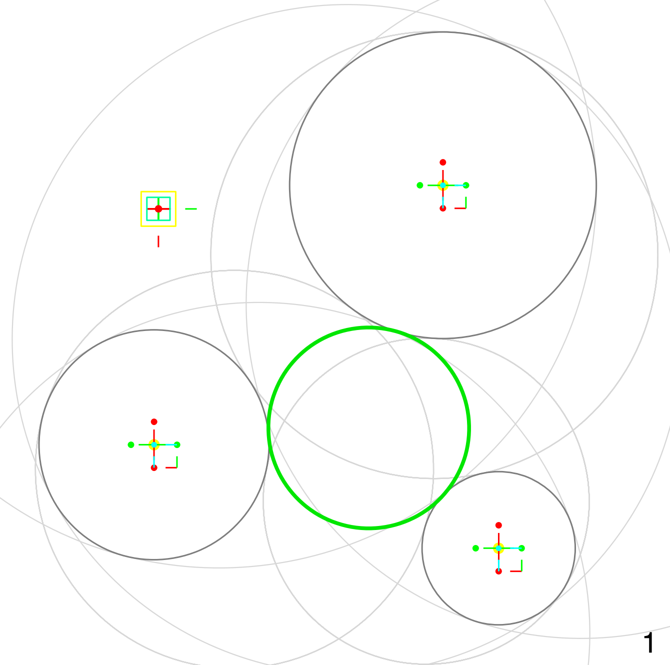
Consequence of one radius set too high

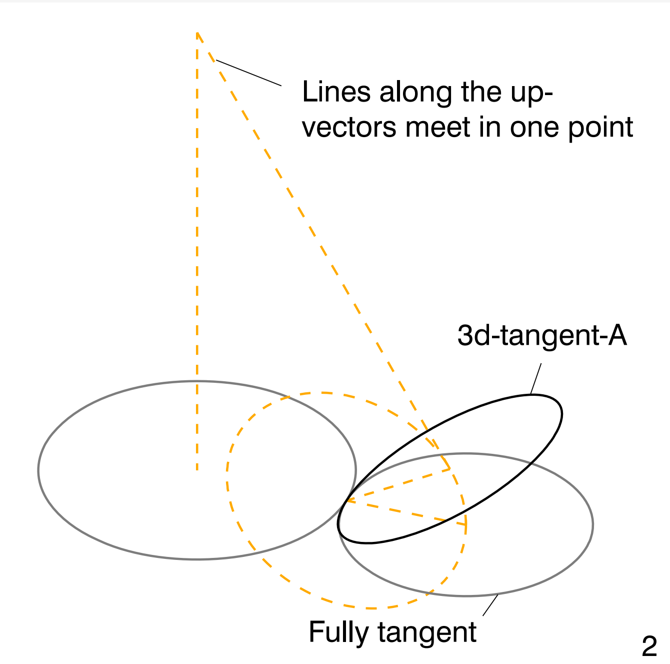


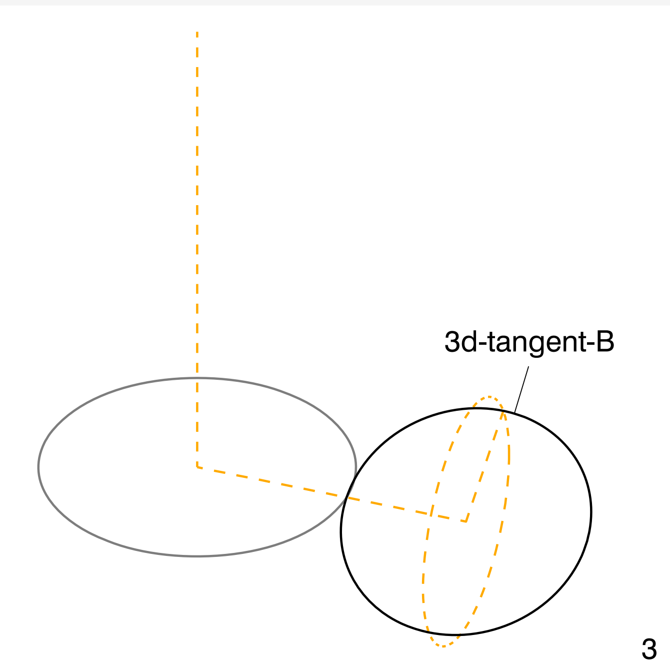
The user can set the circles to any radius; but the neighboring circles must 'follow', and if certain radii are set too high or too low, it becomes impossible to add rows where all circles still touch.



Drawing the rows using Rhino's ability to find 3d tangent circles







1.3 How are circles tangent in 3d?

With views on the respective capabilities of GC and Rhino

Nov 2007

Bentley's GenerativeComponents 2007 (GC) doesn't seem to have the following features:

- A circle tangent to two curves, and passing through a point.
- A circle tangent to two curves, and a given radius (and presumably, an optional "guide point" to decide which circle to create, if there's more than one solution).

GC does have the ability to draw a circle "ByTangencyTo3Curves", (Image 1)

But unfortunately, it fails when the curves are not in the same plane. Compare this with McNeel's Rhinoceros 4.0, which finds a solution. What's this solution?

Tangency in 3d

First of all: what does it mean to be tangent in 3d? With circles, I can see six types of 3d tangency:

- Fully tangent: Same plane. Two circles touch in a single point, and are drawn in the same plane.
- 3d tangent A: Up-vectors in same plane. Two circles touch in a single point, and their respective up-vectors (perpendicular to the plane of the circle) are in the same plane, where they cross, when extended. (Image 2)
- 3d tangent B: Radial line. Two circles touch in a single point, and this point, as well as the two centers, are elements of one line. (Image 3)
- 3d apparent tangency. Two circles touch in a single point, and: when one circle is "viewed from above" (an axonometry drawn from the end of the up-vector, looking down at the circle), the other circle, distorted in view, appears to be tangent. This is true for both circles.
- 3d half-apparent tangency. Same as above, but true for one circle only.
- 3d low tangency. All cases where two circles touch in a single point.

The most restrictive type, "fully tangent", meets the conditions of all others. Similarly, two circles of 3d-tangency-A also meet the criteria of apparent and low tangency.

Rhino: Two circles of low tangency

Now let's see how Rhino behaves. Let's say that I have two circles, "first" and "second", of 3d low-tangency. If I ask for a tangent circle, and select...

- The first tangent circle, the second tangent circle, and press enter: Rhino uses the point where I click on the second circle, and finds a third circle which is 3d-tangent-A to the second circle, and 3d-low-tangent to the first circle. (Image 4 a)
- The first tangent circle, a radius, then the second tangent circle: Rhino uses the point where I click on the second circle, and finds a third circle. It's half-apparent tangent to the first circle, and simply touches the second circle. (Image 4 b)
- The first tangent circle, second tangent circle, then a radius: Rhino fails to find a solution. This seems strange. Without considering the point where I clicked on the second circle, it could have found two solutions like in the first paragraph, of 3d-tangency-A to the first or the second circle. Alternatively, it could have found the same solution as in the second paragraph.
- The first tangent circle, second tangent circle, and a point somewhere in space: Rhino does not consider where I clicked, and finds a circle of 3d-apparent-tangency to both circles. (Image 4 c)
- Let's say that I have a "third" circle. If I ask for a new tangent circle and select all three existing circles: Rhino finds a circle which is 3d-half-apparent-tangent to these three. This solution is found regardless of where I clicked, or the order in which I selected the circles. (Image 4 d)

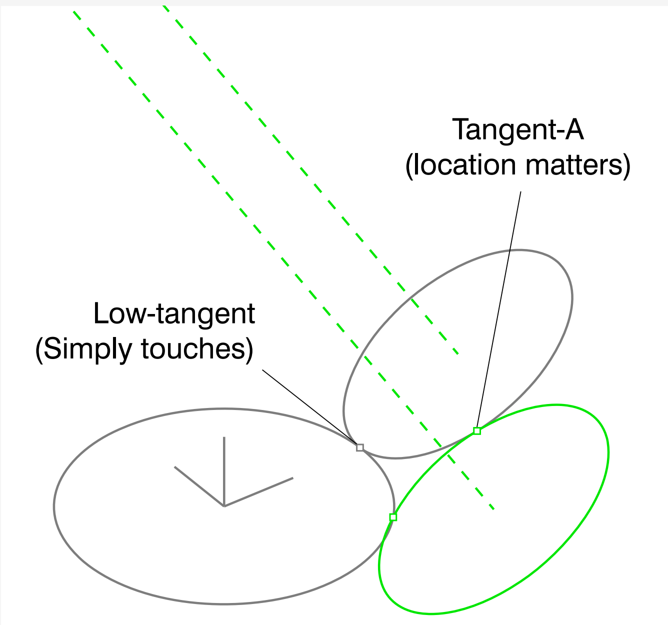
Rhino: Two circles of 3d-tangency A

Now, let's say that I have two circles, that are 3d-tangent-A instead. If I ask for a tangent circle, and select...

- The first tangent circle, the second tangent circle, and press enter: As before, Rhino uses the point where I click on the second circle. The third circle is 3d-tangent-A to both initial circles. (Image 5 a)
- The first tangent circle, a radius, then the second tangent circle: Rhino "hesitates". At a given radius, and hovering over the second circle, Rhino can find circles that are 3d-half-apparent-tangent to the first circle. They are determined by where I click on the second circle. However, with the same radius, Rhino also "snaps" to another solution: one which is 3d-tangent-A to both circles, and does not change wherever I click on the second circle. (Image 5 b)
- The first tangent circle, second tangent circle, then a radius: As before, Rhino fails to find a solution.
- The first tangent circle, second tangent circle, and a point somewhere in space: As before, Rhino finds a circle of 3d-apparent-tangency to both circles. (Image 5 c)

Doing the same in GC

These experiments expose how capable Rhino is at dealing with tangent circles in 3d. Yet Rhino does not remember "how" I asked to create new circles. It does not generate a dynamic model, where I could change the property of a prior circle, and expect the subsequent ones to adjust automatically.



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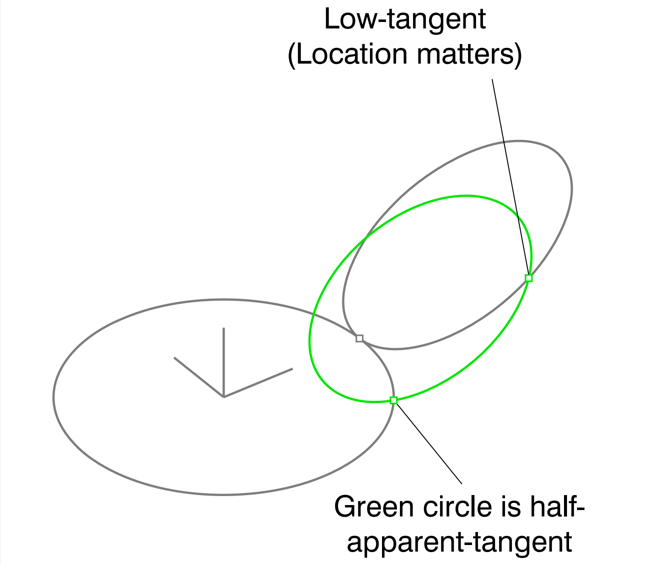
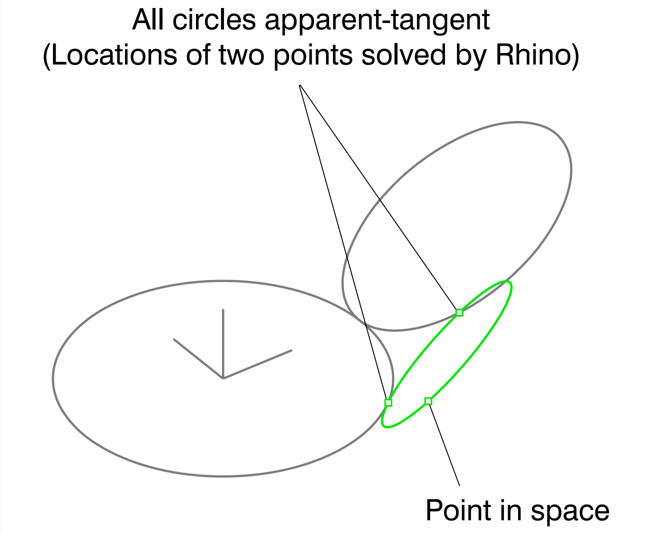
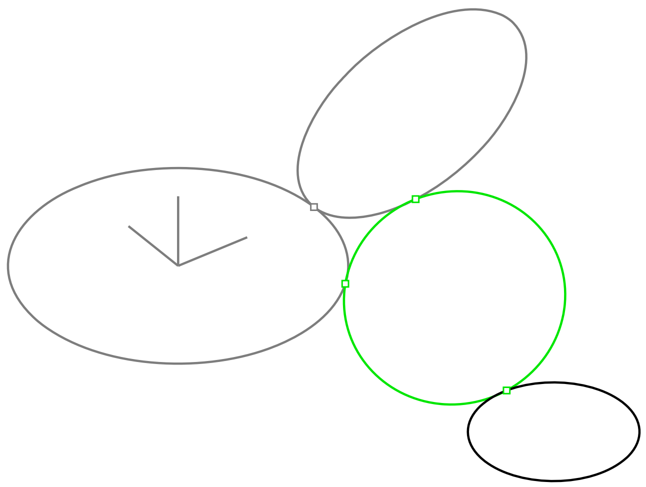


4b

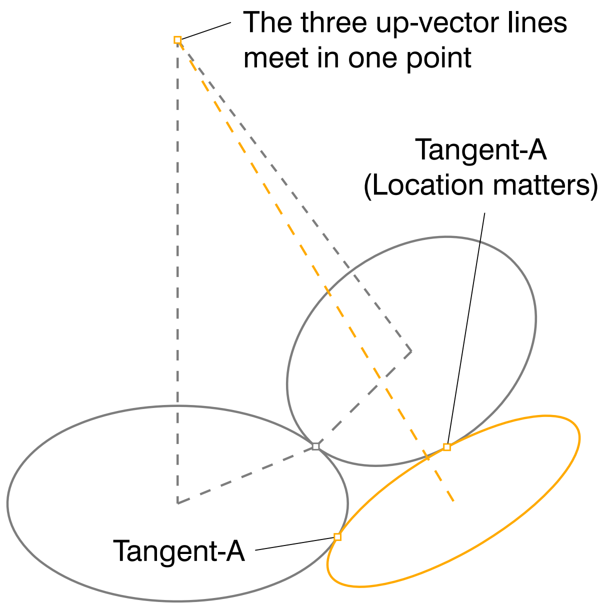


4c

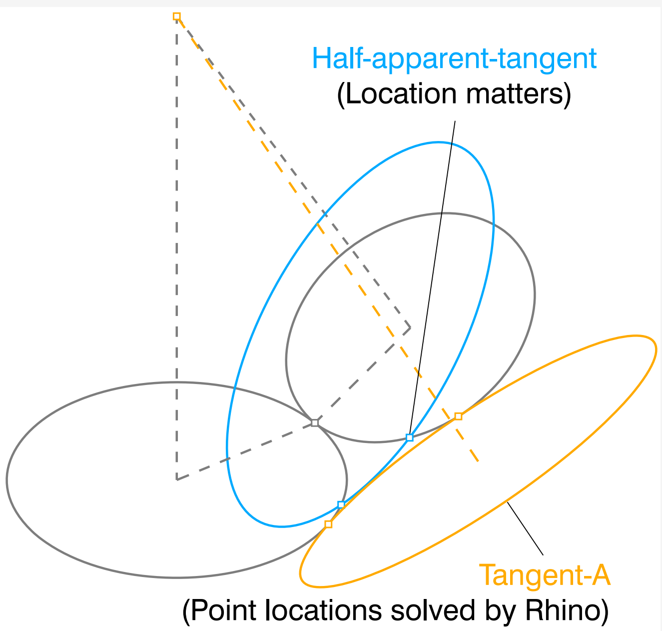
The green circle is half-apparent-tangent to the other three
(Locations of points solved by Rhino)



4d



5a



5b

(For the reference, I attempted to do the same experiments in Catia 5 v14, and I couldn't make it work. If there's a way to make 3d tangent circles in Catia, I couldn't find it.)

As I experimented with Rhino, I wondered if I could make a new feature in GC which would imitate at least one of these capabilities, namely: to create a new circle, tangent to two initial circles, and of a given radius. For the sake of simplicity, the two initial circles would themselves be 3d-tangent-A. As seen in the blue example above, the resulting circle should also be 3d-tangent-A to both initial circles.

How does Rhino find the solution? Probably by defining equations, and using a solver to converge to the center of the new circle, which satisfies all equations. The same solution can also be found using geometry: using a drawing, in a single "pass". This is not always possible: as we'll see later, a more complex problem can require multiple "passes" or attempts at drawing the solution.

Let's see how we can solve this problem in 2d, using geometry. We can offset two initial circles by the radius that we'd like the new circle to have. The intersections of these offsets mark the possible centers where a new circle (of the given radius) can be drawn tangent to both initial circles.

In 3d, the same logic can be used, except that offsetting the initial circles engenders two surfaces – two torii or "donuts" – as opposed to two circles. (Images 6 a , b) The surface intersection of these donuts creates one or more odd-shaped curves. (Image 6 c) Any point on these curves can be the center of a circle (of the given radius) which can touch both initial circles tangentially.

A few points on these curves are centers where a new circle can be "even more" tangent: 3d-tangent-A, for example, as opposed to 3d-apparent-tangent. To find these points, we must select the donut intersection curve where we want the center to be (when there's more than one curve). Next, we must look at one of the two existing circles "from above" (an axonometry drawn from the end of the circle up-vector, looking down) and draw a line from the circle center to the donut curve, such that the line appears (in axonometric projection) to be tangent to the donut curve. The point where the line and the donut curve meet tangentially, is the circle center that we are looking for: one where a new circle of the given radius can touch both initial circles at 3d-tangency-A. (This method was found intuitively; I can't say exactly why it works, but it does.) (Images 6 d , e)

Tweaks to make this work in GC

This method can be programmed as a new feature in GC, with a few tweaks. In the script, the new feature is named "CircleC01_" .

– Often, during the process, we need to use the plane, up-vector or Cartesian coordinate system of an existing circle. I made two features, "UpLine" and "SurfaceProj", which create these elements, since I couldn't find them in the sub-properties of circles. It would be great if these were available (if they're not already), for example as myCircle.Plane, myCircle.UpVector, myCircle.CoordinateSystem.ZDirection , etc.

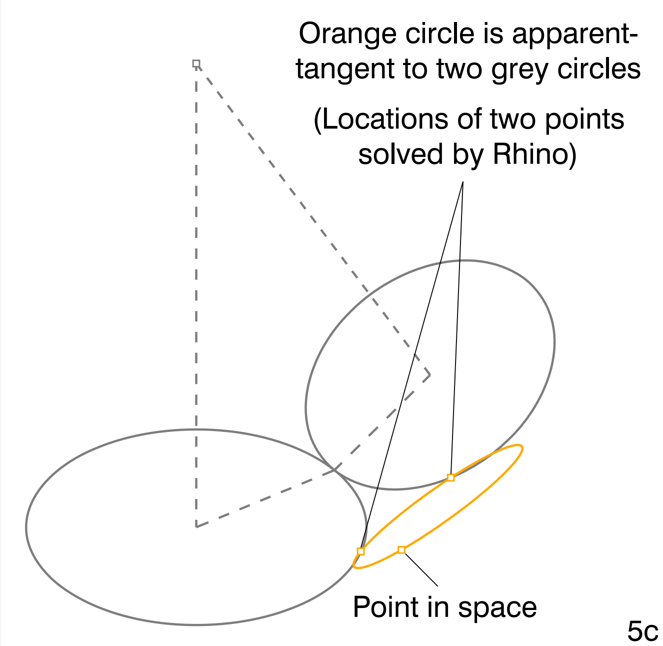
- We also need to have a point of reference to indicate roughly where we'd like the new circle to be. For example, from the very start, at least two solutions exist: one on either side of the initial circles. (Images 7 a , b) The GC process thus creates a coordinate system (CS) that's oriented by the initial circles, and creates a default reference point in this CS. When the process is made into a new feature, the coordinates of the reference point in this CS are passed as optional variables that the user can adjust.
- The curve "SurfaceSurfaceIntersection" stumbles when more than one intersection exists. Thus, we cannot create donuts around the initial circles, since they almost always yield more than one intersection curve. The process thus generates several arcs, and creates two rail-and-section sweep surfaces, effectively fragments of donuts, restrictive enough to intersect only once.

This would've been simpler had the "Torus" solid, or the "SweepCircleAlongPath" surface, had angle (or point) parameters for the start and end of both circles – the cross section, and the revolution. I was also confused by the distinction between solids and BSplineSurfaces. I understand that platonic solids and BSplineSurfaces are programmed differently, but other softwares, like Maya and Catia, juggle seamlessly between both. Lastly, I was disappointed by "SweepCrossSectionAlongPath", when used with an arc as the cross section, and another arc as the path. The resulting surface was different from the trimmed torus that I expected, as if GC did not know how to orient or relate the cross section to the path. For this reason, I had to use "FromRailsAndSweptSections" sweeps.

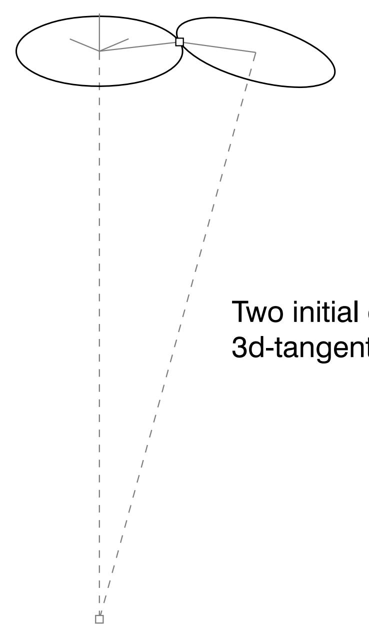
- We seek a line from the center of an initial circle, which appears to be tangent to the donut curve, when viewed "from above" this initial circle. Rigorously, we have to create a plane, parallel and lowered from the plane of this circle, and project both the initial circle center and the donut curve onto this plane. Then we can create a GC point "ProjectAtTangentToCurve" to find the projected center of the new circle. We then have to relate the new projected center back to the non-projected donut curve. We can use the up-vector of the plane to trace a vertical line from the projected center, and find where this vertical line intersects the original donut curve.

Because of software precision, the vertical line can miss the donut curve, and make the whole process stumble. It would be great if GC provided simultaneous, "alternative" U coordinates on the projected curve, which would correspond to the U coordinates of the original curve, and hopefully make it really easy to relate points between one curve and its projection.

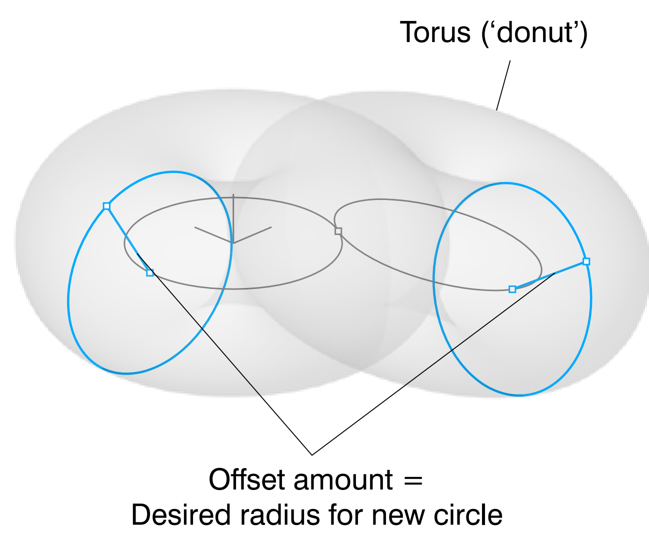
- The vertical line can also intersect with the original donut curve more than once. We thus have to create a point, "SelectNearestInSetToReferencePoint", which uses our reference point to select the good intersection between the vertical line and the donut curve. This point is the long-sought center of the new circle.
- We have the center of the new circle, but we need two points on the circle to trace it. These points can be the points of tangency with the two original curves. We must trace two planes, one



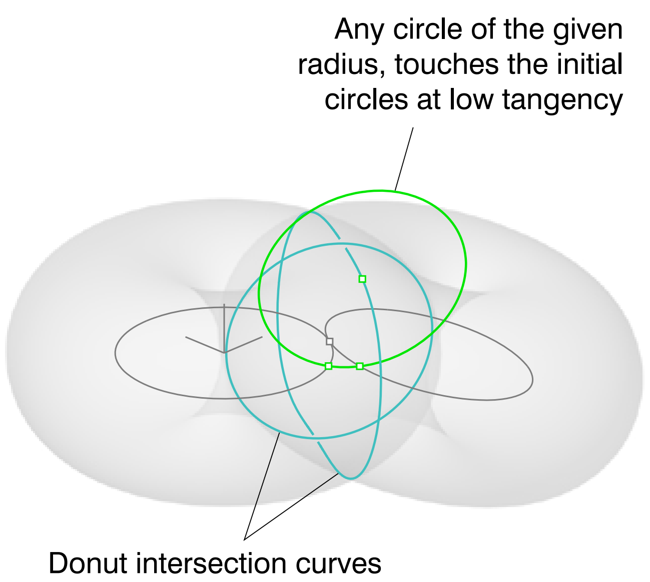
5c



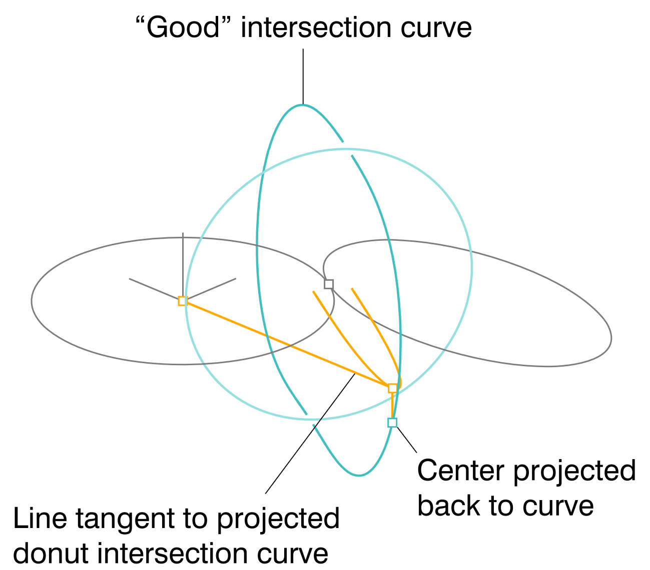
6a



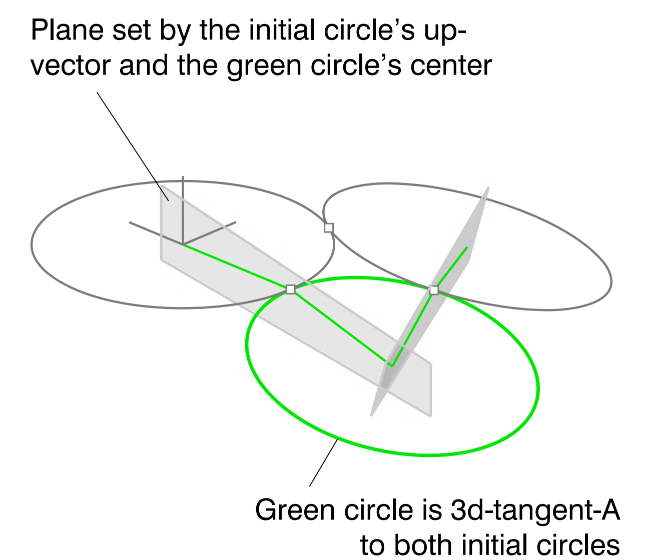
6b



6c



6d



6e

for each initial circle: they are defined by the up-vector of these circles, and the center of the new circle. The intersection of each plane with its respective circle, yields a point of tangency. Once we have these two extra points, we can at last trace the circle using "ByCenterStartPlanePoint".

Making this whole process into a feature was quite tedious. Indeed, when generating a new feature type, I could not find a way to remove input or output properties that I knew where unnecessary. I thus had to edit the code of the new feature, and remove the unnecessary properties manually. Also, I couldn't find a way to unload a feature and regenerate it with the same name, without restarting GC. Every refinement to a custom feature thus required to restart GC. Lastly, GC "lower-cased" the first letter of the name of new feature instances, even when the feature name itself starts with an upper-case letter. This made it difficult to edit the script. I wonder why GC is case-sensitive at all.

A circle tangent to three circles

How can we trace a circle which is tangent to three circles, themselves tangent? In 3d, we can use the logic of intersecting donuts. In this case, however, there are three donuts to intersect, and there is typically only one point where they all meet: it is the center of the desired circle. Unfortunately, I could not find a one-pass drawing which allows to find this center. The offsets which yield the donuts must be increased or decreased until the one intersection is found, and this requires multiple attempts or "passes" - a loop.

I managed in extremis to script a process which finds this center point approximately, in a single pass. It requires, however, to start with donuts that already intersect. If the initial circles change, the donuts can become too small to intersect. If this accident happens within a feature, the process fails. When other circles depend on this three-tangent circle, the script can thus become really fragile. The three-tangent circle feature is named "CircleD01_" . The circle's default donut offset is available as a parameter, "DbDRadius".

Conclusion

I first thought that it would be easy to "program" dynamic 3d tangent circles in GC, despite the fact that GC did not have the built-in ability to draw them. It turned out to be difficult, and in the end, too slow and unstable to be useful. 3d tangent circles are elemental; any geometry software should be able to handle them. I hope that GC will do so in the near future. I also wish that it was possible to create features using "implicit" geometries (relationships). In this way, we could tell GC that a point is on a line at the intersection of two surfaces; and GC would not calculate the surfaces nor the intersection, until we provided further conceptual geometry to solve the point itself.

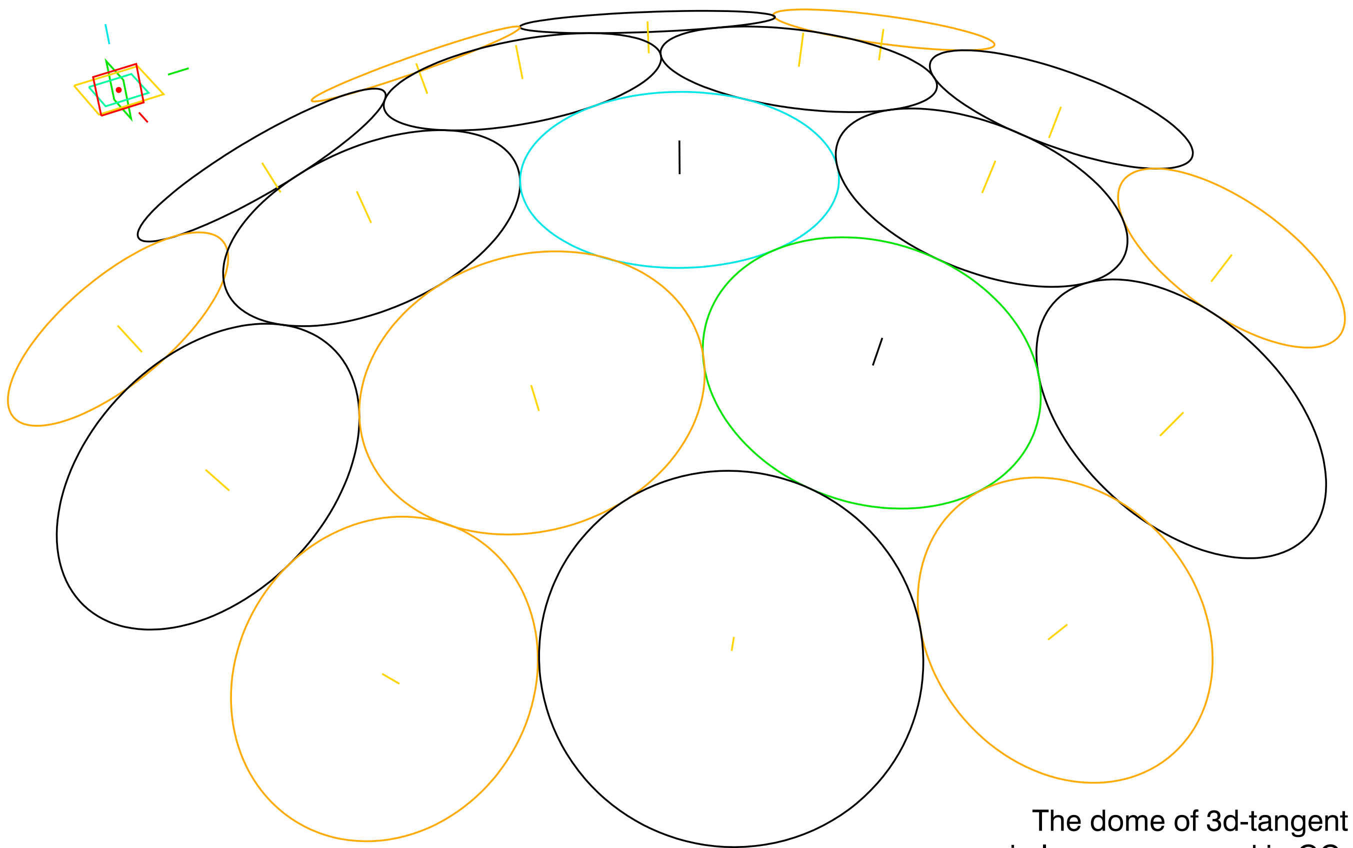
A personal note: Even if it had been easy to set up a dynamic model of tangent circles, I feel that I would have had greater freedom in a no-history software like Rhino. Dynamic models offer freedom within the bounds of their own parameters, but they restrain exploration outside of these bounds. We can spend so much time making a dynamic model work, that the notion of going elsewhere, where the dynamic model cannot go, may become unbearable. And yet, this elsewhere may be quite close to the current proposal, and our imagination may understand it as a small step. For these reasons, during the initial design, I think that we should approach the use of dynamic software with care.

Notes

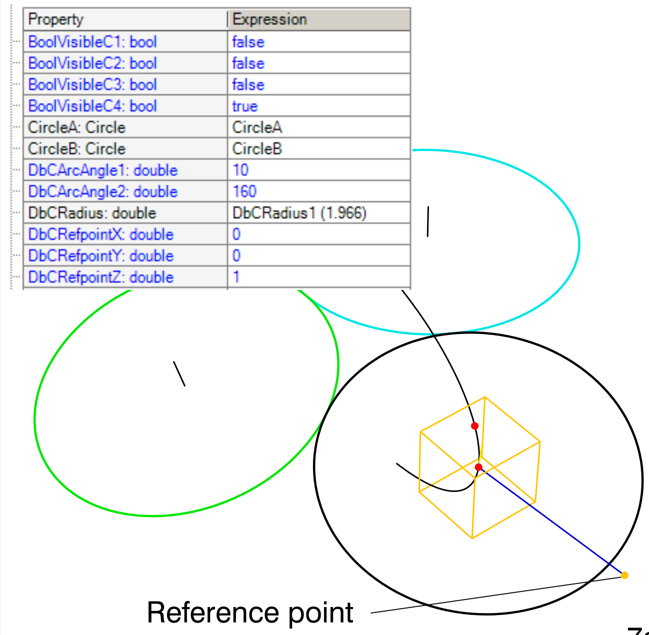
The script generates CircleA (aqua color), then CircleB (green), of which the angle of inclination can be adjusted. However, circles “circleC01_” fail when the inclination is zero. When it is positive, the reference points of the latter must be adjusted.

The feature “circleC01_” has a few parameters. Four booleans set the visibility of its “internal” elements. CircleA must be the circle from which a projection plane “surfaceProj01_” is generated. It must be generated separately. “upLine01_01” must be the upLine feature of CircleA, and “upLine01_02”, the upLine feature of CircleB. The “DbCRefpoint” coordinates allow to relocate the reference point. The “DbCArcAngle” angles allow to fine-tune the trimming of the donuts.

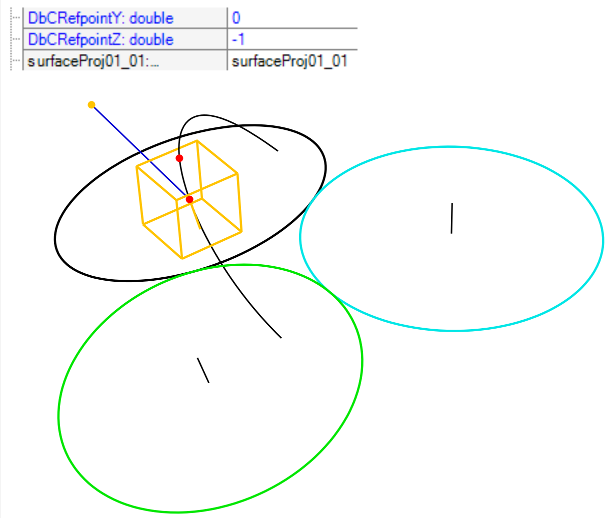
Transactions 5-6, 9-10, 12-17 and 20-26 should be run once, then suppressed. Transactions 28 and 32, “For 25 degrees”, should be run to test the whole script with CircleB inclined at 25 degrees, as opposed to 15 degrees. To test the flexibility of the script, it’s better to stop at transaction 19, since the “circleD01_” features are very fragile. The radii of the circles are available as graph variables. Extreme values require to adjust the reference points.



The dome of 3d-tangent
circles programmed in GC.



7a

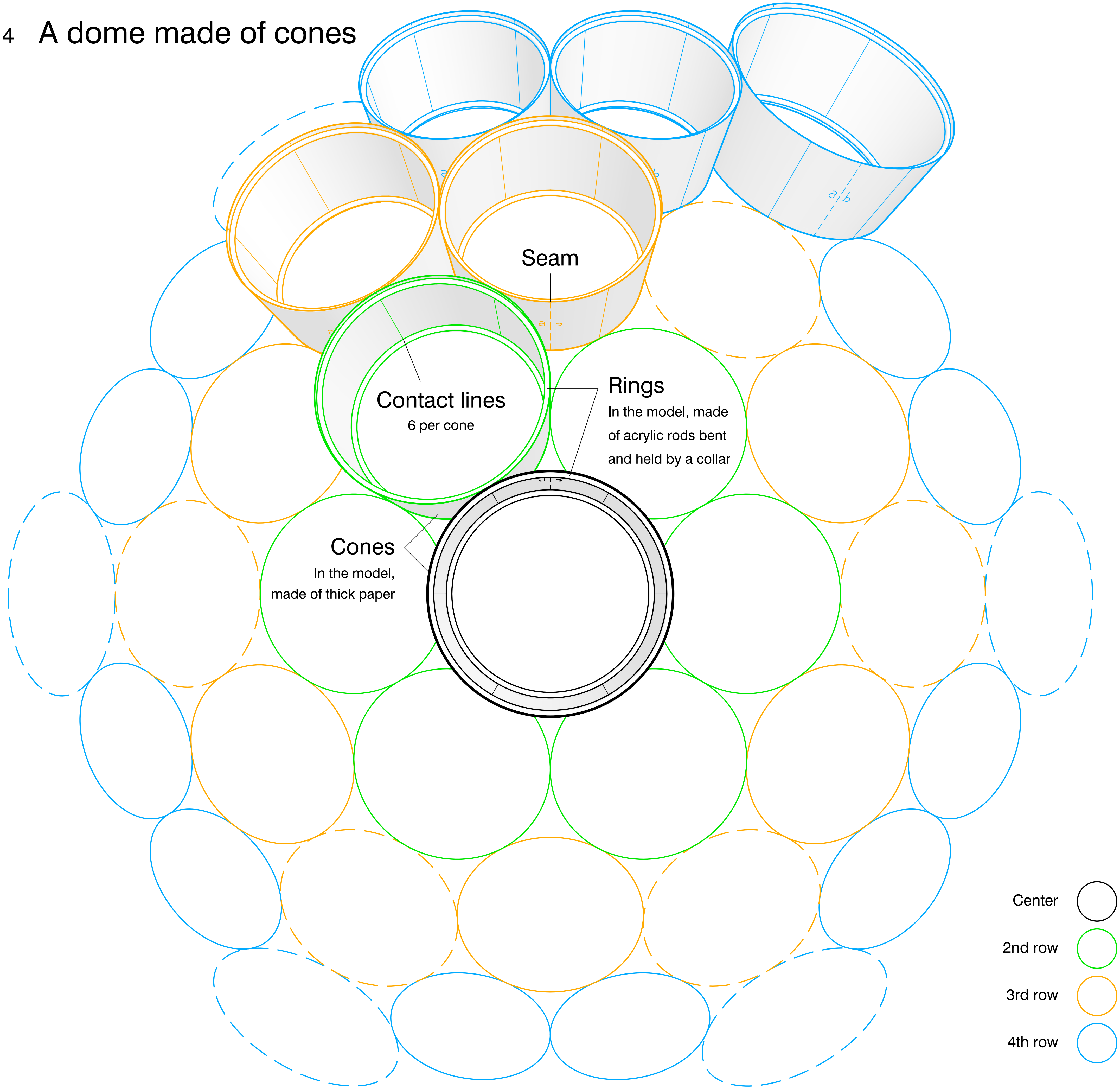


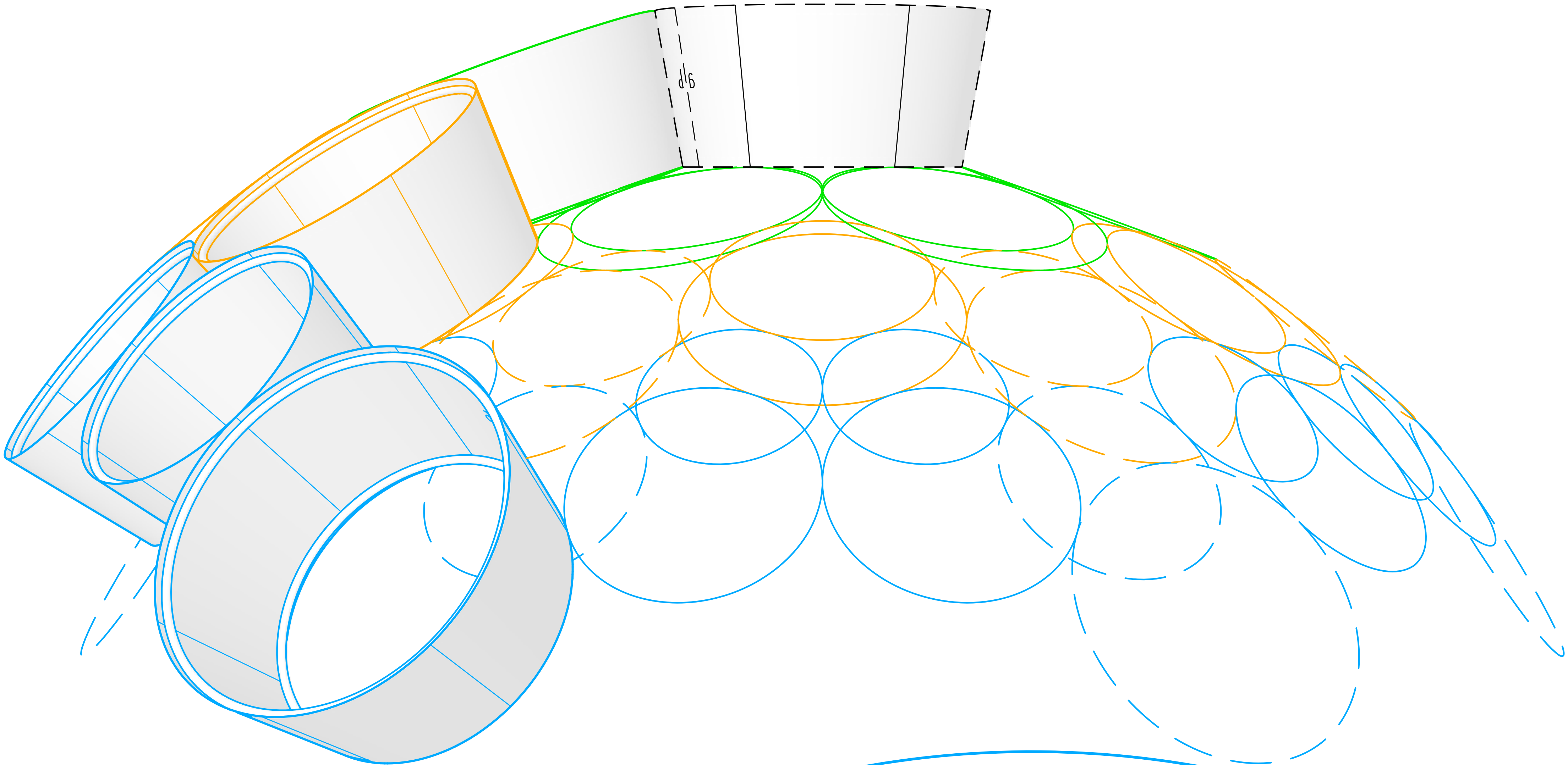
DbCRefpointZ parameter changed to minus 1:
reference point flipped.

7b

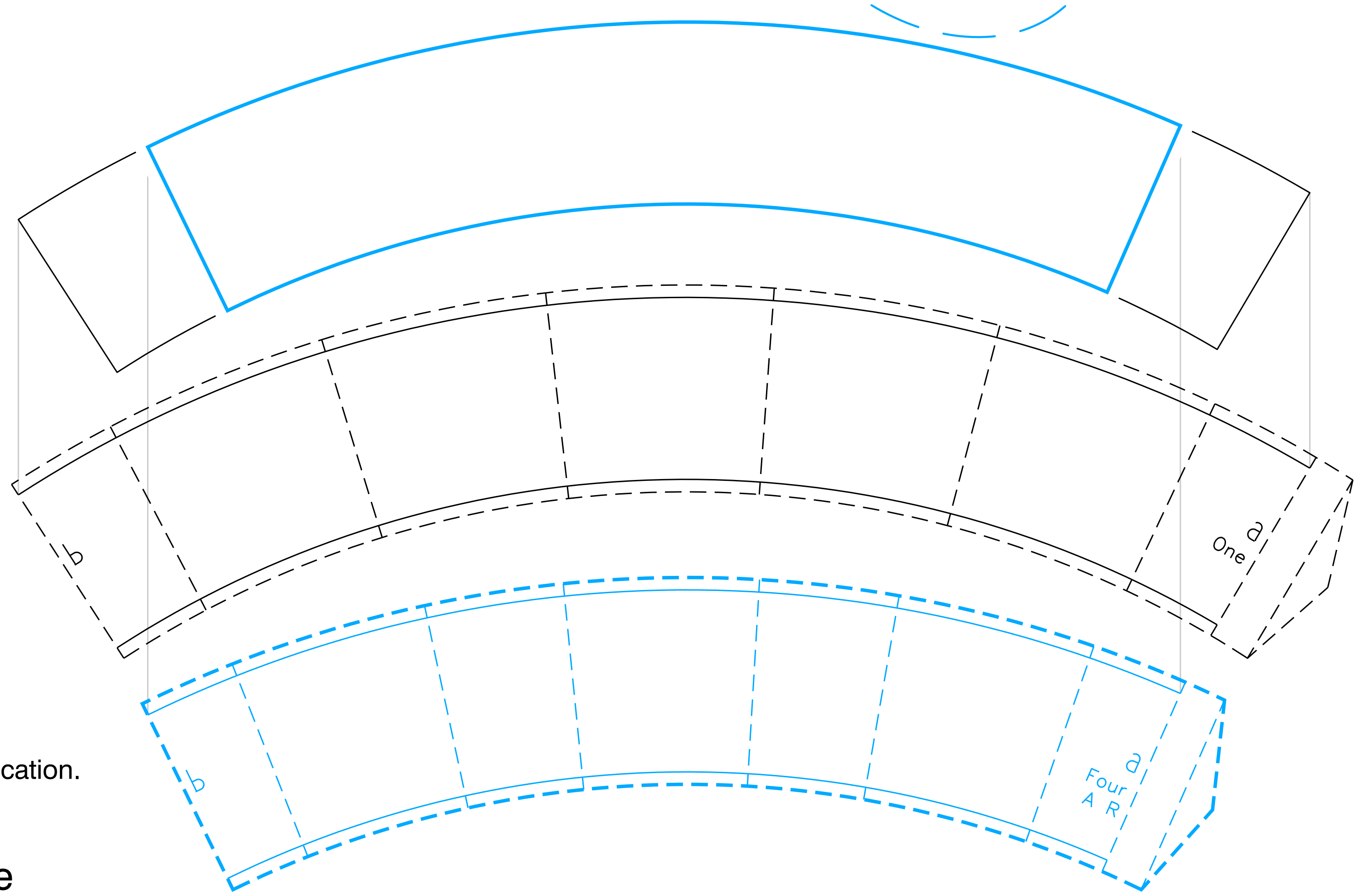
The GC script is available on the Internet at www.mailoci.com/jf

1.4 A dome made of cones





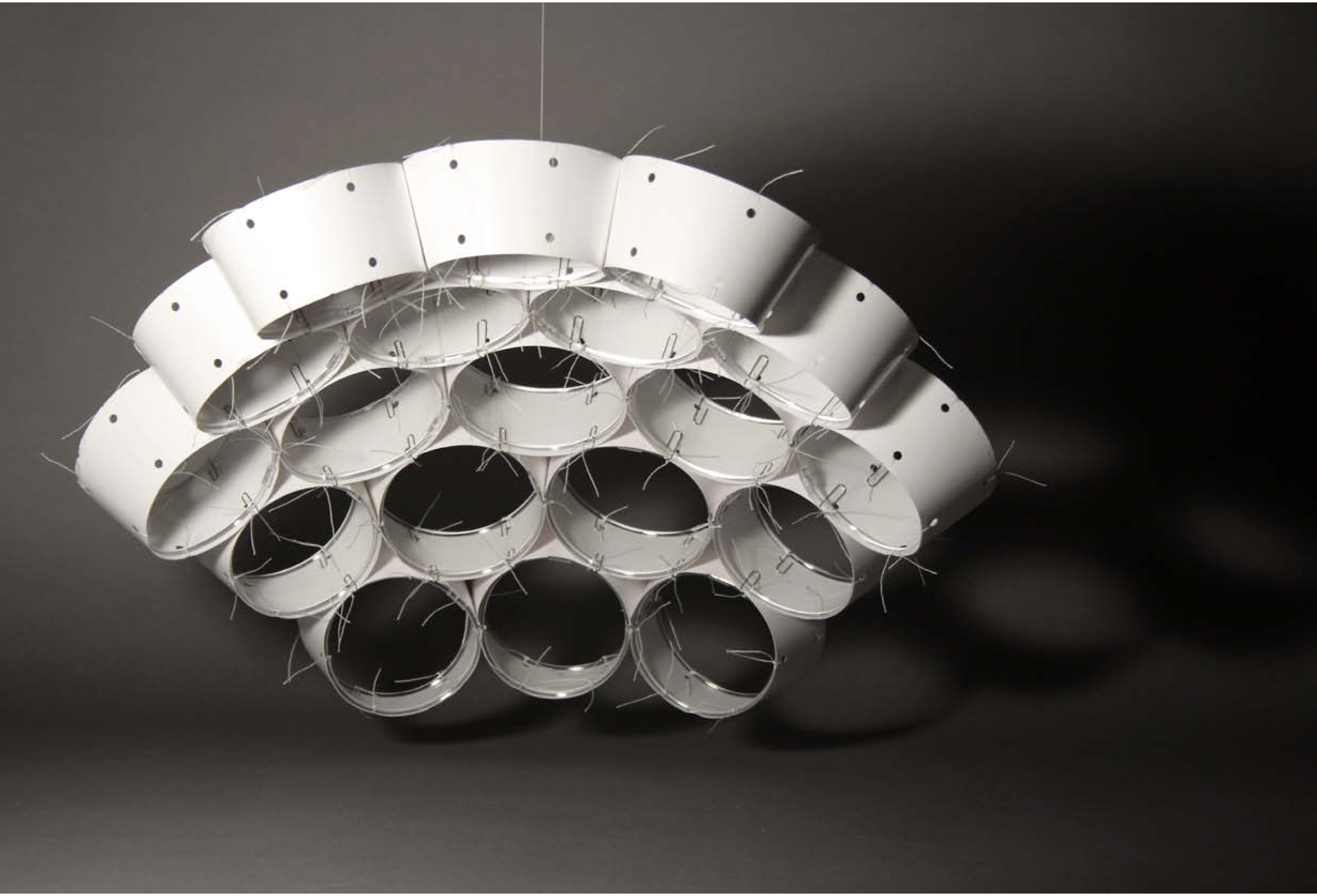
Elevation (perspective)



Since the cones are of different radii, their unfolding yields ribbons of varying lengths. But incidentally, all these ribbons share the exact same curvature: a property which could facilitate their fabrication.

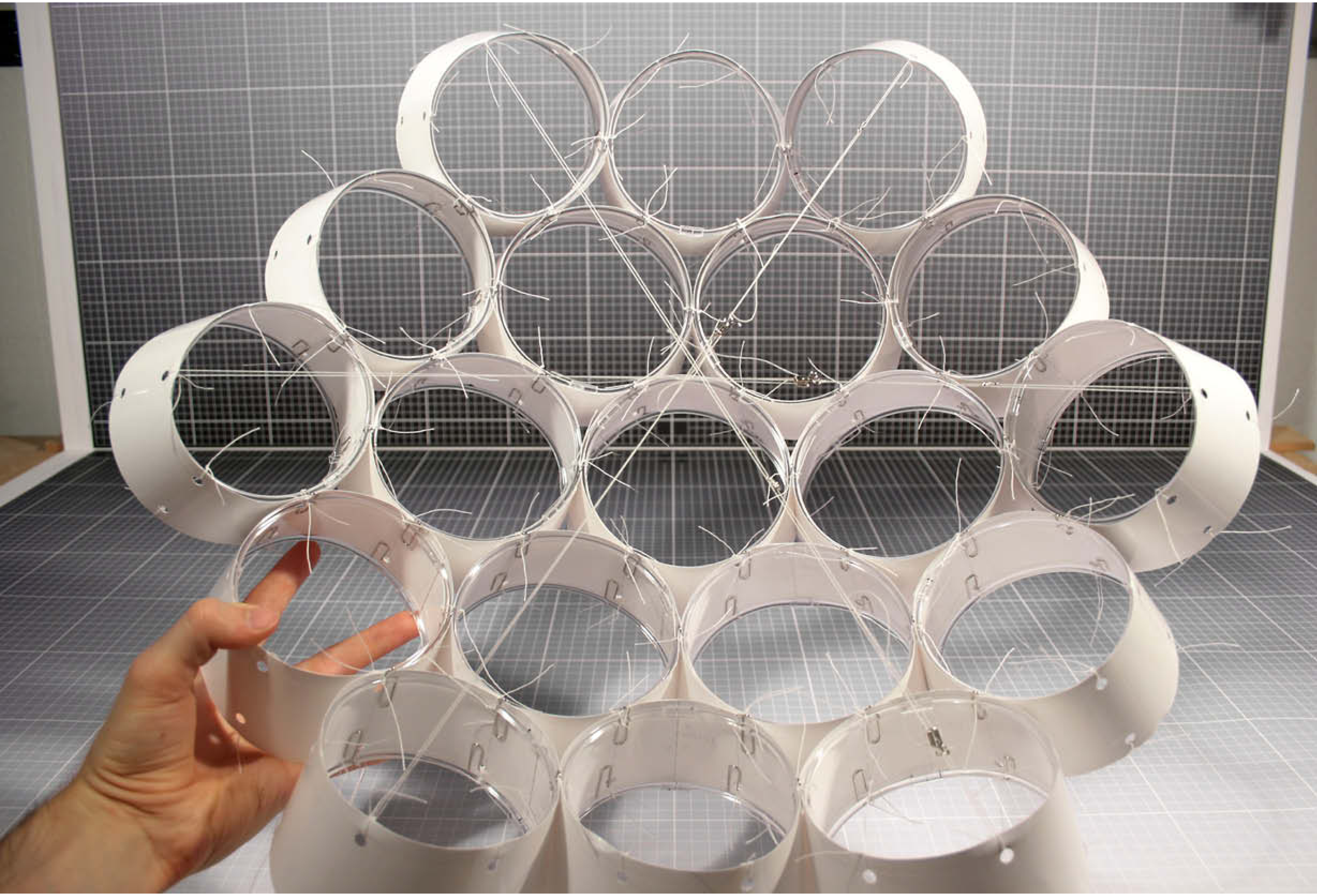
Preparing a model of the cone dome

A video of the dome in rotation is available on the Internet at www.mailoci.com/jf



Model of a cone dome

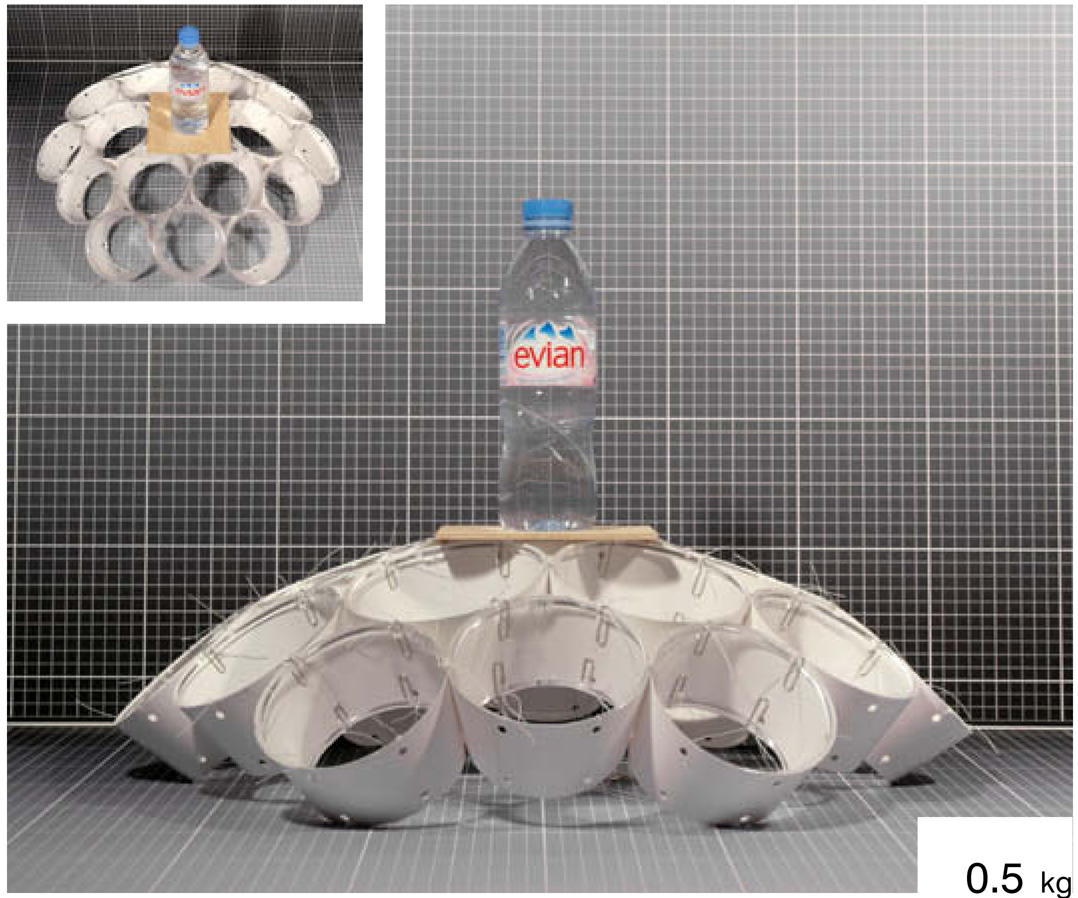
The cone dome, like the geodesic dome, is the result of a simple geometric recipe. Yet, it feels like a 'new idea', a new way of making a strong and economical structure.



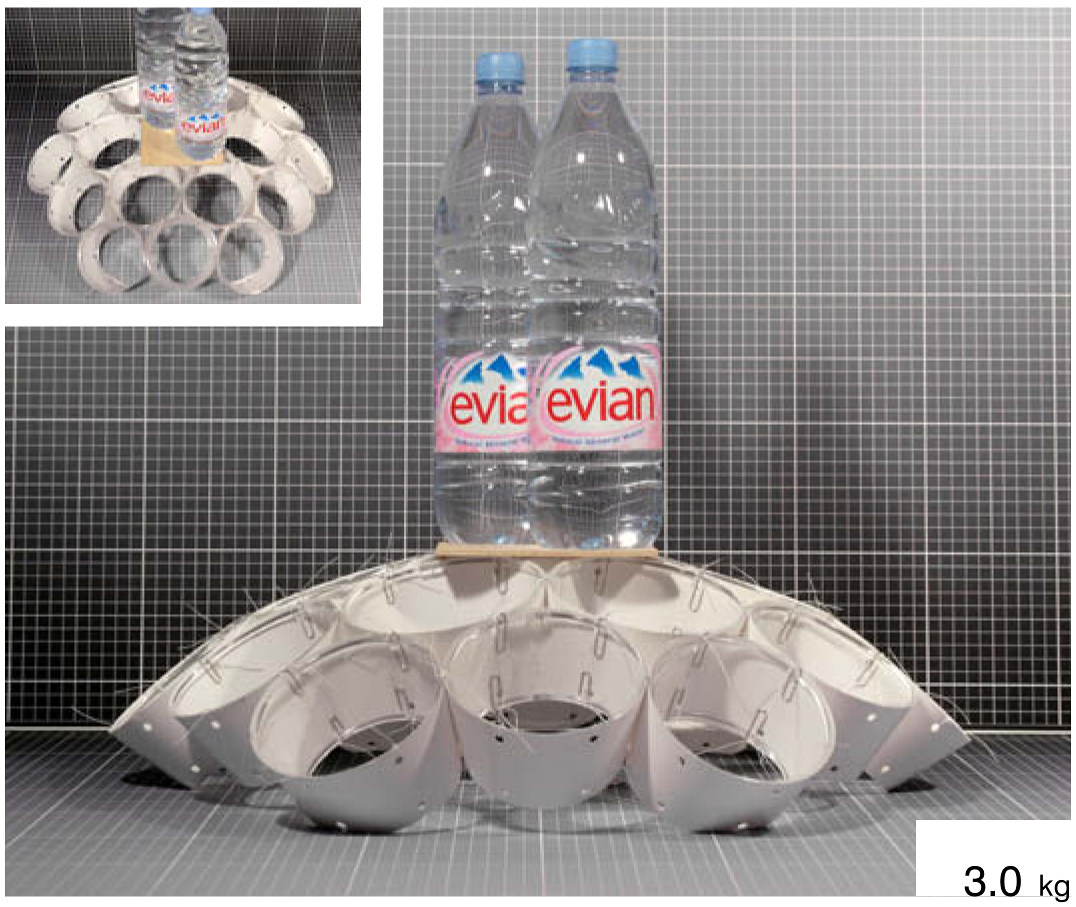
Testing the cone dome

The cone dome, which weighs about 250 grams, was loaded with 11.5 kg. Under the load, the bottom cones were heavily deformed, but the upper cones were almost intact and still did not touch the ground.

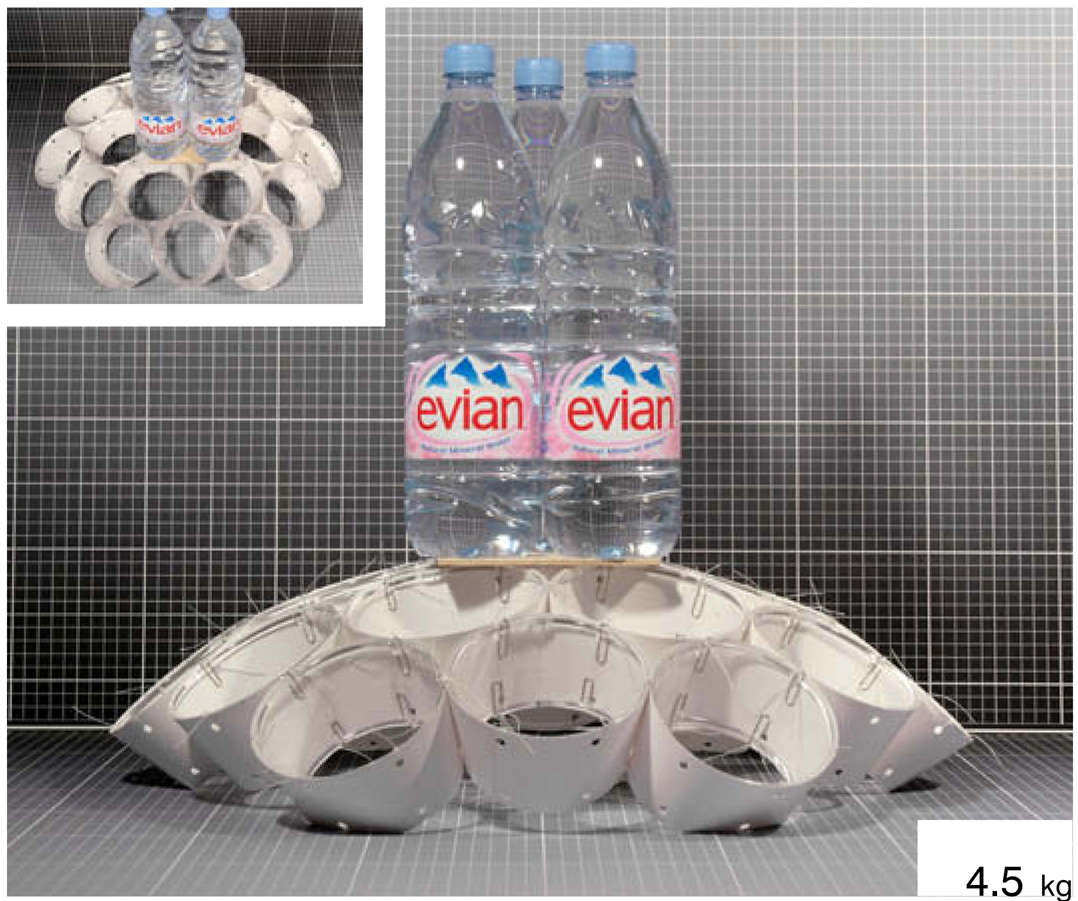
After unloading, the structure reverted instantly and without much damage to its original form.



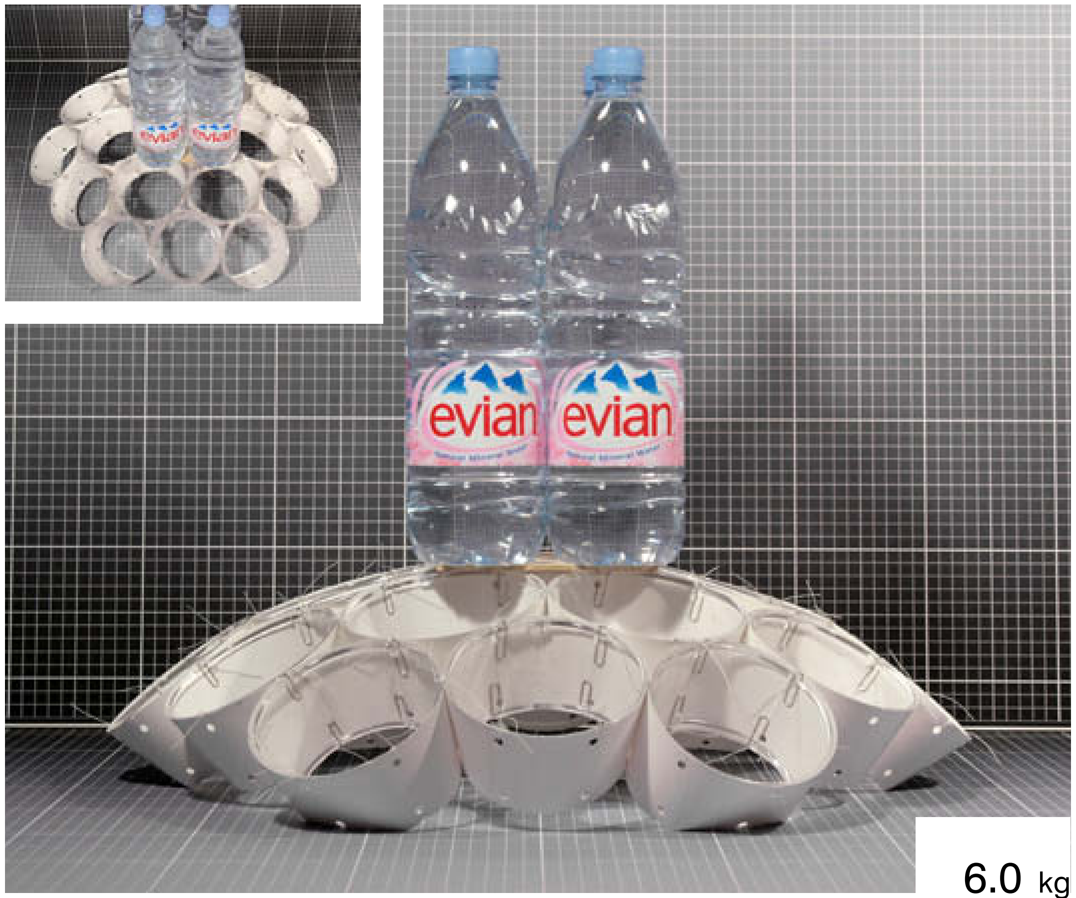
0.5 kg



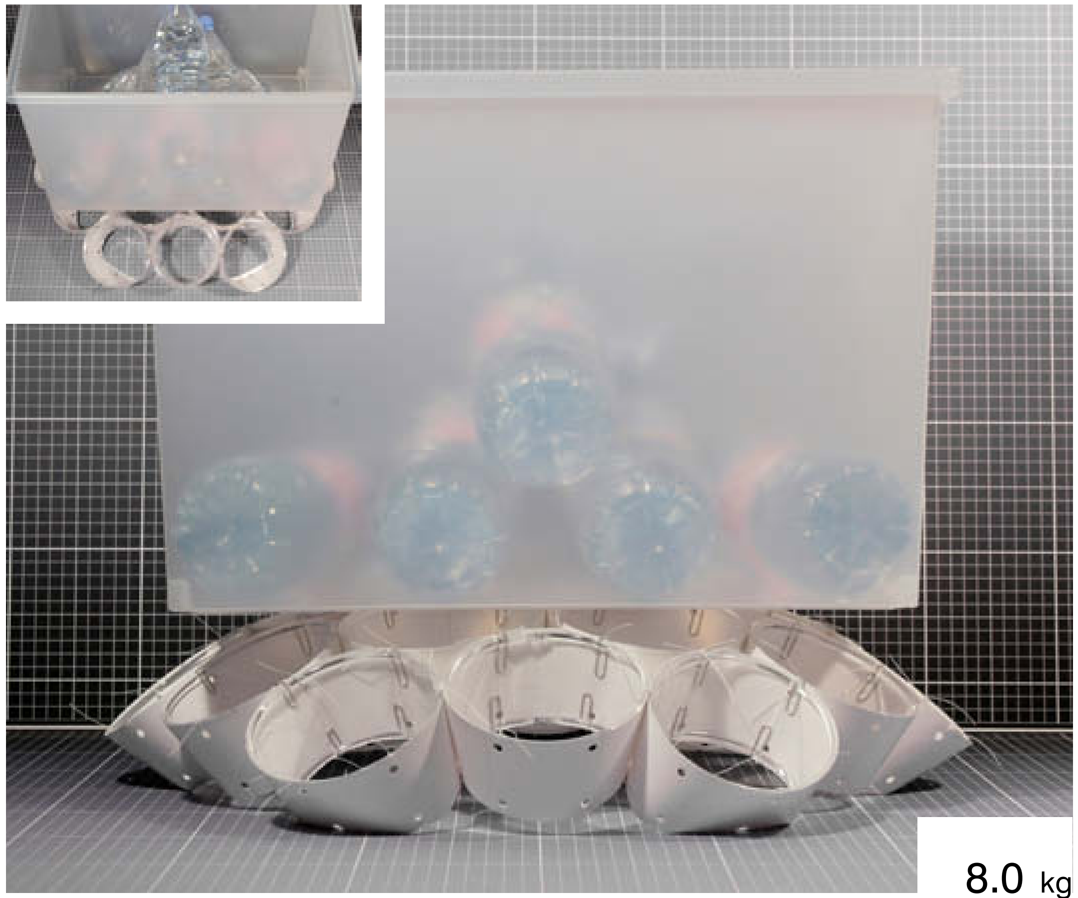
3.0 kg

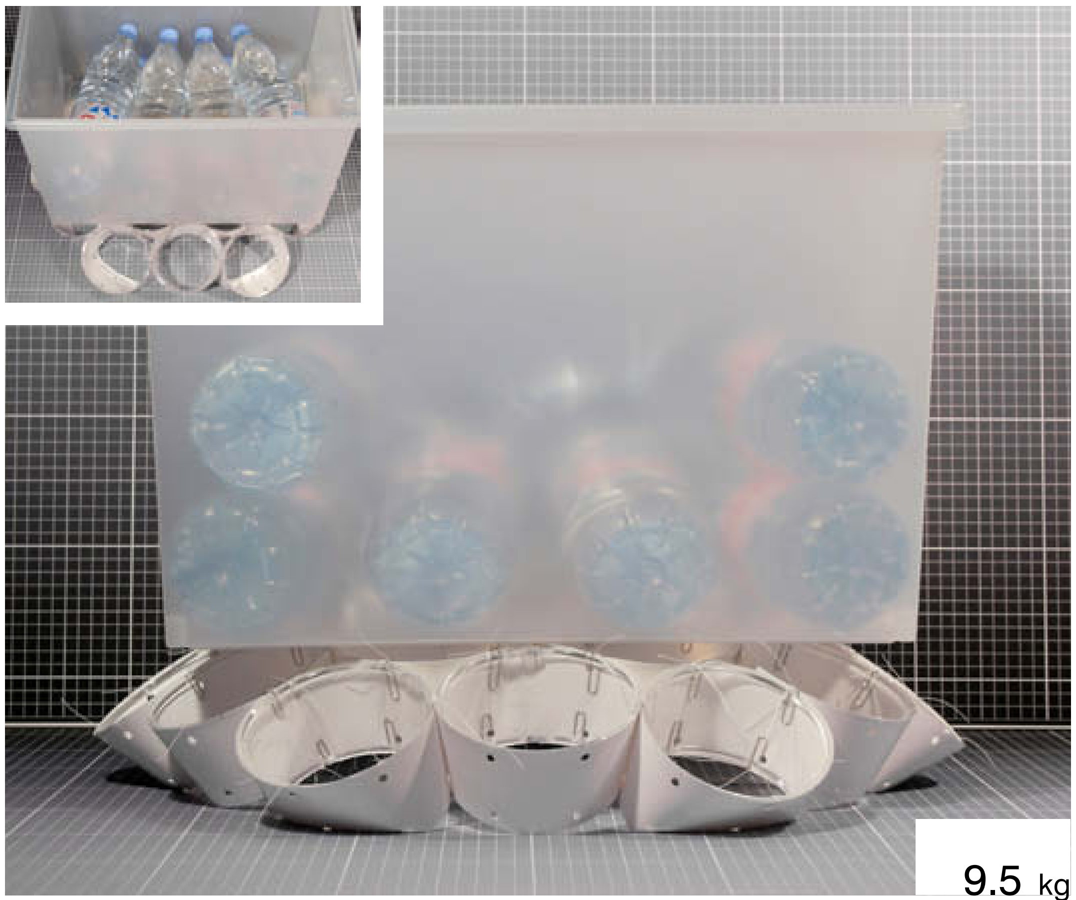


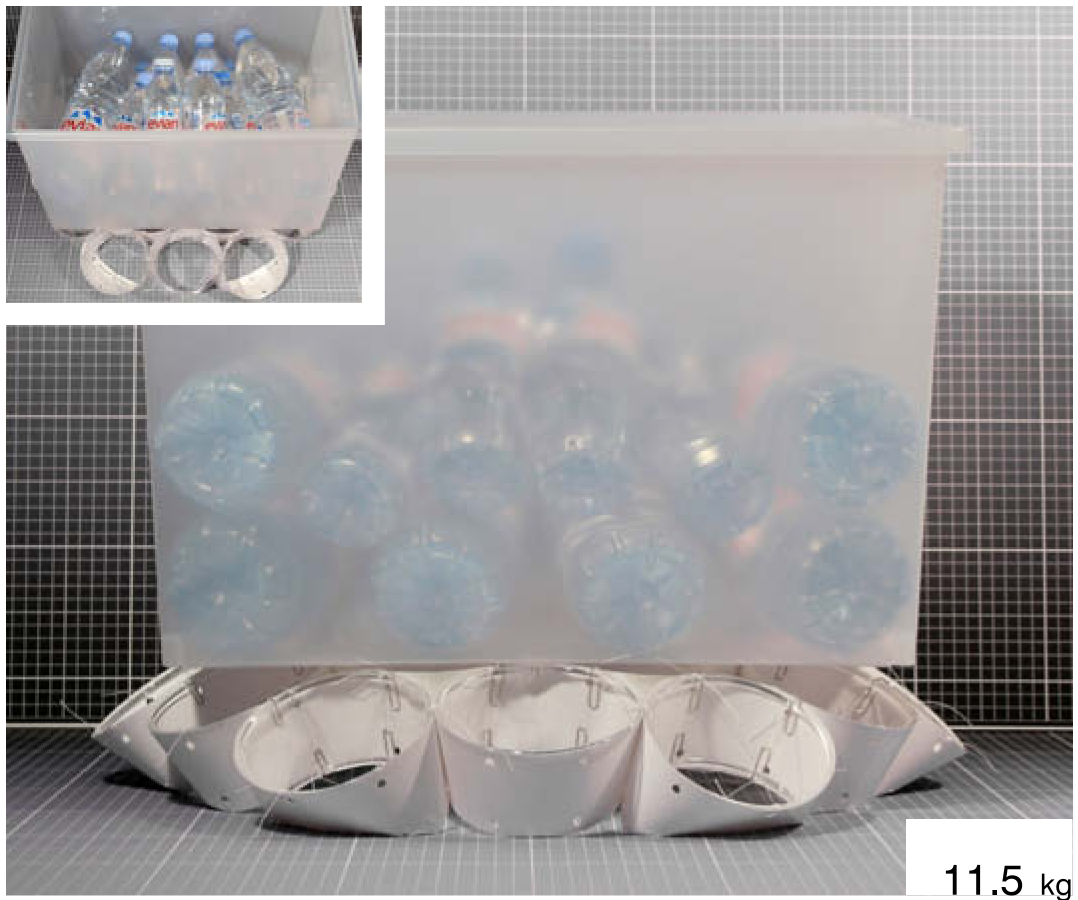
4.5 kg



6.0 kg

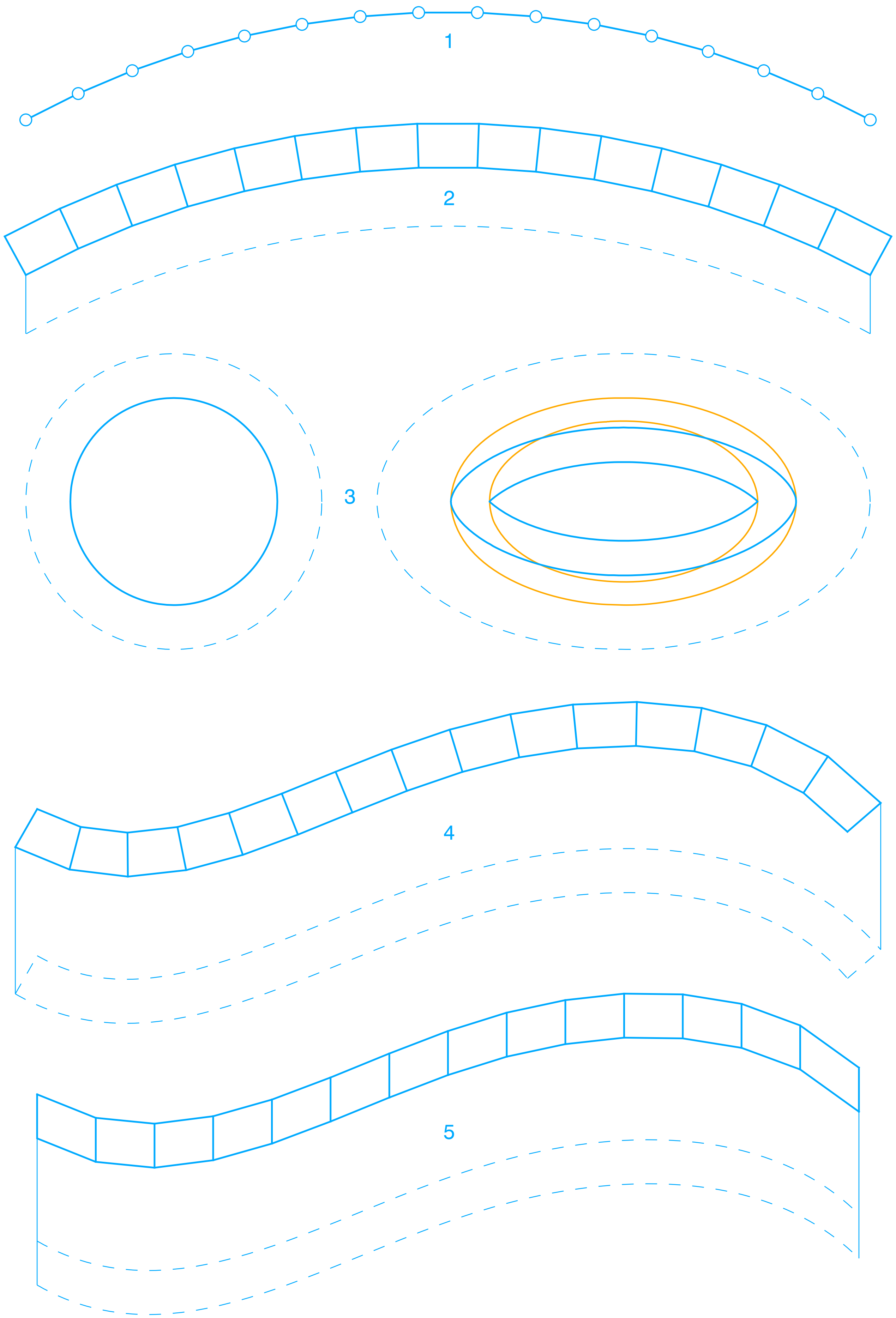

8.0 kg


9.5 kg


11.5 kg

1.5 Achieving double curvature freedom

Moving from offsets to extrusions



A curve, say an arc, can be made out of segments (1). But for it to have strength, it must have depth.

We can make the segmented curve into a truss (2, cross members not shown) of constant depth. For the truss to be of constant depth, its bottom guide curve must be offset, not scaled. This is also true in 3d, where the truss is a space frame.

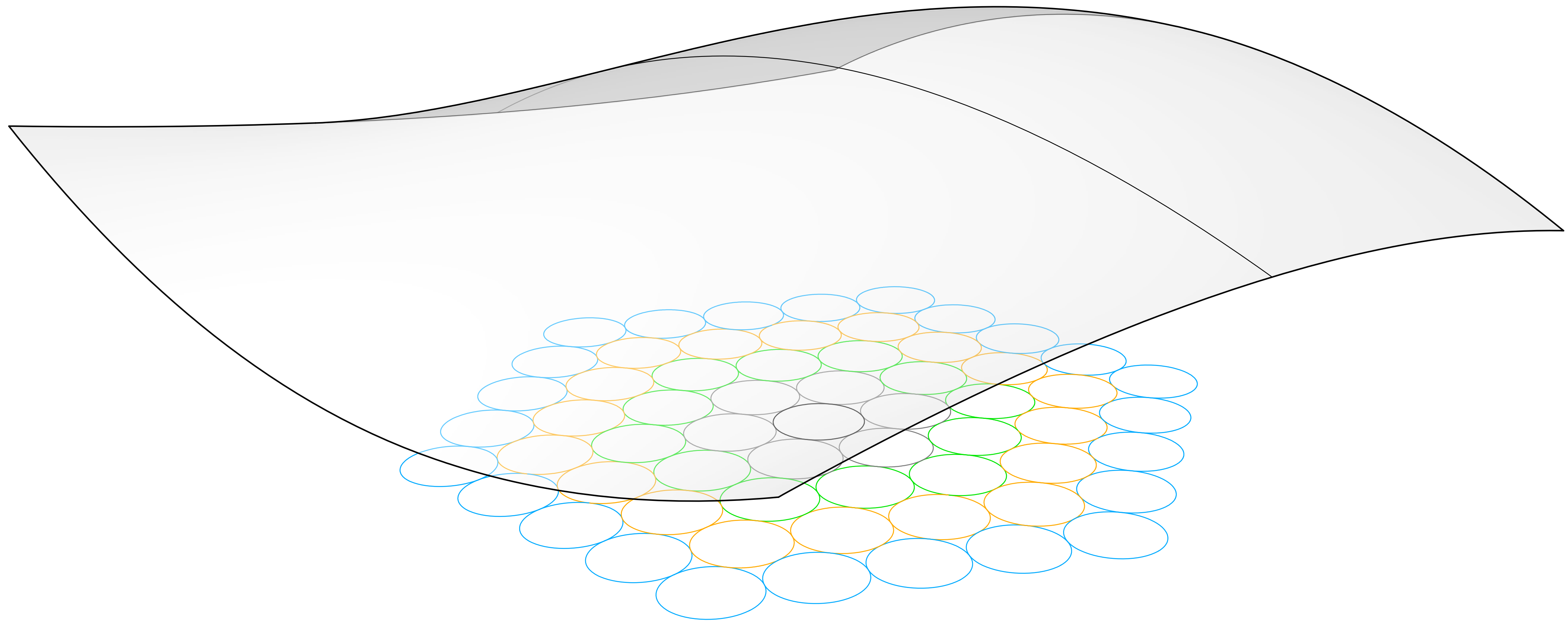
An offset is almost always different from a scale transformation. In 2d, only the line and the circle remain a line or a circle after they are offset. Even the ellipse (3 right, dashed) is denatured by an offset (blue; scale in orange).

The same is true with 3d surfaces. Only a few surfaces (the plane, Platonic solids, sphere, cylinder and torus) can be offset without being denatured. A spline surface, for example, cannot simply be offset; it must be offset at sample points, and reconstructed approximately. The true offset of a spline surface is not a spline surface, but a complex 'degenerate' entity.

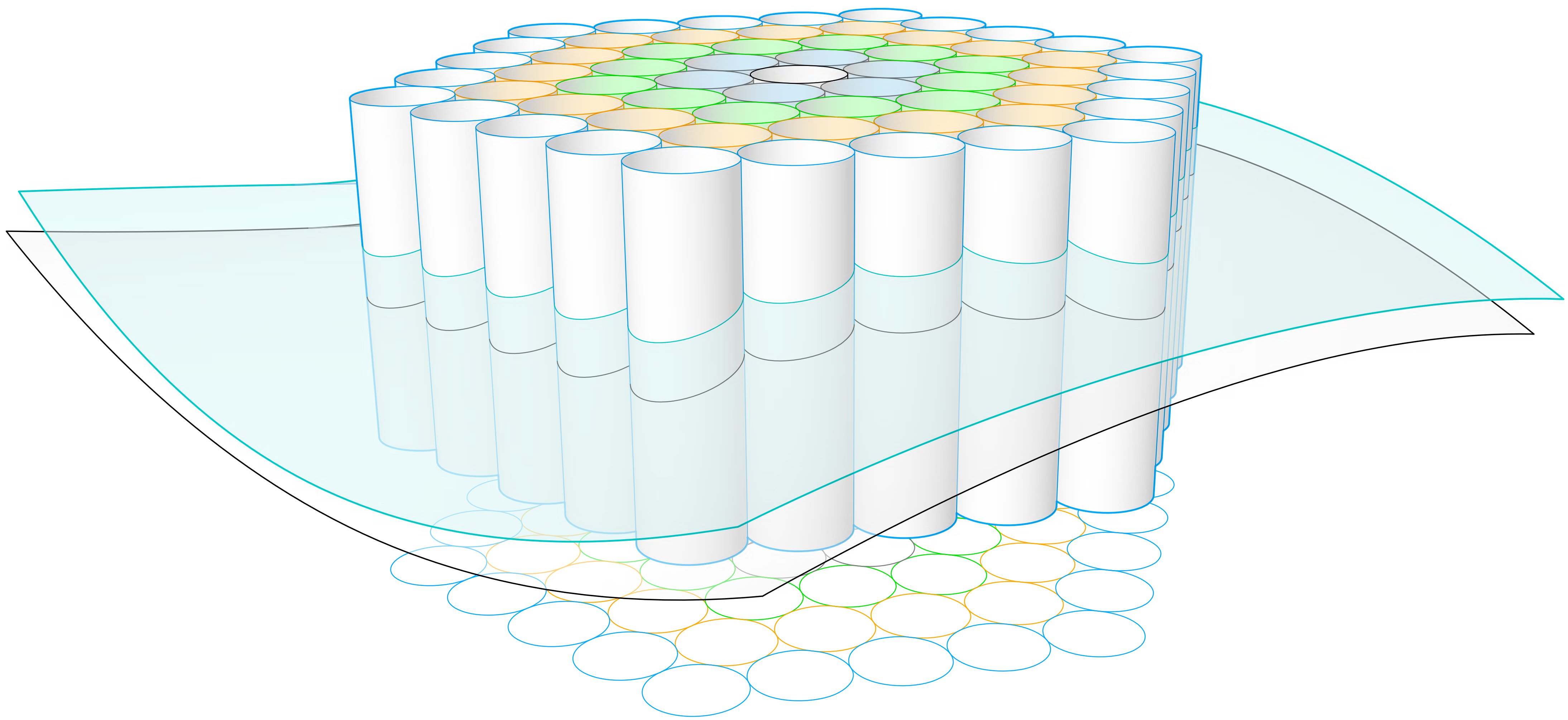
Here (4), a truss approximates a free-form curve. The top chord, an offset, can be described with lines, just like the bottom chord.

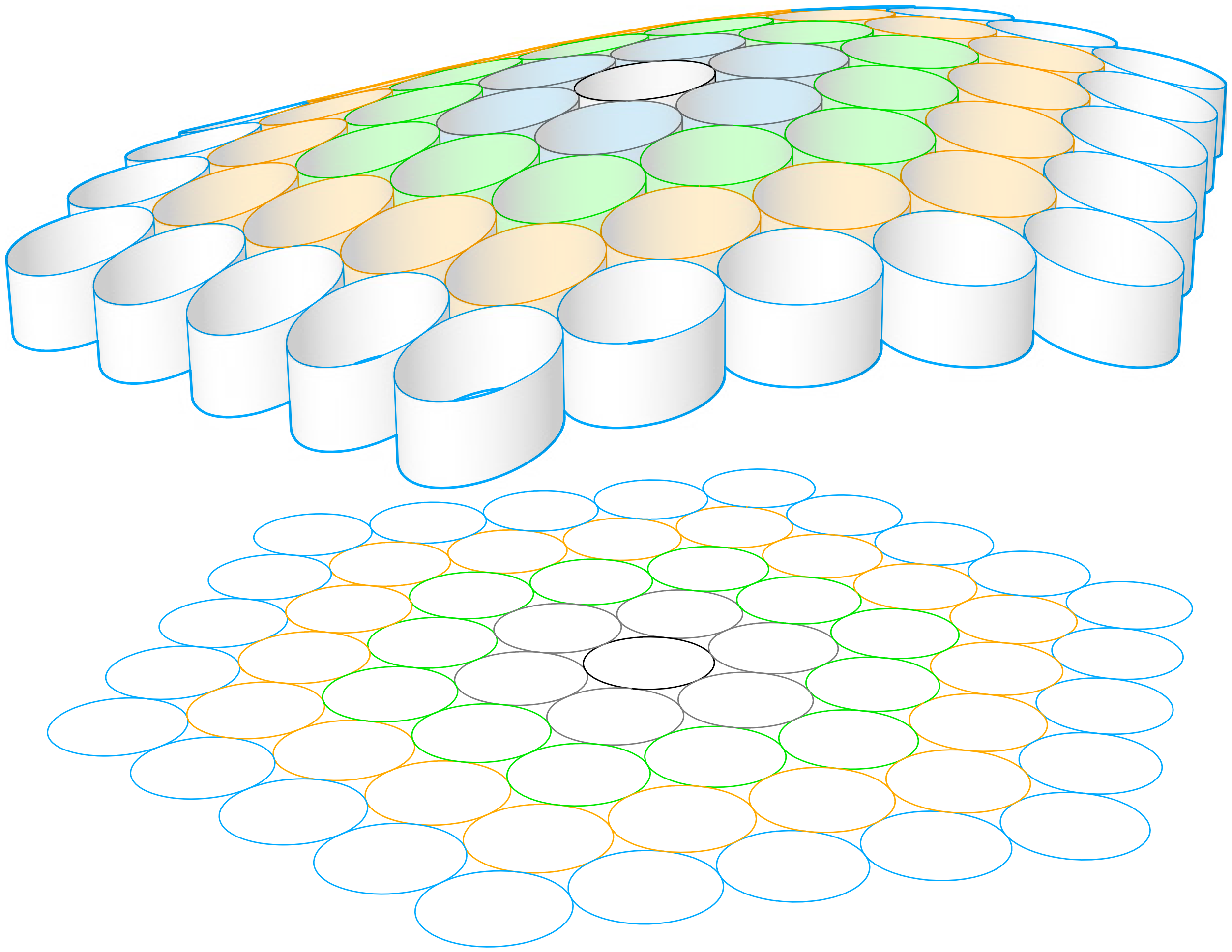
However, let's say that we found a way to describe a free-form surface using tangent circles (say, using close-packing). To create the "top chord" of the space frame, we would need to pair each bottom circle with a top circle (to create truncated cones). But because of the difficulties of offsets, we may not be able to describe the offset surface using the same number of tangent circles, in the same arrangement, as in the bottom chord. It may thus be impossible, or geometrically not nice, to "double-up" a set of tangent circles describing a free-form surface.

One solution is to scale the bottom surface instead of offsetting it. Another (5) is simply to extrude the bottom surface. The vertical members of the space-frame remain just that: vertical.



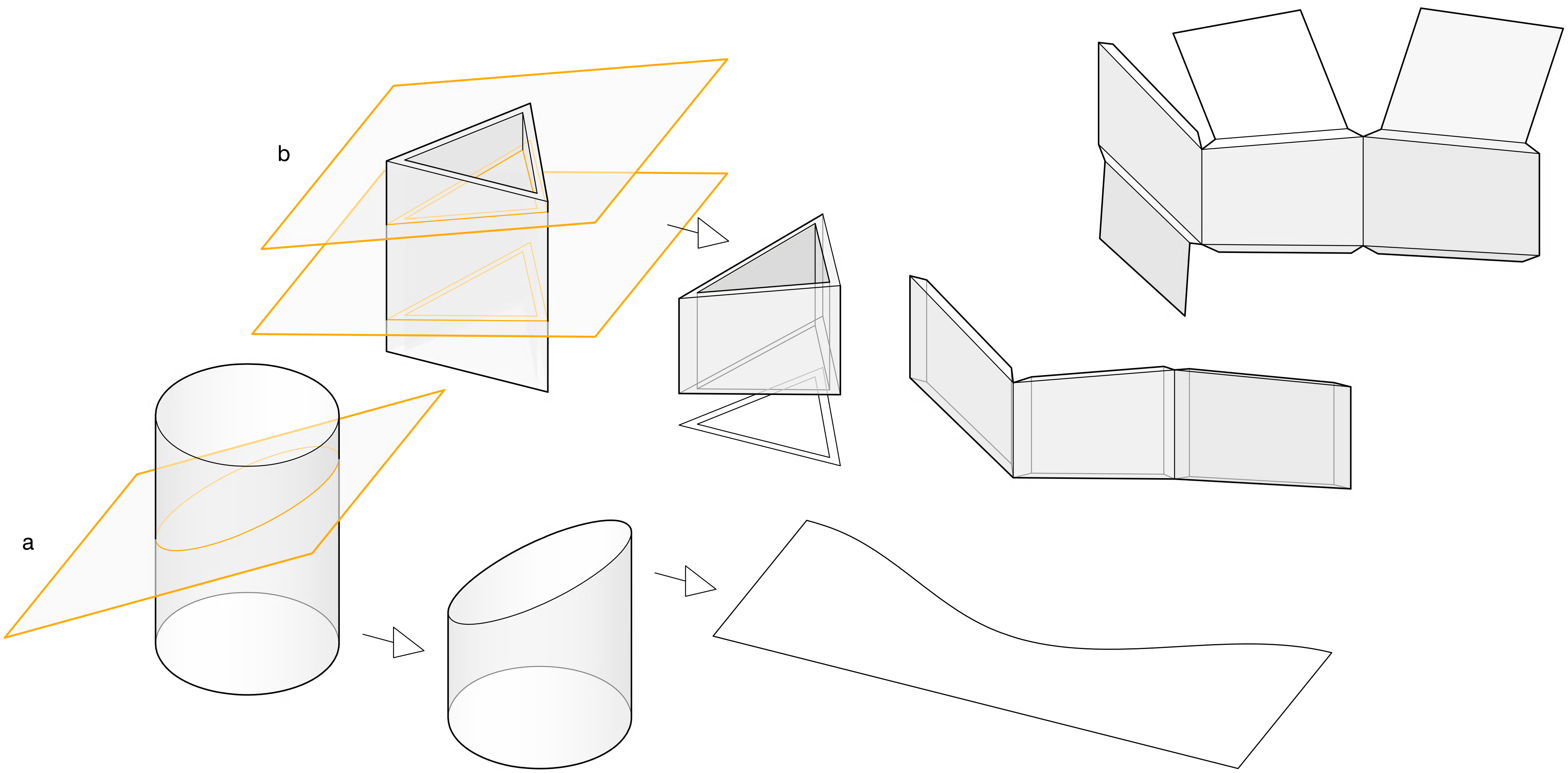
So, taking the honey-comb-circle pattern and a free-form double curvature surface, and extruding the pattern...



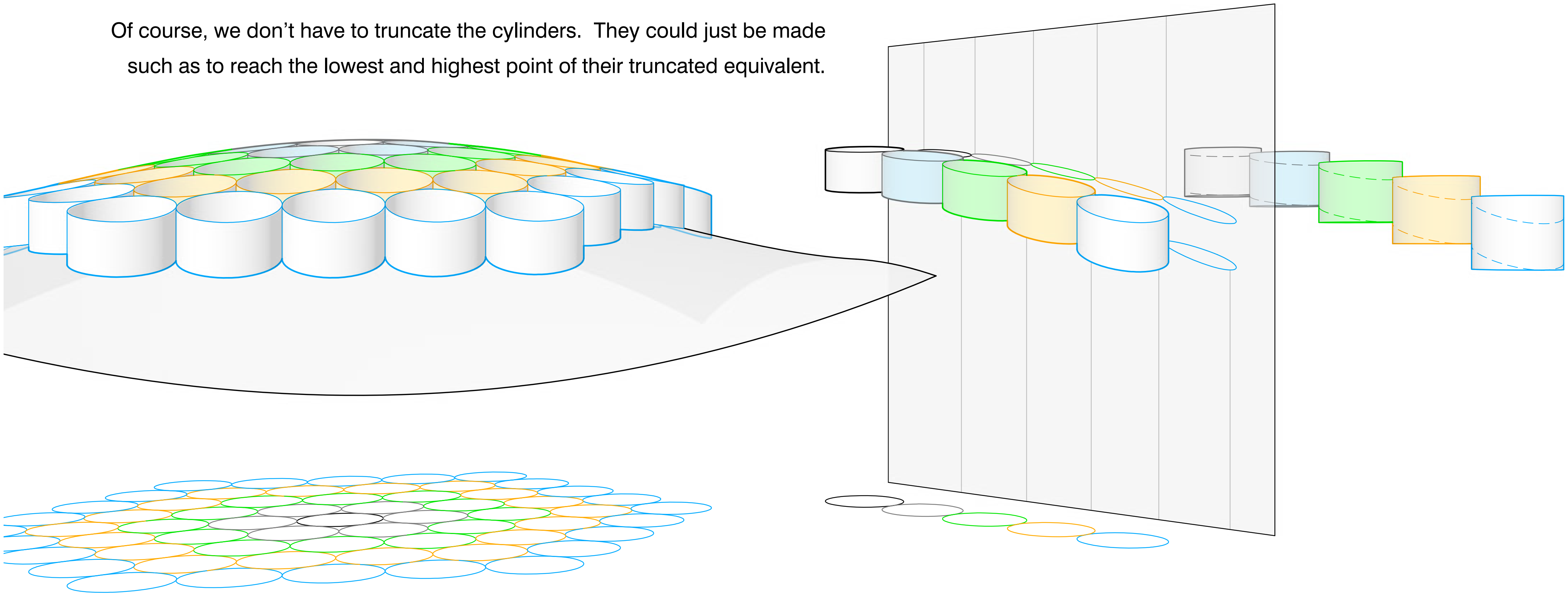


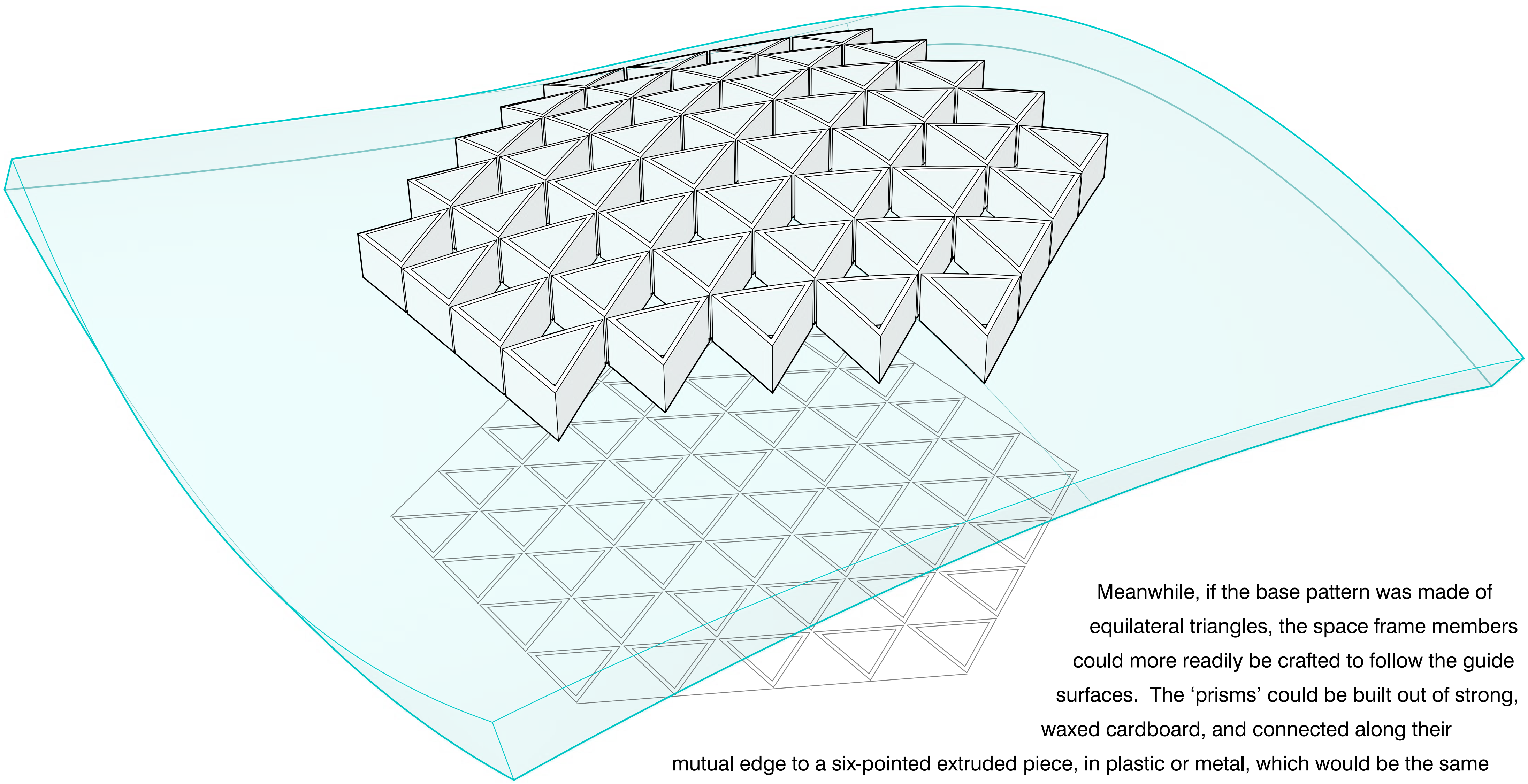
... We can describe a space frame made up of tangent ‘circles’, all with 6 points of contact, of double curvature, without difficulty. It would probably be as strong as the dome made of cones.

There’s one caveat: a cylinder, truncated by a plane at an angle, and unfolded, yields a sine curve (a). It might be difficult to reinforce the edge of the cylinder if, unfolded, it follows a sine. The same problem does not apply to a thickened-up truncated prism (b).

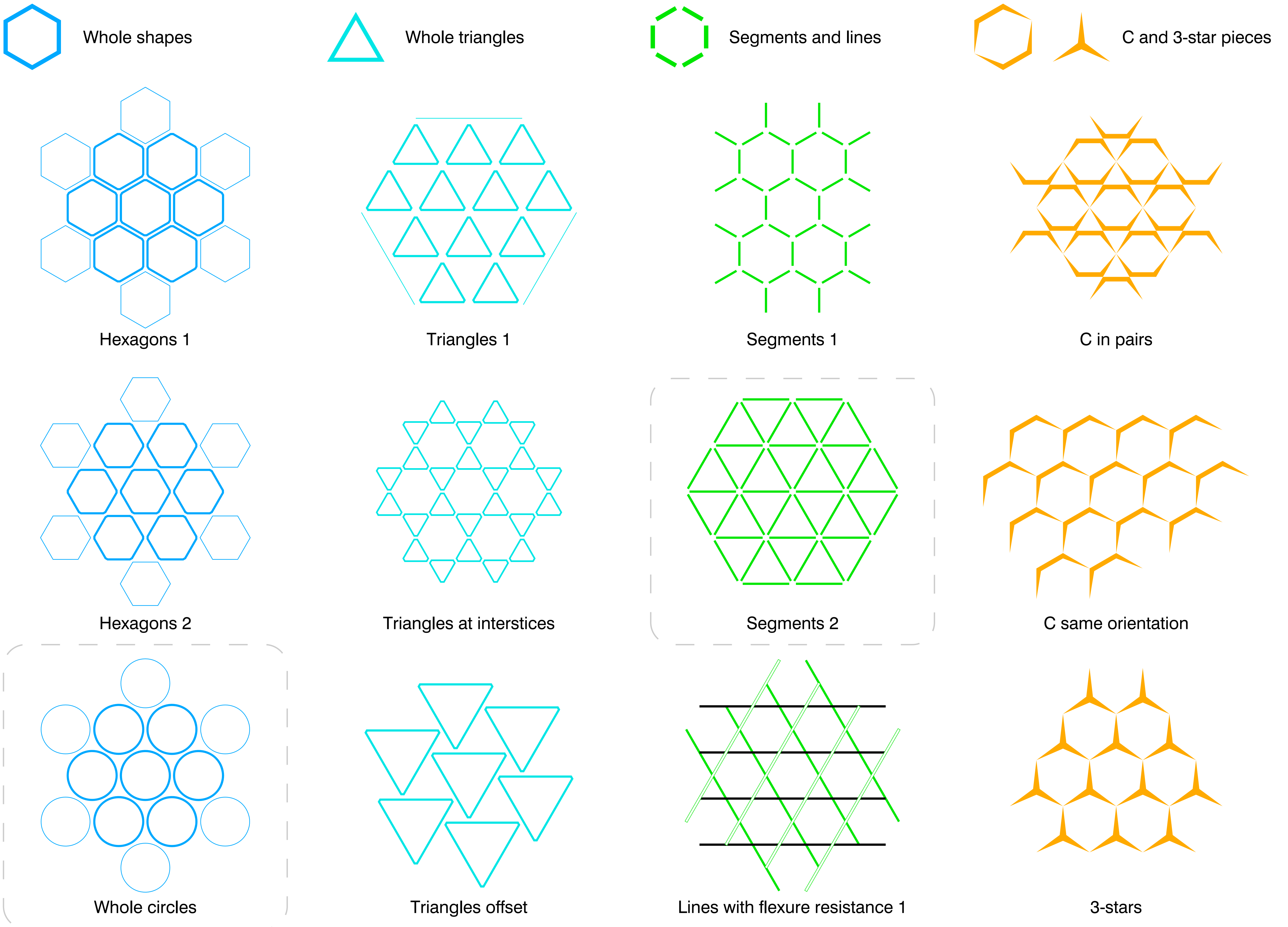


Of course, we don't have to truncate the cylinders. They could just be made such as to reach the lowest and highest point of their truncated equivalent.

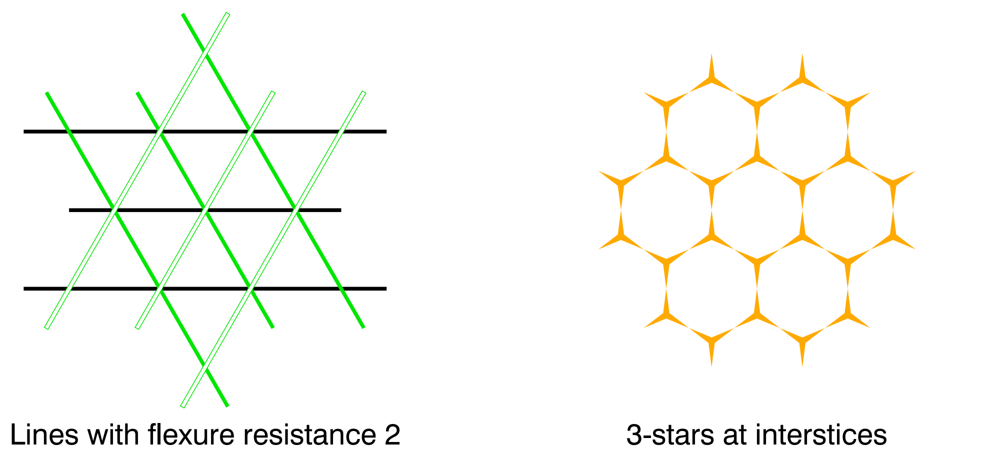




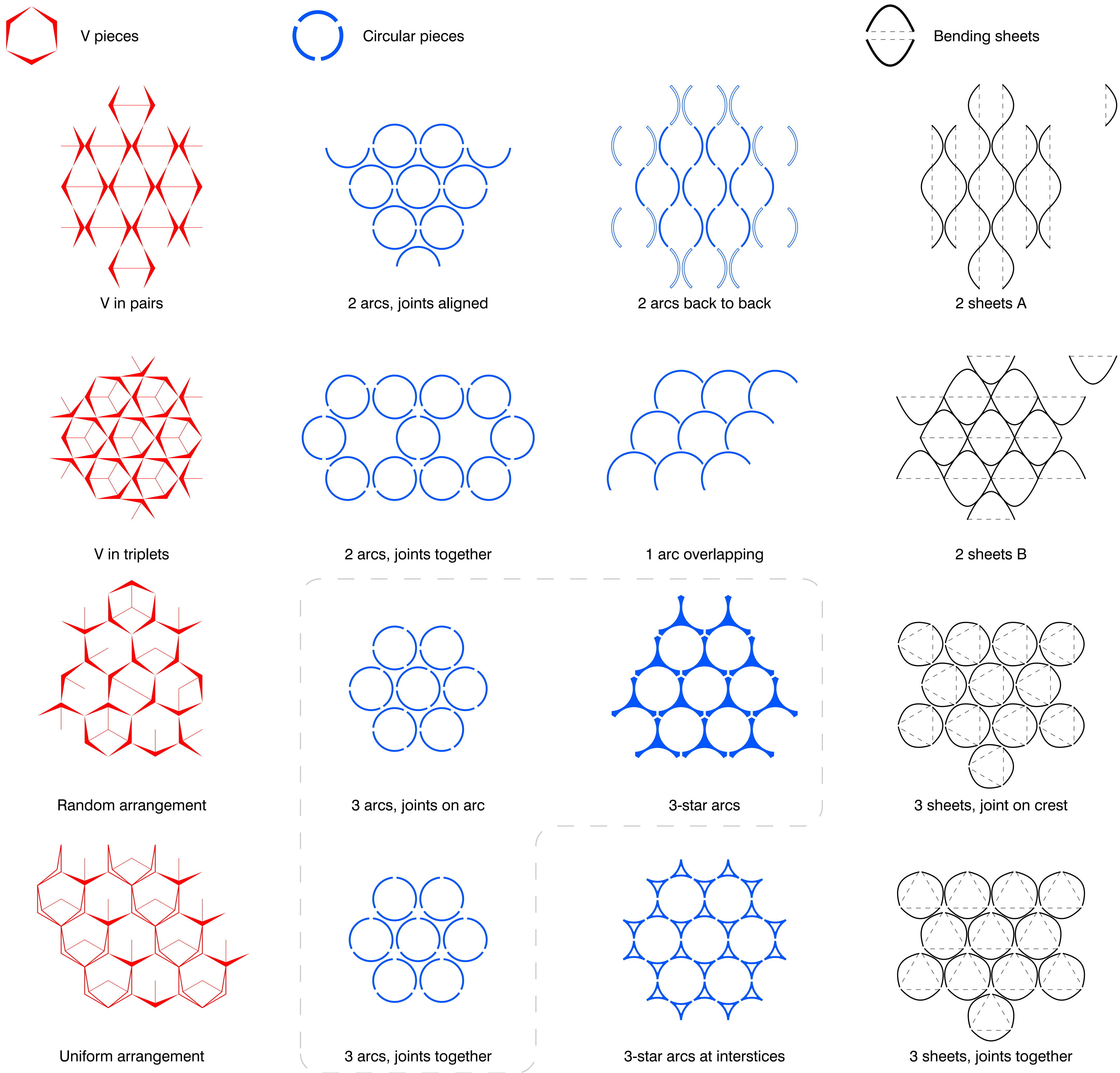
Meanwhile, if the base pattern was made of equilateral triangles, the space frame members could more readily be crafted to follow the guide surfaces. The 'prisms' could be built out of strong, waxed cardboard, and connected along their mutual edge to a six-pointed extruded piece, in plastic or metal, which would be the same everywhere. In sum, both ideas – circles and triangles – are interesting.

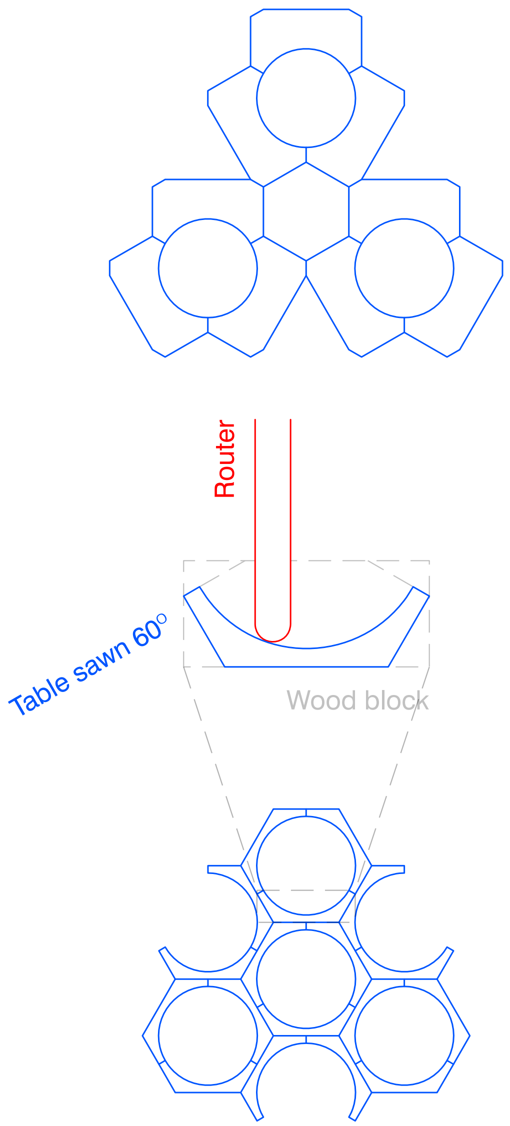


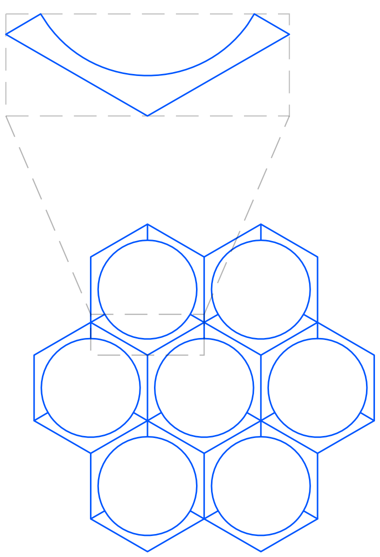
These were drawn in order to consider other hexagonal patterns than the one with whole circles, used until now in this exploration of components and space frames.

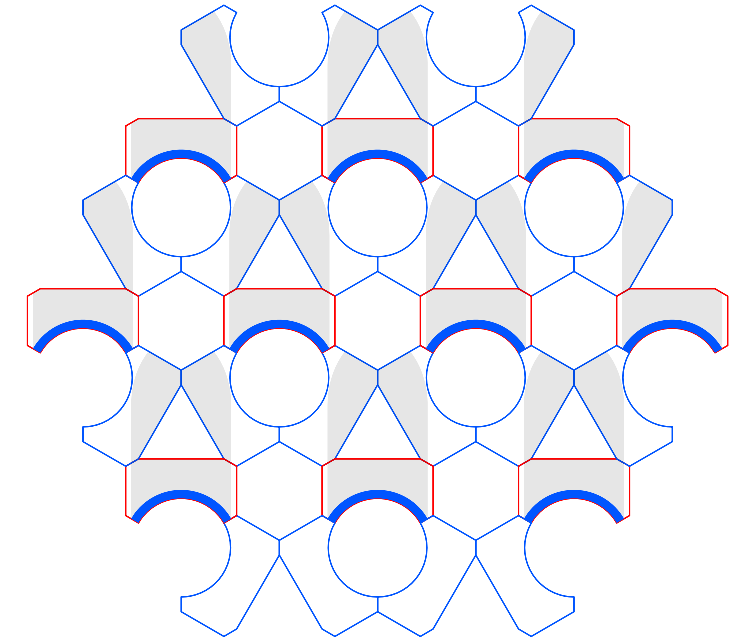


1.6 Hexagonal extrusions

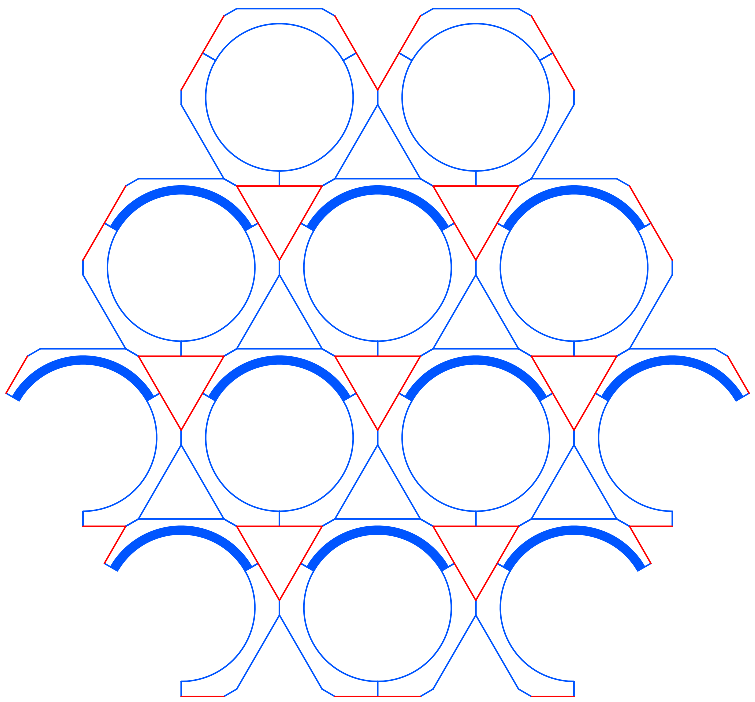

V pieces
Circular pieces
Bending sheets
V in pairs
2 arcs, joints aligned
2 arcs back to back
2 sheets A
V in triplets
2 arcs, joints together
1 arc overlapping
2 sheets B
Random arrangement
3 arcs, joints on arc
3-star arcs
3 sheets, joint on crest
Uniform arrangement
3 arcs, joints together
3-star arcs at interstices
3 sheets, joints together

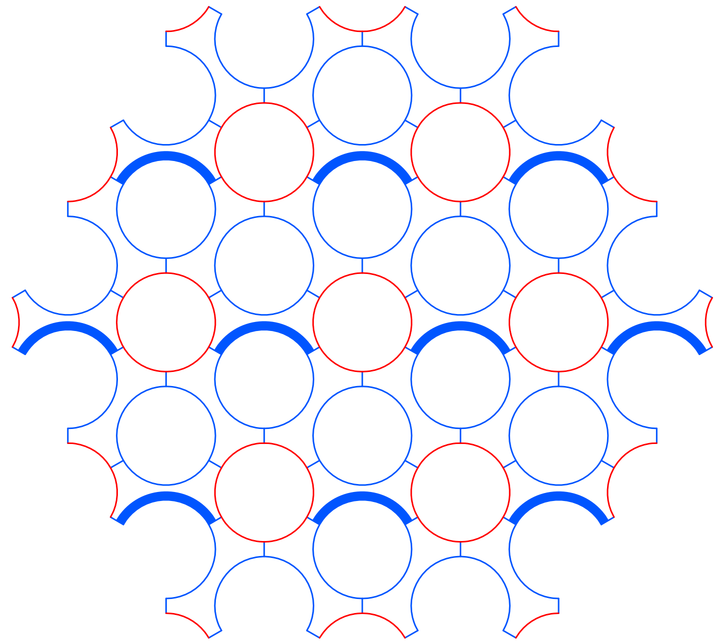






1



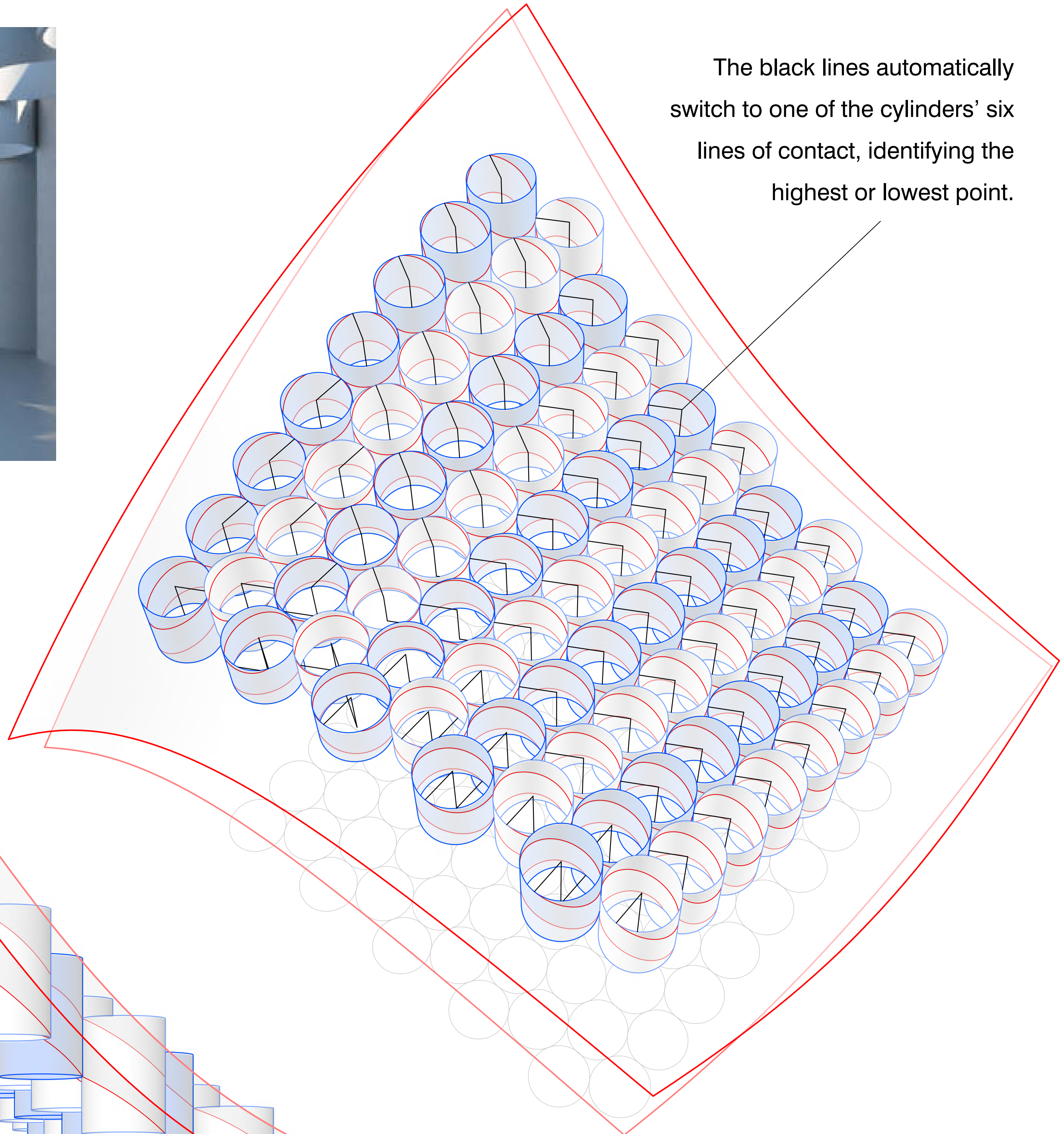


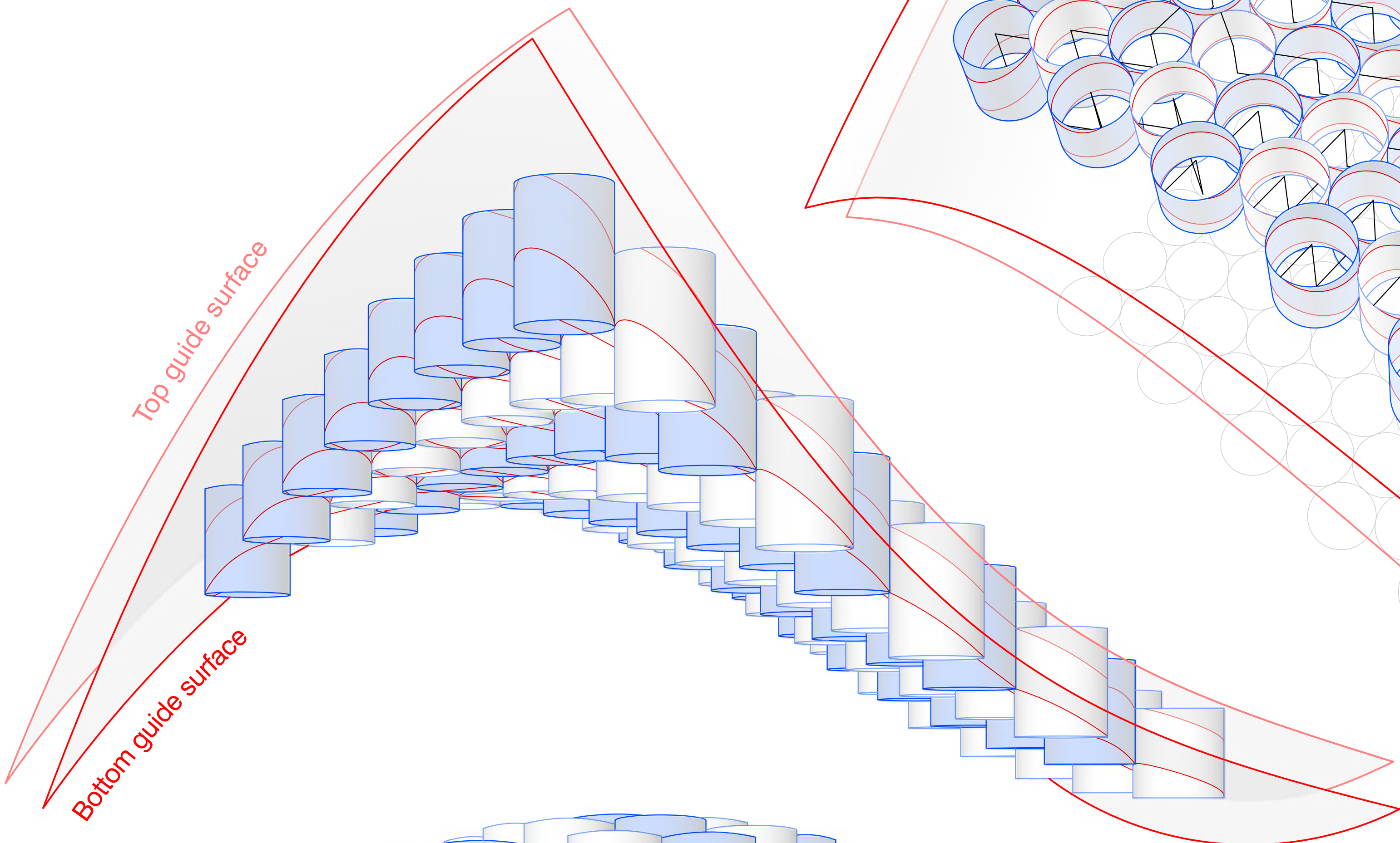
2

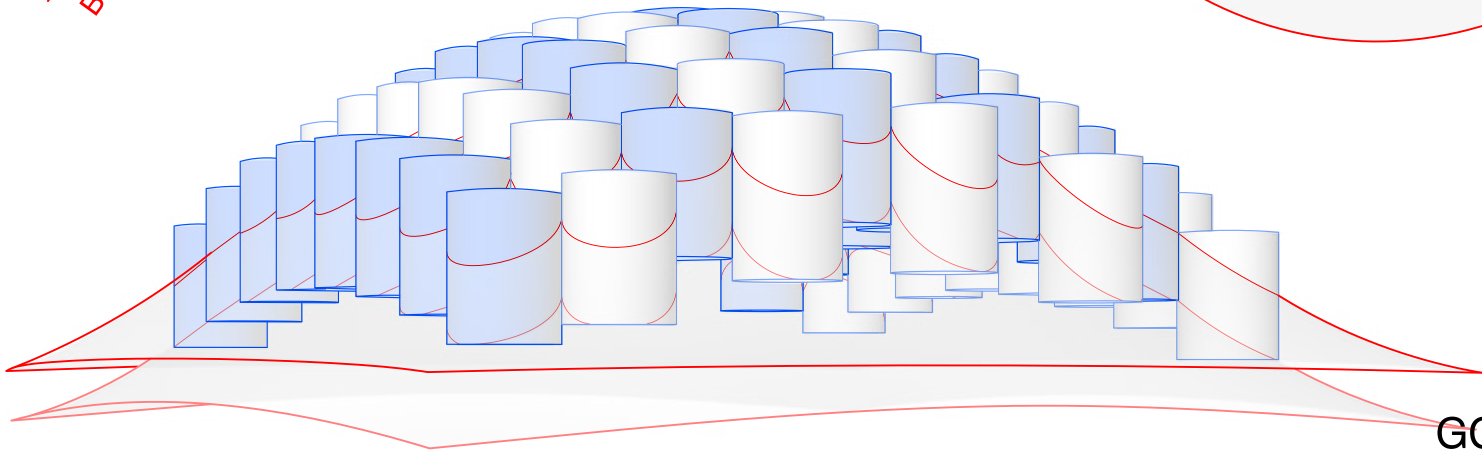
Extruded space-frame components

In November 2007, we were preparing an exhibition for the BRAC University Department of architecture in Dhaka, Bangladesh. Our teachers asked us to prepare a model of our shelter ideas. I thought of modeling extrusions which I would've cut to length, shifted up and down, and glued to form a dome-like structure (1). Some extrusions would have extended higher, perhaps to catch wind or light, as in the Atlanta High Museum of Art expansion by the Renzo Piano Building Workshop (2).

Draft rendering of the ‘cylinder shelter’



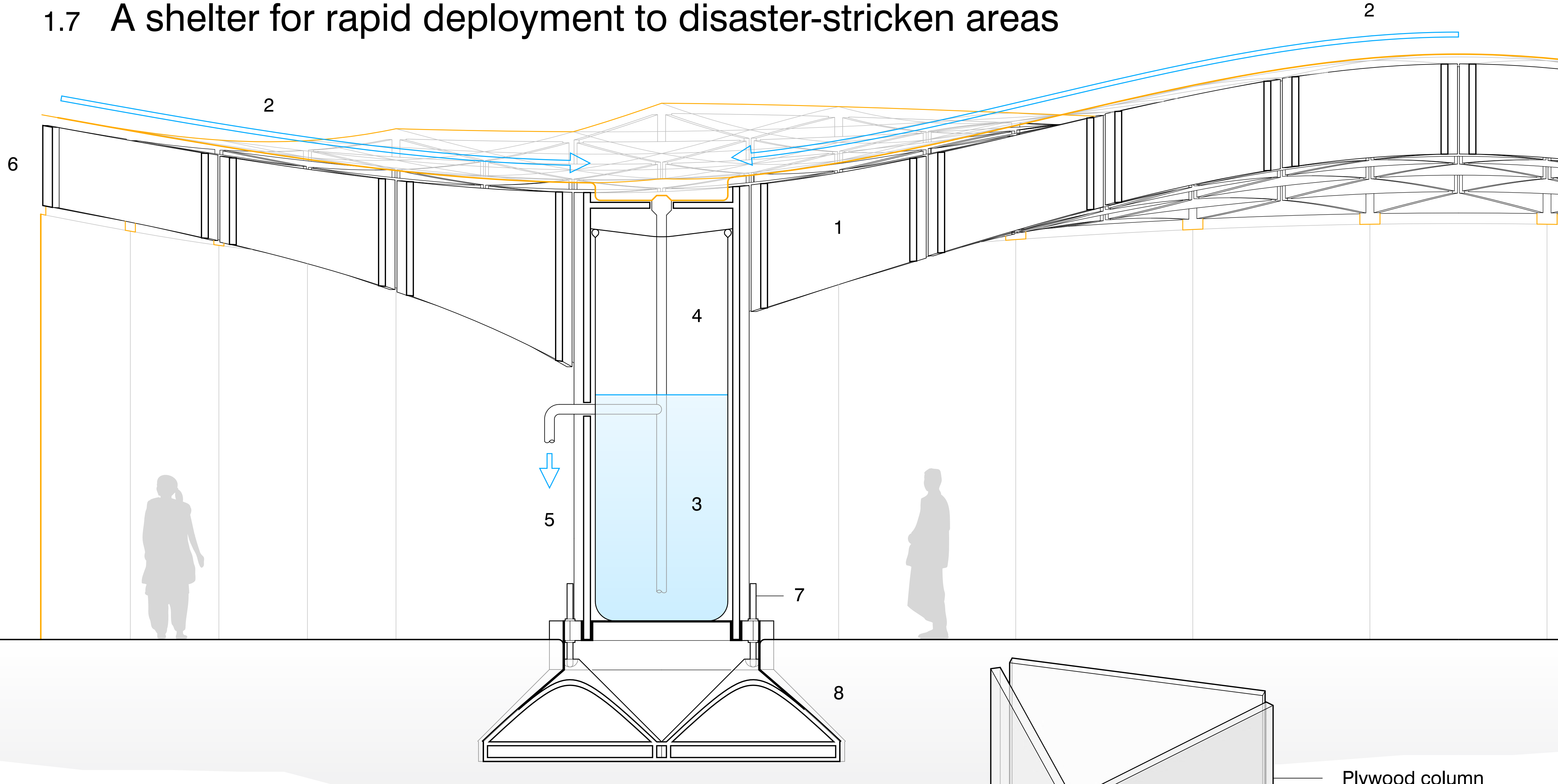


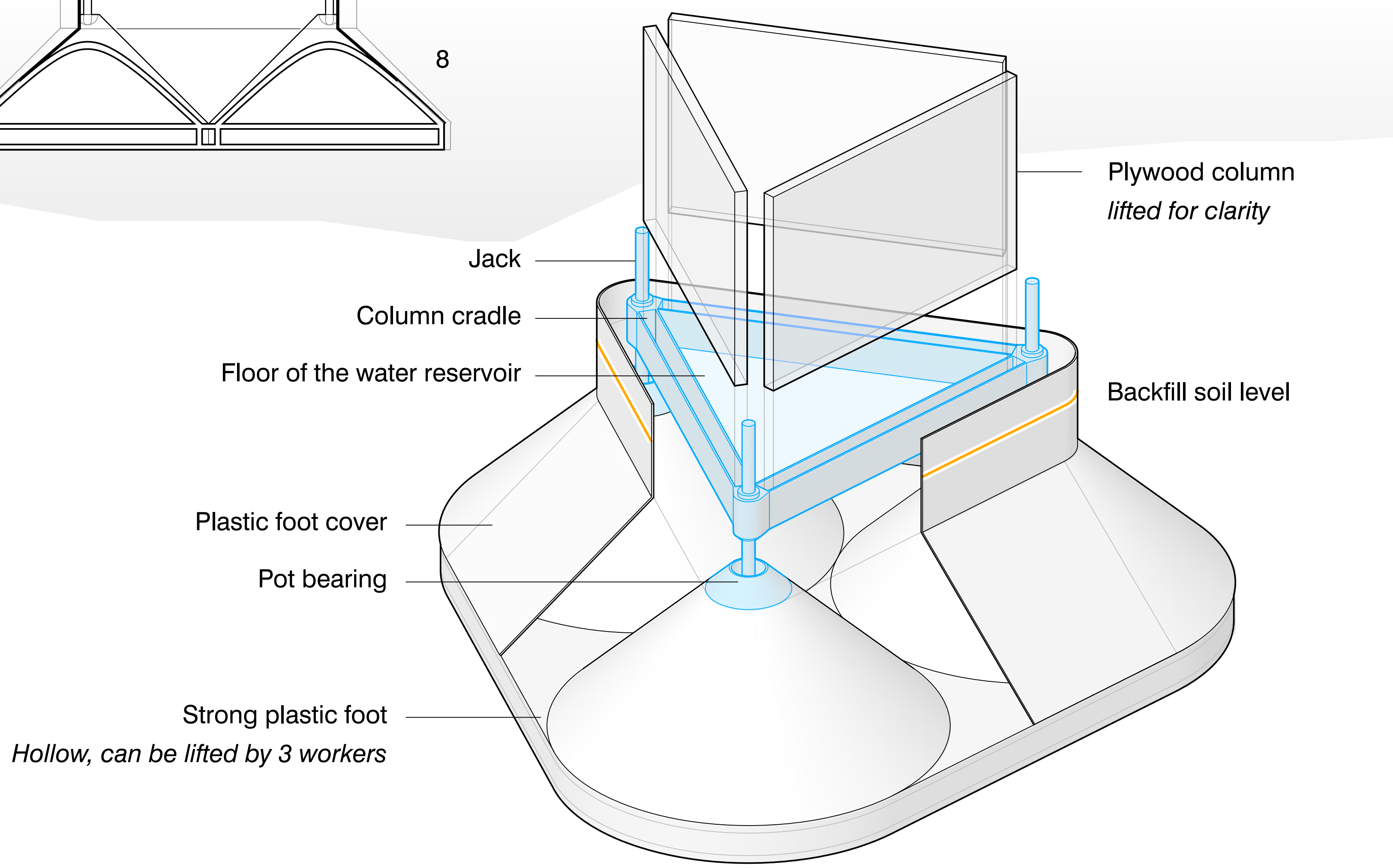


The GC script takes the six points where the cylinders touch, projects them onto the top and bottom guide surfaces, and finds the highest and lowest points, respectively. When the free-form guide surfaces are adjusted, the cylinders adjust automatically. It automates the process described on page 26, saving the user a lot of time.

GC automation of the extrusion heights

1.7 A shelter for rapid deployment to disaster-stricken areas





1 Plywood planks
Lower edge curves to create strength near the columns; upper edge curves to channel rain towards the columns.

2 Rain converges to the columns

3 Water is stored in a bag inside the column; the lower water serves as ballast.

4 Upper space for consumable rain water

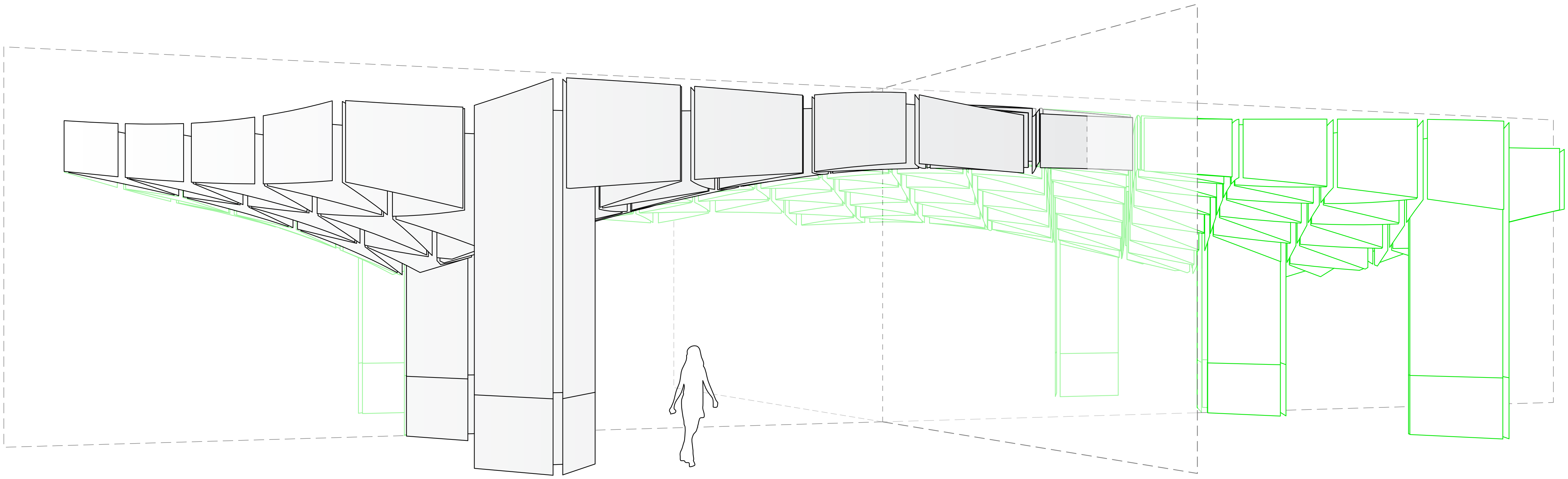
5 Collected water is output to filtration

6 Part of the structure could be exposed, or the membrane could cover it entirely.

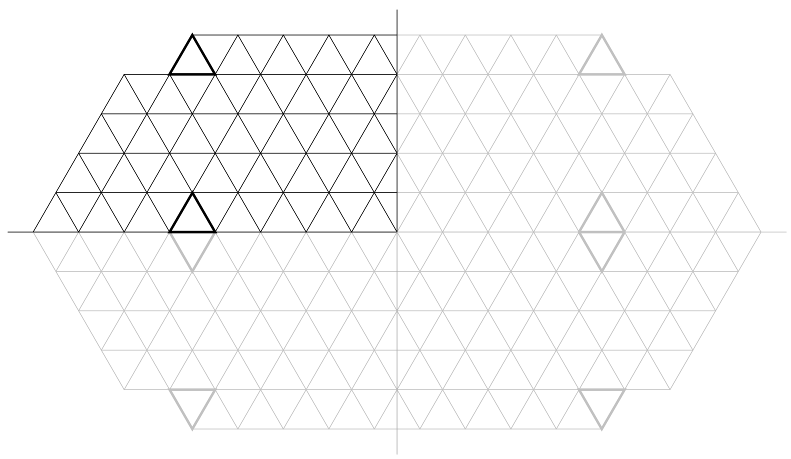
7 Jacks allow for constant adjustments to the uneven settling of the ground

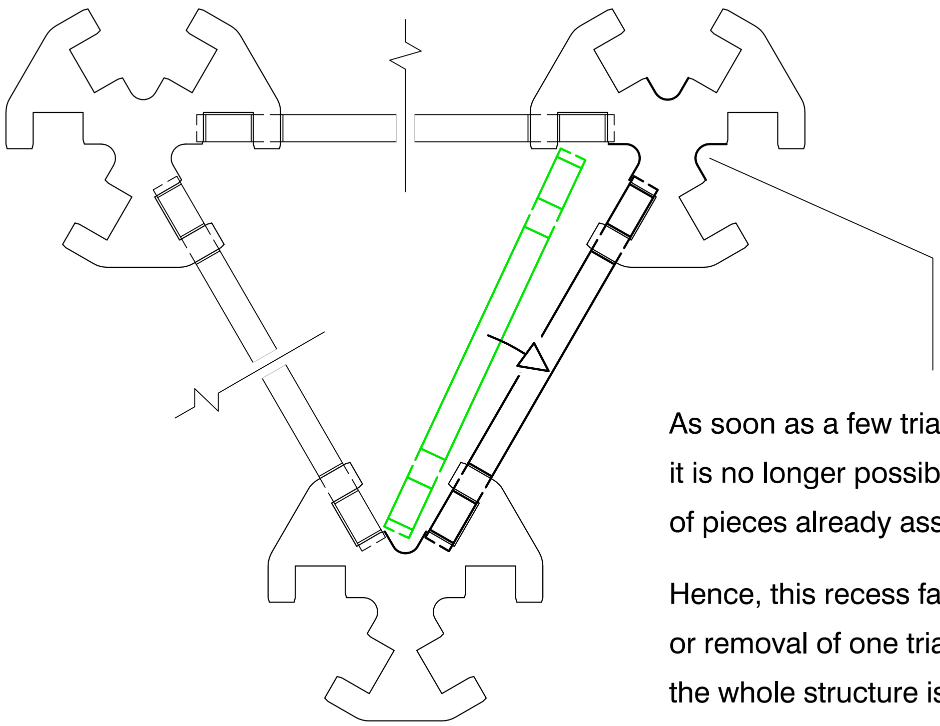
8 Foundation for rapid deployment

This shelter could be shipped to a disastered area in Bangladesh, for example to house a clinic. For economy, all plywood planks are the same width and connect at the same angle; and the whole structure can be flat-packed. It harvests drinkable water, a scarce resource after a cyclone when the wells are contaminated.



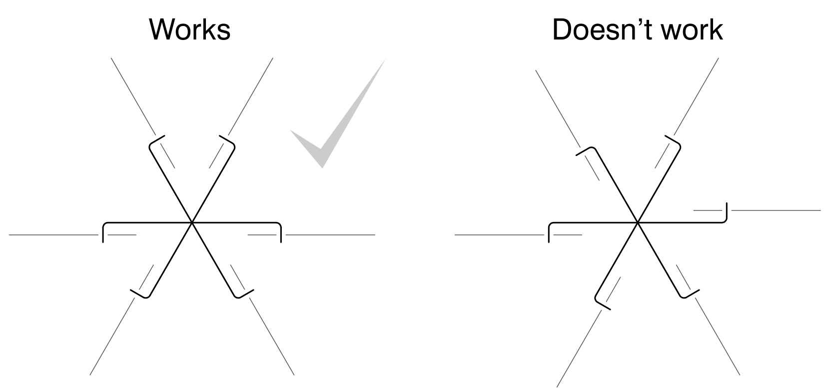
Only 1 / 4 of the structure was modeled; the rest was visualized using two perpendicular mirrors.

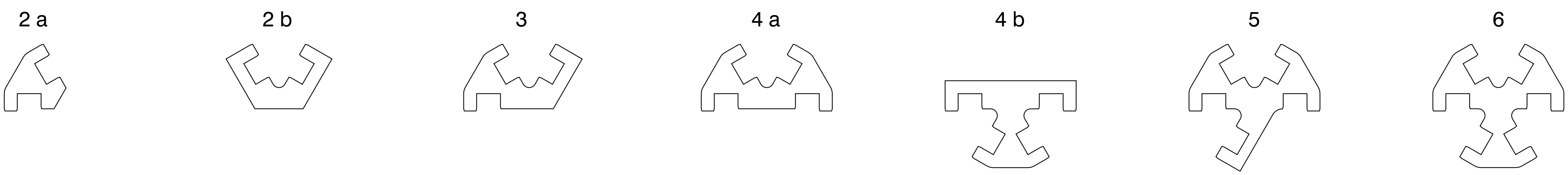




As soon as a few triangles are assembled, it is no longer possible to 'twist' the angles of pieces already assembled.

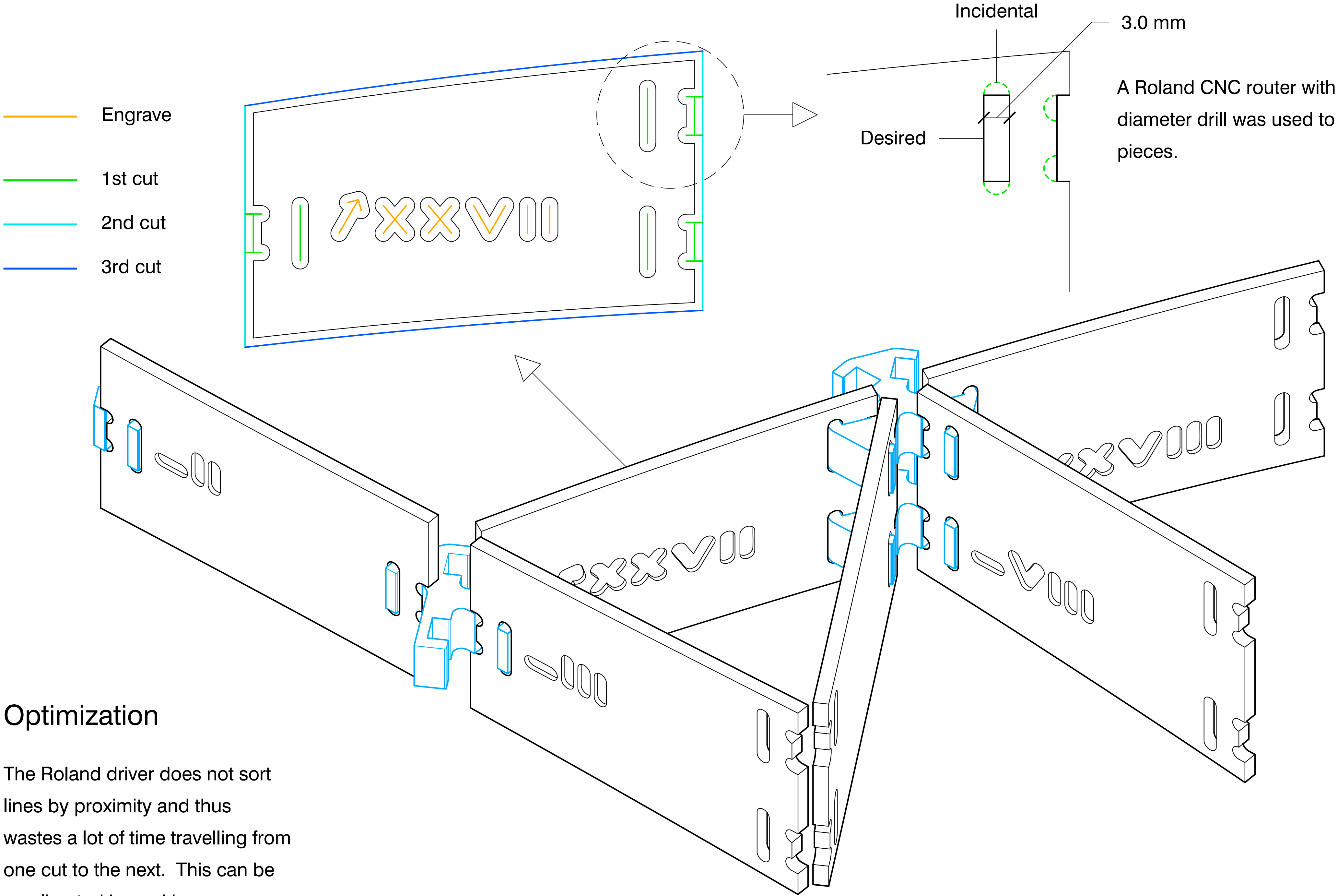
Hence, this recess facilitates the insertion or removal of one triangle side, even when the whole structure is assembled.





Making a model of the triangle shelter

Connector 6 would work everywhere, but the additional types address the edge conditions more nicely.



A Roland CNC router with a 3 mm diameter drill was used to cut the pieces.

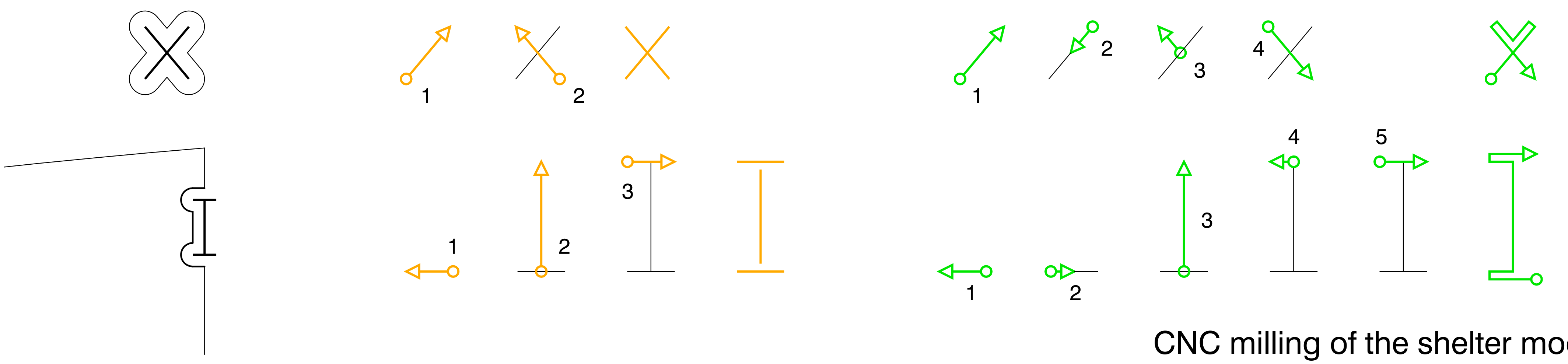
Optimization

The Roland driver does not sort lines by proximity and thus wastes a lot of time travelling from one cut to the next. This can be ameliorated by making as many polylines as possible.

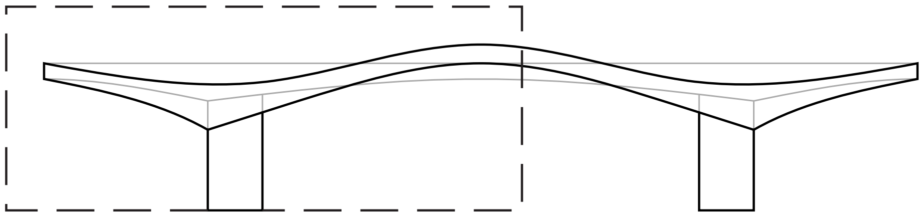
Router follows a random path
Lots of time wasted

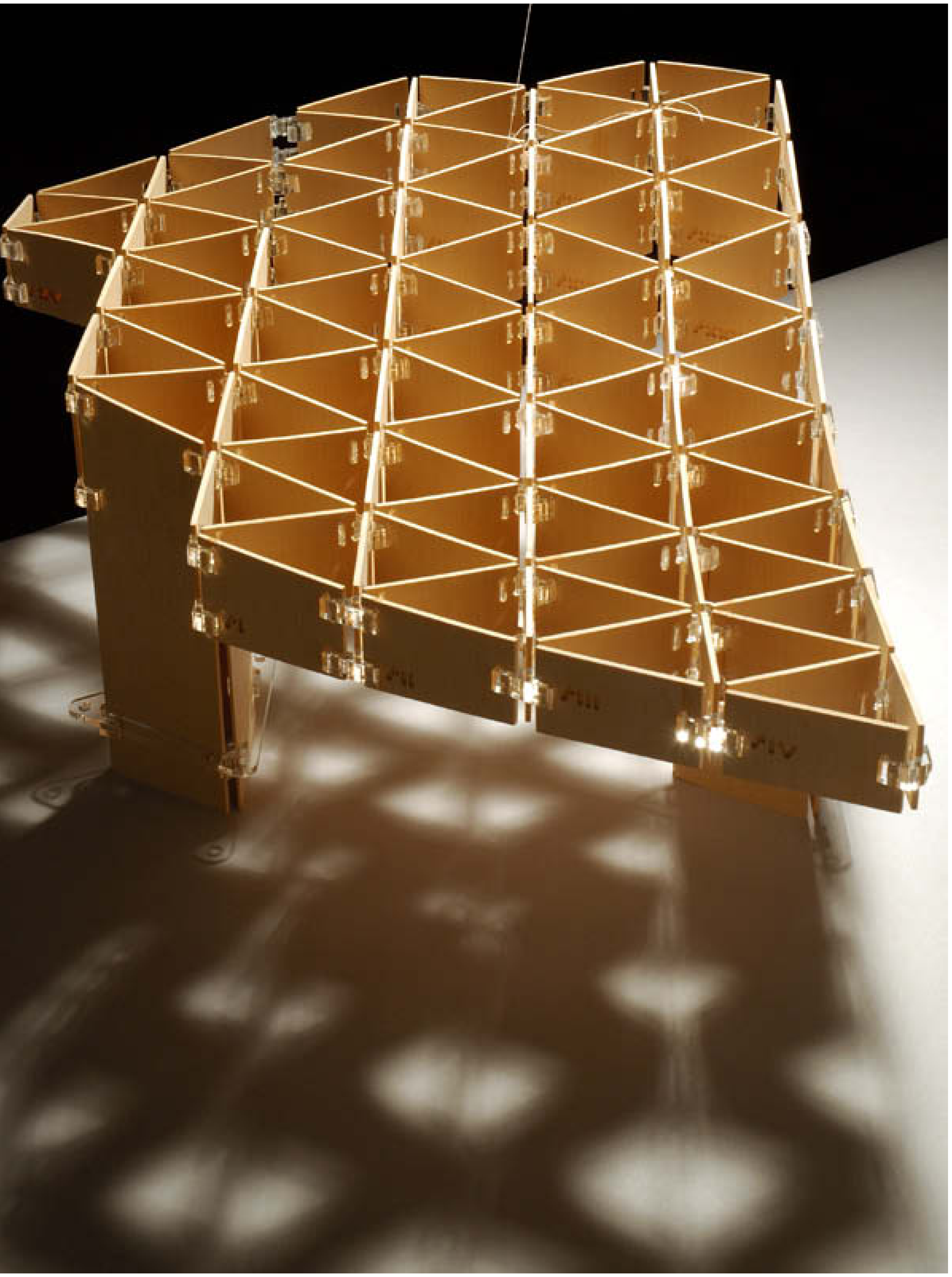
Polyline path is strictly followed by the router
→ Minimum waste of time

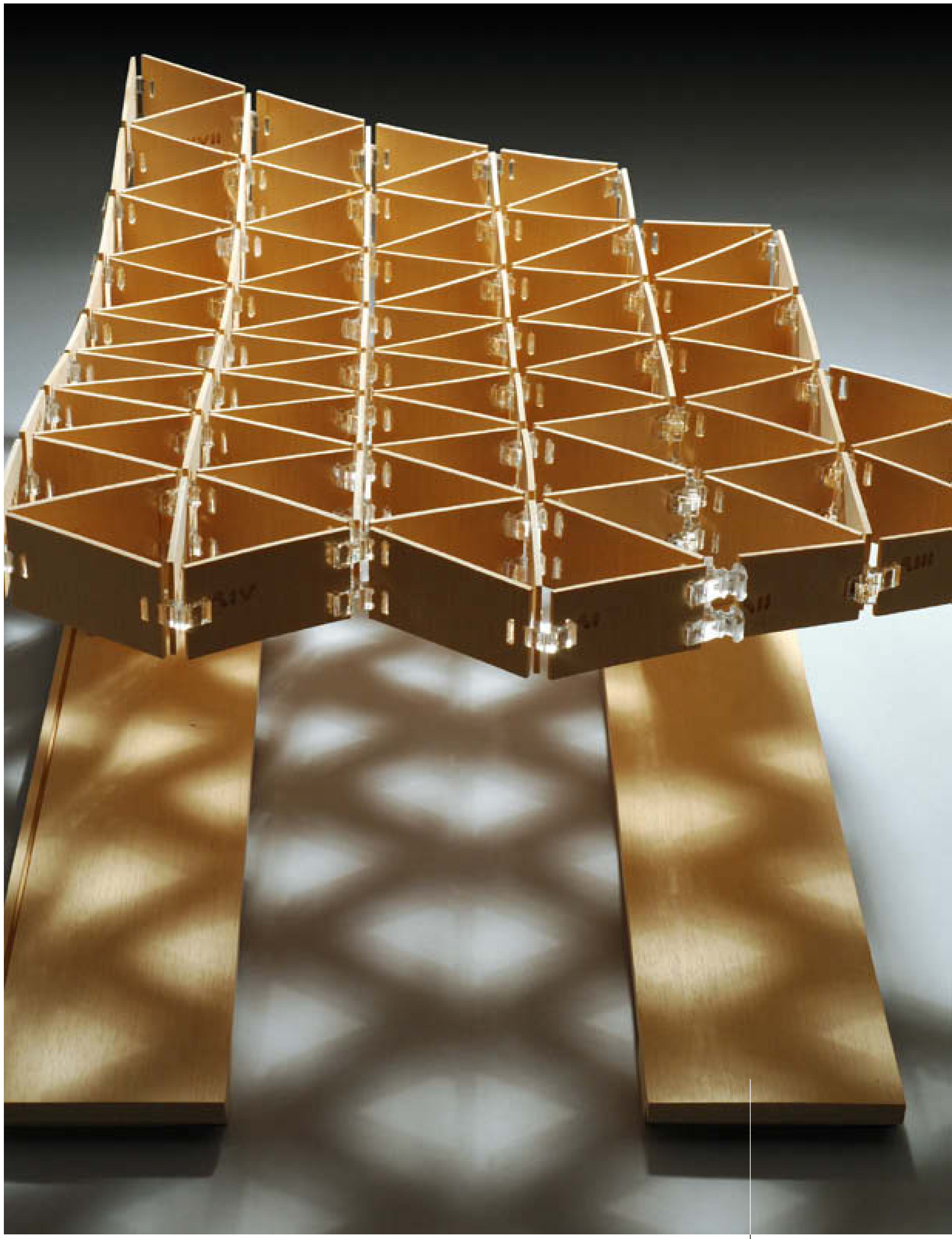
Polyline



CNC milling of the shelter model

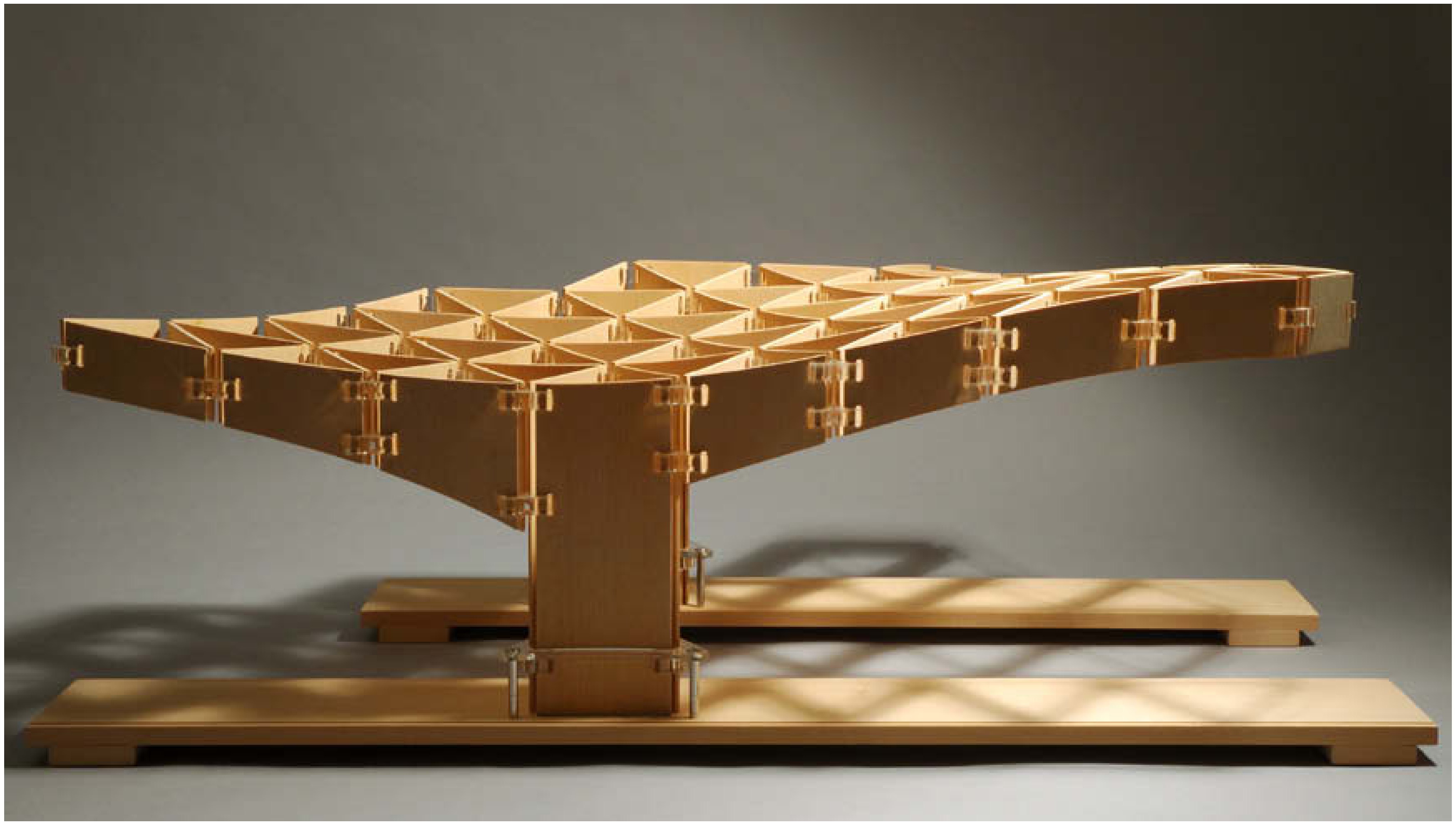


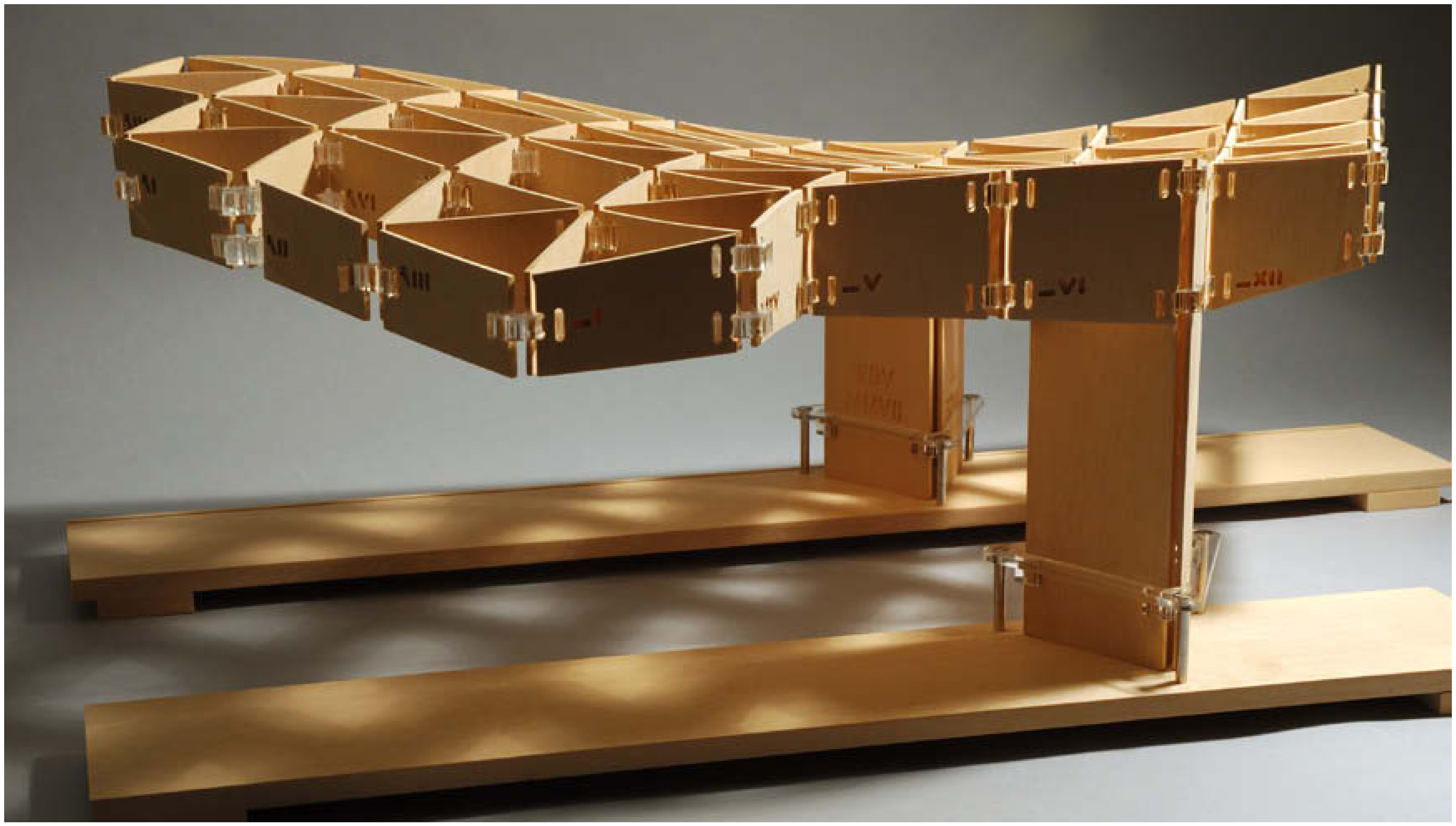




This model travelled to Dhaka, Bangladesh in December 2007, as part of Diploma 7's exhibition of shelter ideas at the Brac University Department of Architecture.

The 'skis' served to hold the mirrors (see previous page).





On 29 November, two weeks after cyclone Sidr, we arrived in Dhaka.
We exhibited our shelter ideas at the Brac University Department of Architecture, and with their generous help, we also visited the parliament building.

In Bangladesh, soil is rare. Accordingly, next to a building, there is usually a pond: formerly a pit where the soil was extracted as required for the construction.
Louis Khan reproduced this vernacular feature on a monumental scale by surrounding the parliament with a vast pool, which accumulates the monsoon rains.

Dhaka, Gulshan-1 district.
Children play in the city center.

Diploma 7 travelled to Bangladesh in December 2007, two weeks after the cyclone Sidr had struck the coastal areas.

At the end of January 2008, we opened an exhibition in the AA bar to raise awareness of the hardship endured in Bangladesh.

ARCHITECTURAL ASSOCIATION
SCHOOL OF ARCHITECTURE

DIPLOMA 7
LIFE AFTER CYCLONE SIDR

ARCHITECTURAL ASSOCIATION
SCHOOL OF ARCHITECTURE

THE DIRECTOR OF THE ARCHITECTURAL ASSOCIATION SCHOOL OF ARCHITECTURE BRETT STEELE INVITES YOU TO A PRIVATE VIEW ON MONDAY 28 JANUARY 2008 AT 6PM

This exhibition of photographs, documentation and film footage aims to increase awareness of the situation on the ground following Cyclone Sidr, and to help raise funds for the organisations Diploma 7 are working with: BRAC (the largest NGO operating in Bangladesh), Shelter Coordination Group Cyclone Sidr (led by UN Habitat and IFRC) and the World Bank. All of these organisations are responsible for live-field projects in Bangladesh that explore philosophical, social, political and technical responses to the provision of long-term settlements in this kind of environment.

For more information please email
bonniechu@aaschool.ac.uk

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Chapter 2

Sheltering people and safeguarding houses from cyclones

8 December 2007
In a village near Sarankhola, a man and his wife stand on the remnants of their house, blasted three weeks earlier by cyclone Sidr.

2.1 Bogi, a village ravaged by Sidr

Bogi is near the town of Sarankhola and the Sundarbans forest. We visited it on 8 December 2007, three weeks after cyclone Sidr.

The village has many fresh water ponds, used to harvest fish. After the cyclone, all the fish had died and the water was contaminated by dead cattle.

The better houses are made of lumber (not bamboo), anchored to a tall cemented podium, well braced, and their roofs well tied.

A house once stood on this podium, but it was blown away. Its walls and roof were covered in corrugated iron, which impedes the wind until it flies off.

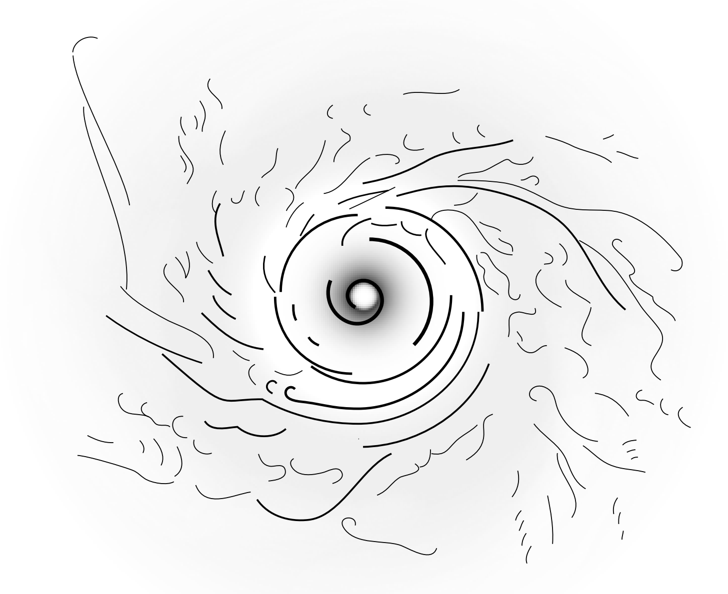
Photos by the author

A man who has lost his mother, his sister, and three brothers to cyclone Sidr gathers his children, nieces and nephews around him.

During a cyclone storm, the winds reach 220 km / h; palm trees bend, but many deciduous trees fall. Here a house was crushed by a mature tree.

2.2 Cyclones and shelters

A tropical cyclone is a violent storm system forming over warm oceans, such as the Indian Ocean. They are also called hurricanes (in the Atlantic) and typhoons (in the Pacific). They are characterized by a circular shaft of low atmospheric pressure, around which the storm rotates, which is sometimes marked as a cloudless eye. They often reach maximum amplitude before reaching the land, where they dissipate relatively quickly.

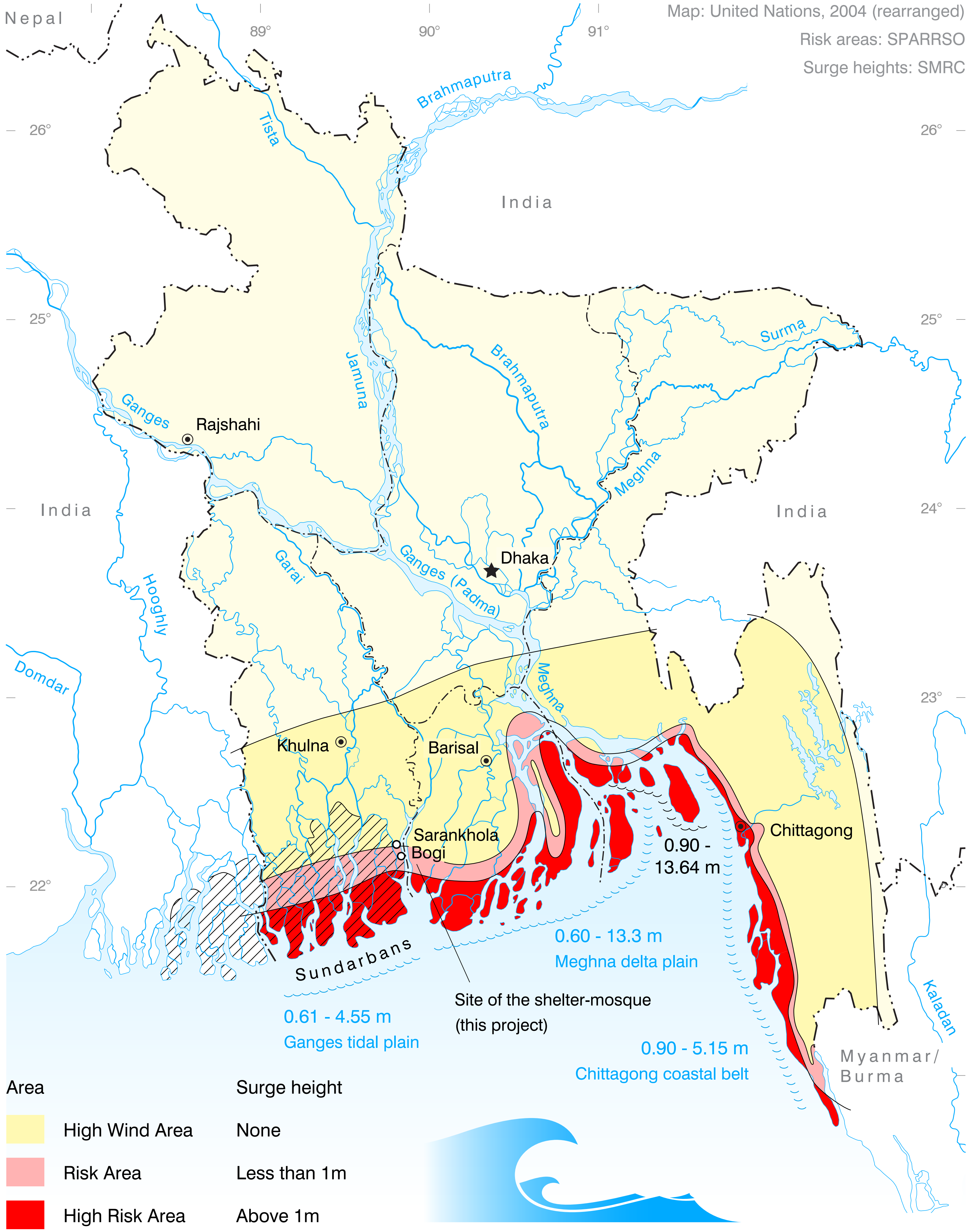


“About one-tenth of the global total of tropical cyclones occur in the Bay of Bengal. About one-sixth of tropical cyclones born in the Bay of Bengal had landfall on the Bangladesh coast.”

Multipurpose cyclone shelter programme 1993

The High Risk Area covers 9200 sq km. It is home to 7 million people (census 2005).

Risk areas



Cyclone risk areas

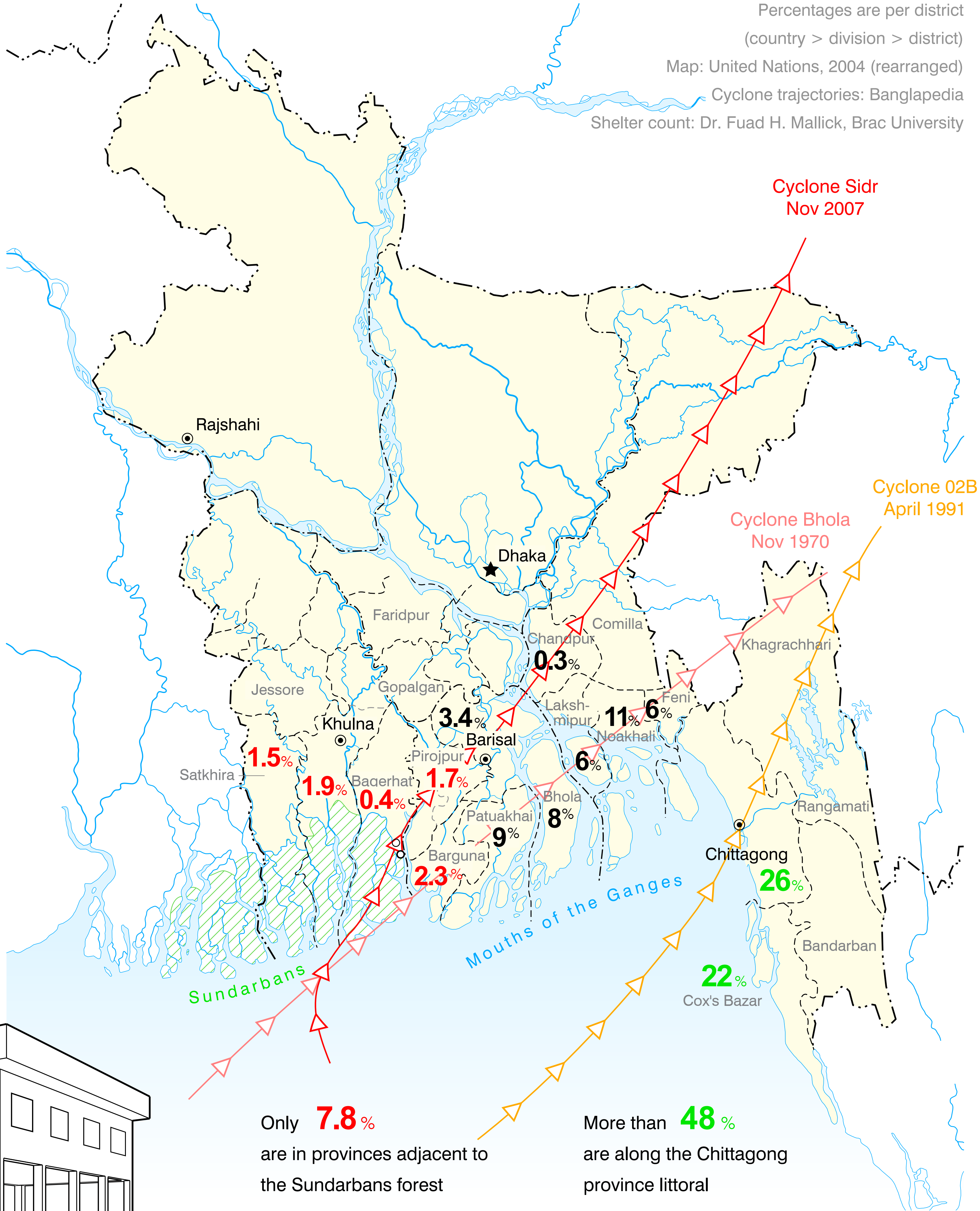
Surge wave at littoral

The distribution of purpose-built shelters owes primarily to the following: historically, cyclones have struck more often and more violently along the littoral of the Chittagong division. The population density is also higher around Chittagong than, say, Barguna. The cyclone Bhola of November 1970, which killed more than 300 000 and initiated the construction of shelters, landed in the middle of the country. The next deadliest cyclone, the '02B' of April 1991, landed over Chittagong. Accordingly, from 1970 to 2007, most shelters were built East of the Mouths of the Ganges.

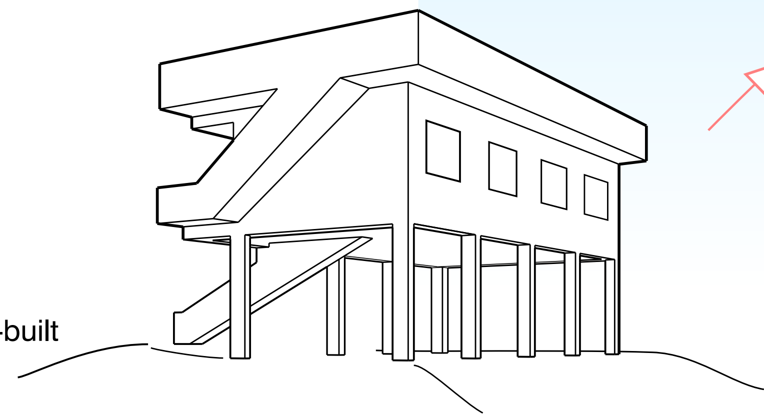
“The global distribution of cyclones shows that only 1% of all the cyclones that form every year strike Bangladesh; but unfortunately, the fatalities they cause here is 53% of the whole world.”

Mr. Ali, from Dr. Malik, Brac University

Cyclone Sidr passed in November 2007 over the Khulna and Barisal divisions, where most of the 3500 casualties were recorded. A well coordinated evacuation, a combination of shelters, human and natural defences, and notably a low tide, lead to less damage and fewer casualties than in 1970 and 1991. Nevertheless, Cyclone Sidr highlighted the necessity of building more shelters on the West of the littoral.



Distribution of purpose-built cyclone shelters



A typical purpose-built cyclone shelter

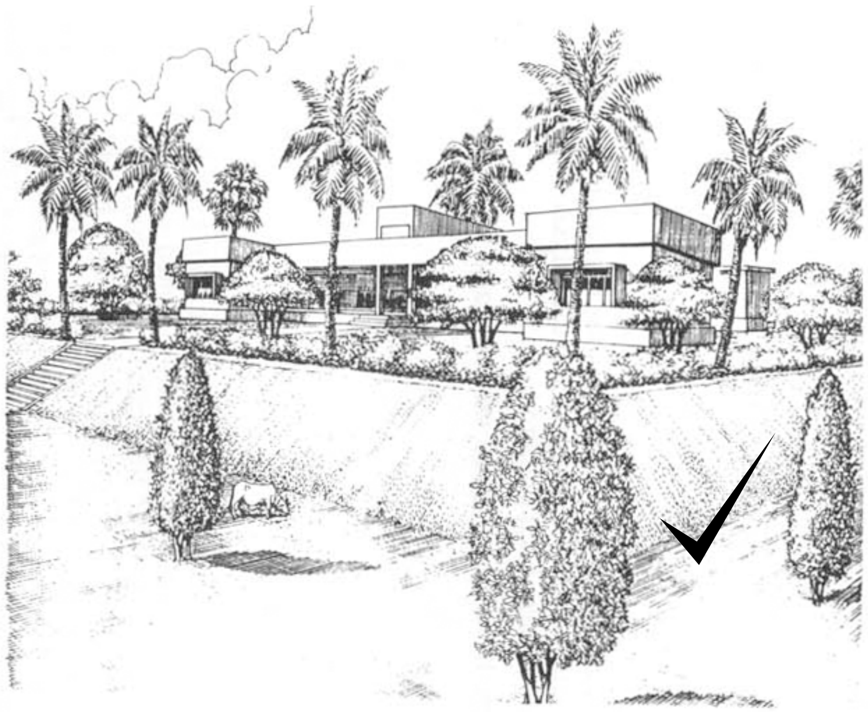


Fig. 8 (a) Perspective of Shelter on Killa

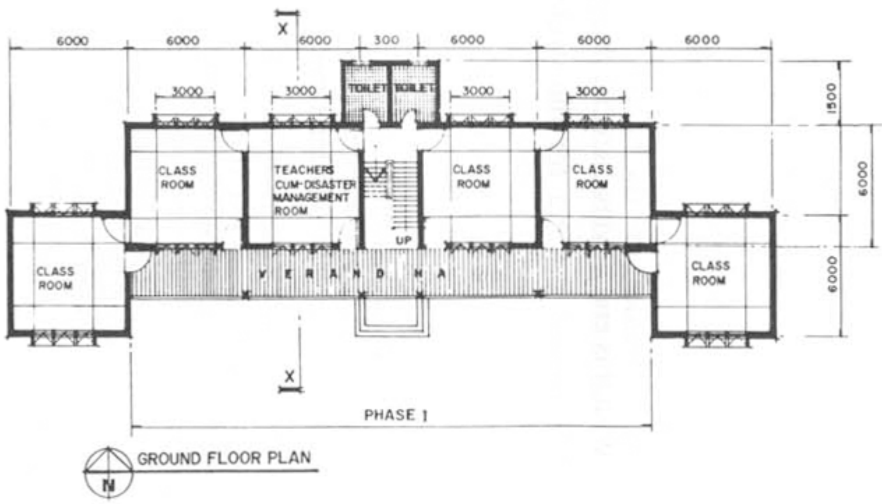
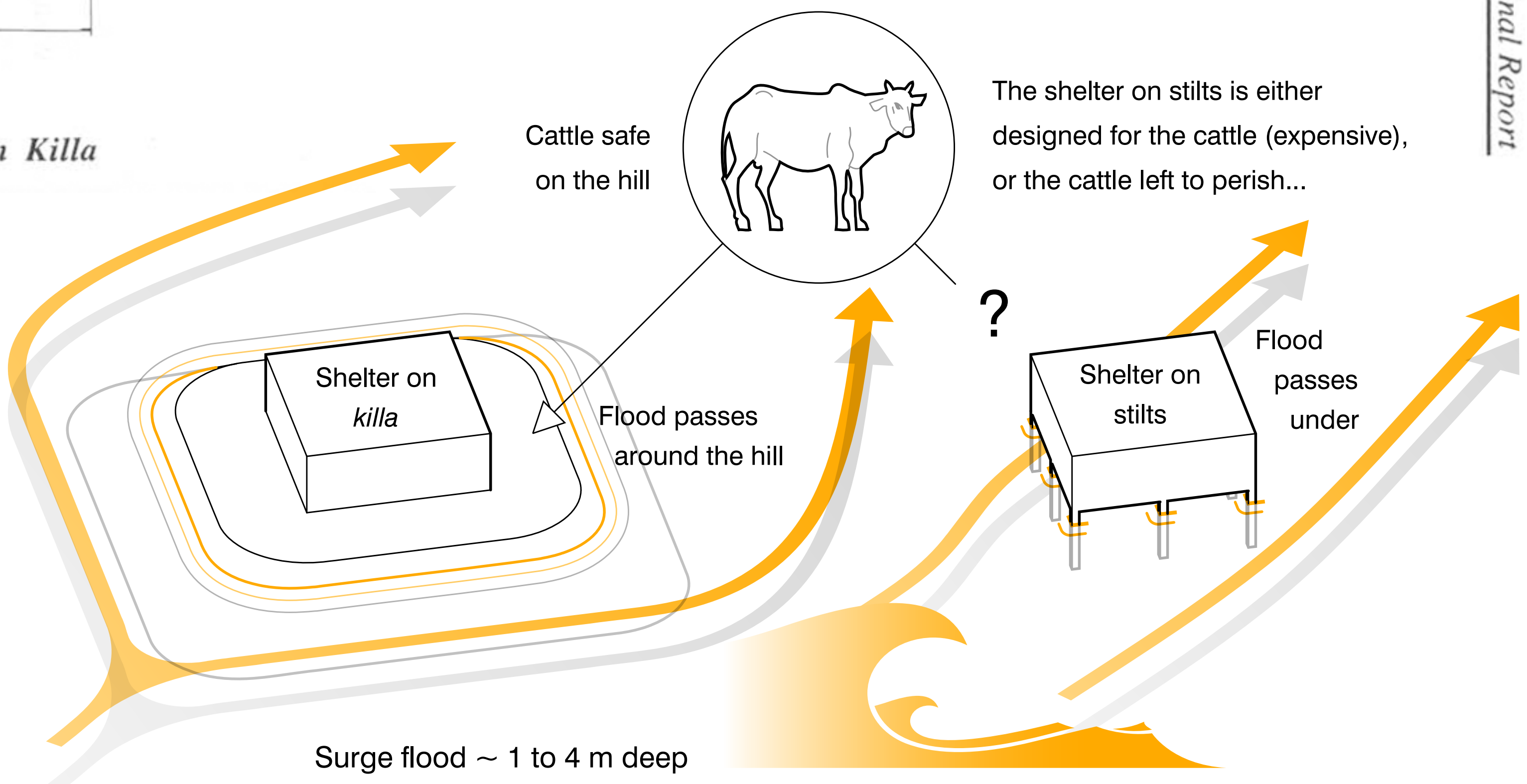


Fig. 8 (b) Plan of Shelter on Killa

Fig. 9 (a) Perspective of Shelter on Stilts

To protect the shelter above the surge flood, the Report proposes two schemes: the shelter raised on a *killa* (hill) and on stilts.

Most shelters in Bangladesh are on stilts, and do not provide a space for the protection of the livestock. When the cyclone is violent, the latter perish in the flood, leaving the farmers without the means to cultivate their land. Since the shelter on a hill naturally provides a space for the cattle to stand above the flood, it appears to be preferable, and is selected for this project.

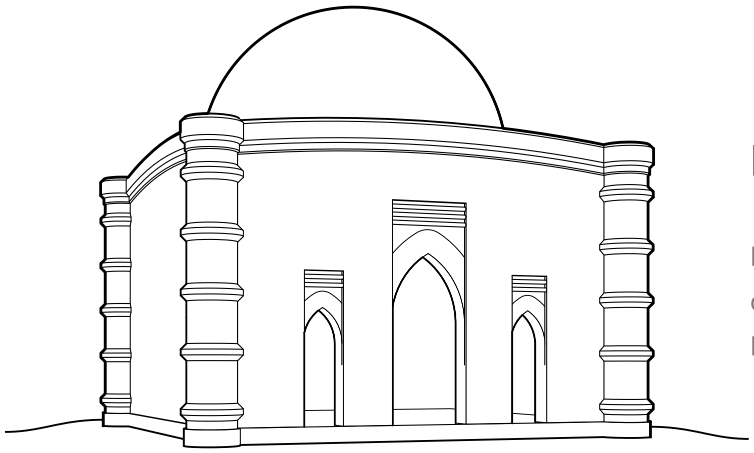


“ In order to protect the livestock from storm surge, killas or earthen mounds, with the top level raised above maximum probable surge height, appear to be the least cost solution. ”

"Multipurpose Cyclone Shelter Programme Report" Planning commission, Government of Bangladesh; United Nations Dev. Programme; World Bank; 1993.

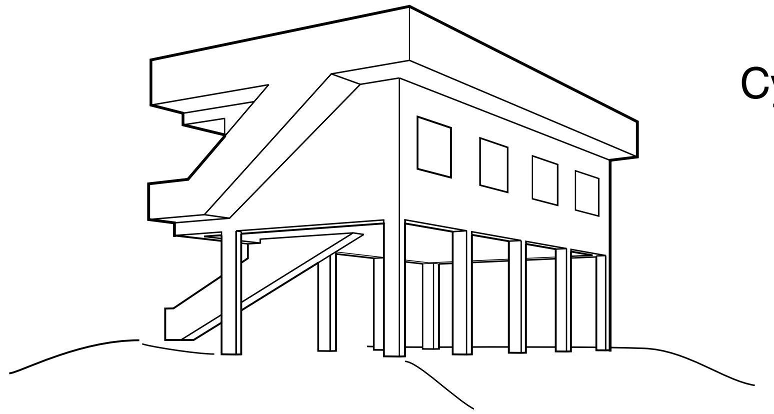
The choice of a shelter scheme

The choice of a complementary program



Mosque

Here drawn, the Ranvijaypur one domed mosque near Bagerhat, Bangladesh



Cyclone shelter

A mosque should be well built, to last many generations.

A mosque should be high architecture, to represent the cult and community at their best.

A mosque is a civic building.

A mosque should be large enough to house everyone in its congregation.

A mosque should be equipped with ample sanitary facilities and fresh water supplies, for the ablutions.

A mosque is often divided in spaces for men and women.

People come to the mosque to be with the community, to revere Allah and Muhammad, to pray that life will go well, etc.

A cyclone shelter should be strongly built, to withstand many storms.

A shelter is rarely high architecture.

Most cyclone shelters are used as civic buildings in between storms.

A shelter must be large enough to house its tributary population.

A shelter must be equipped with ample sanitary facilities, to accommodate its users during a storm.

A shelter is practically always divided in spaces for men and women.

When a cyclone comes, people take refuge in a shelter and pray that life will go well, etc.

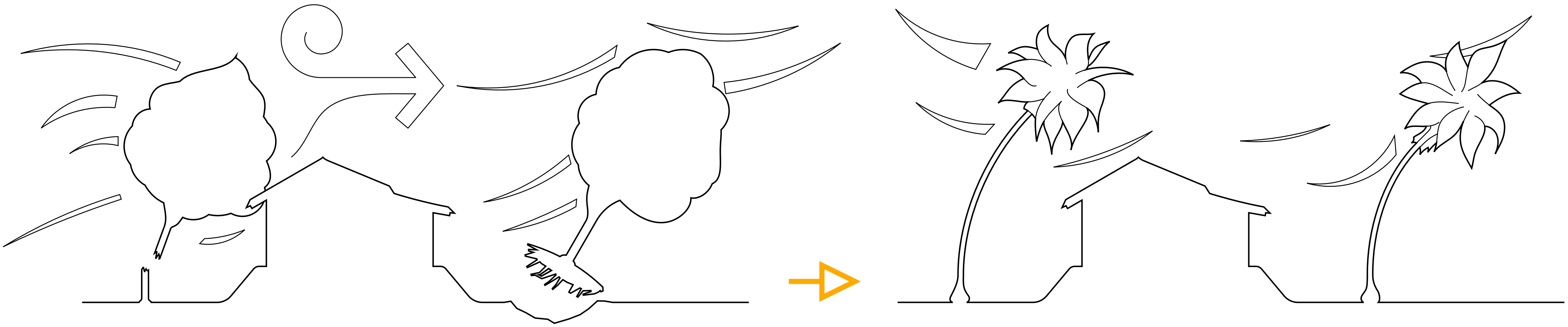
Mosque + Cyclone shelter → This project

In between storms, most cyclone shelters are used as schools or offices. However, considering that Bengali towns and villages almost always have a mosque (85% of the population is Muslim), and the affinities between a mosque and a shelter; considering that mosques are some of the most valued civic buildings in Bangladesh (as they are illustrated on most paper currency); and with my teachers' agreement that this could be an original and valid approach, I decided to design a shelter - mosque.

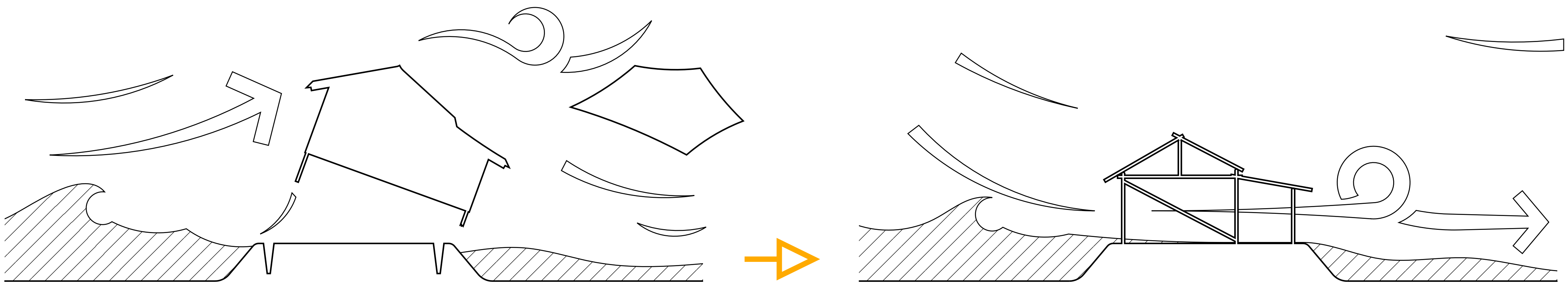
While it may seem dubious to choose a religious program as complementary to a shelter (which by nature welcomes everyone regardless of their faith), I chose to do so to open my horizons. Indeed, had I chosen a school as a complementary program, I would have referred to my prior knowledge of what is a school; whereas I knew nothing of mosques, and found that I had everything to learn. Mostly, I wished to address how odd it felt to design a building for Bangladesh from the context of a school in London.

2.3 A strategy for safeguarding houses and sheltering people from cyclones

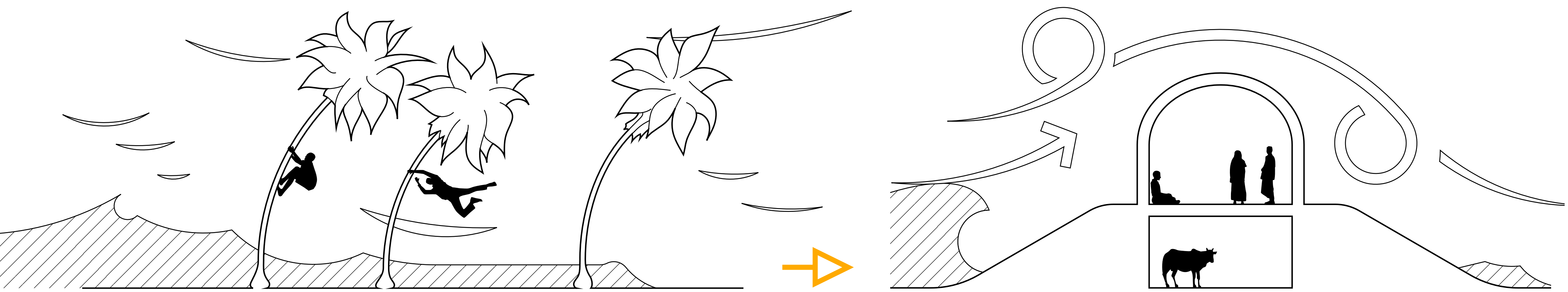
1 Trees are necessary around the houses to create privacy and shade, to hold the soil, and to break the wind. But deciduous trees can fall during a cyclone and severely damage a house. Within a radius from each house, the deciduous trees should be replaced with palm trees, which bend and do not break.

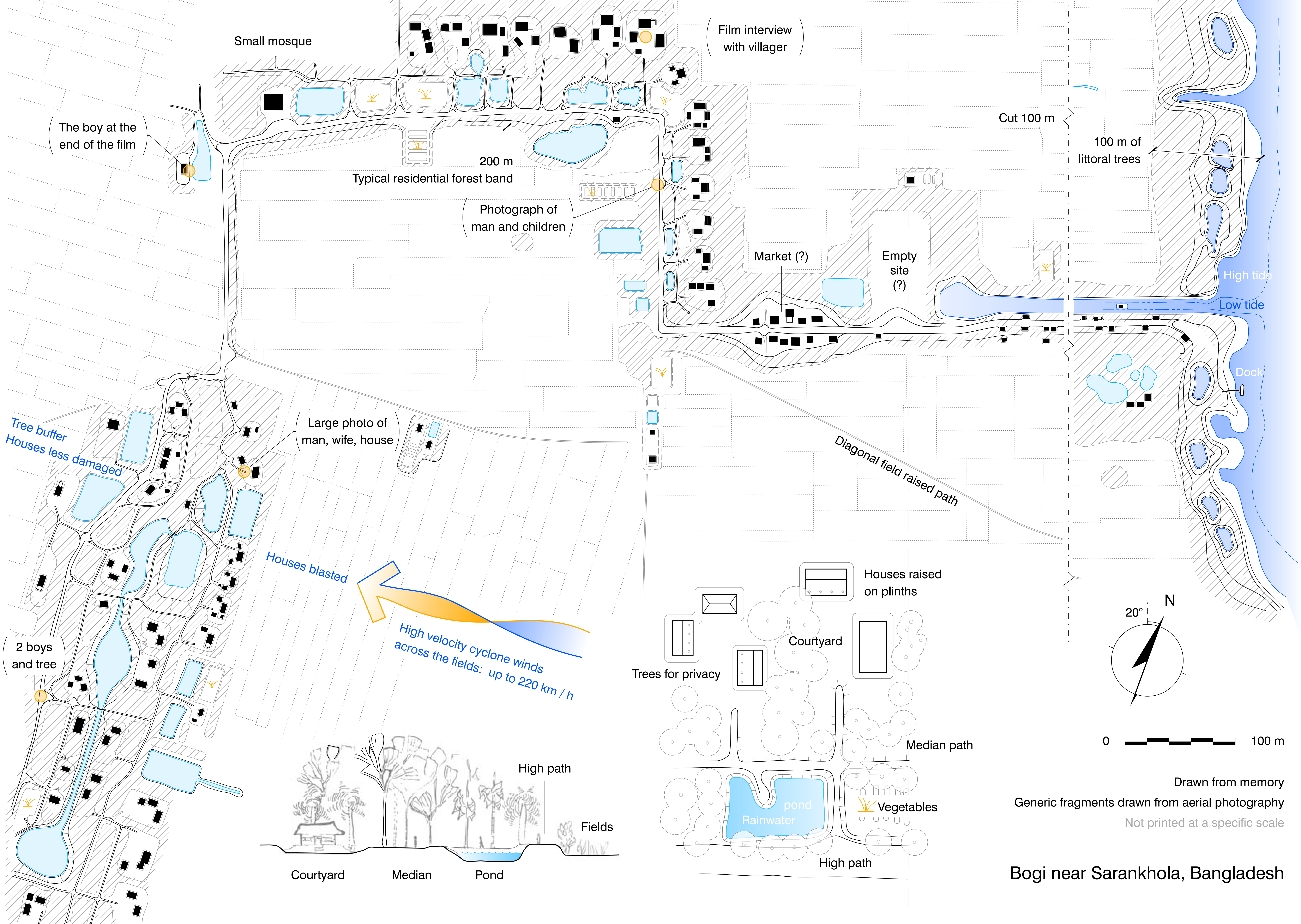


2 Many houses, built in bamboo, do not resist the wind and surge flood of a cyclone. Building them to resist the cyclone (e.g. in lumber, in concrete) would be too expensive. However, if the walls and roof were removable, the bamboo structure could withstand the storm, and the house be quickly rebuilt afterwards.



3 In 1993, the Multipurpose Cyclone Shelter Programme estimated that only 16% of the population affected by cyclones could take refuge in a shelter or public building. When cyclone Sidr landed in 2007, hundreds of villages were still deprived of a shelter. This project proposes a shelter - mosque.





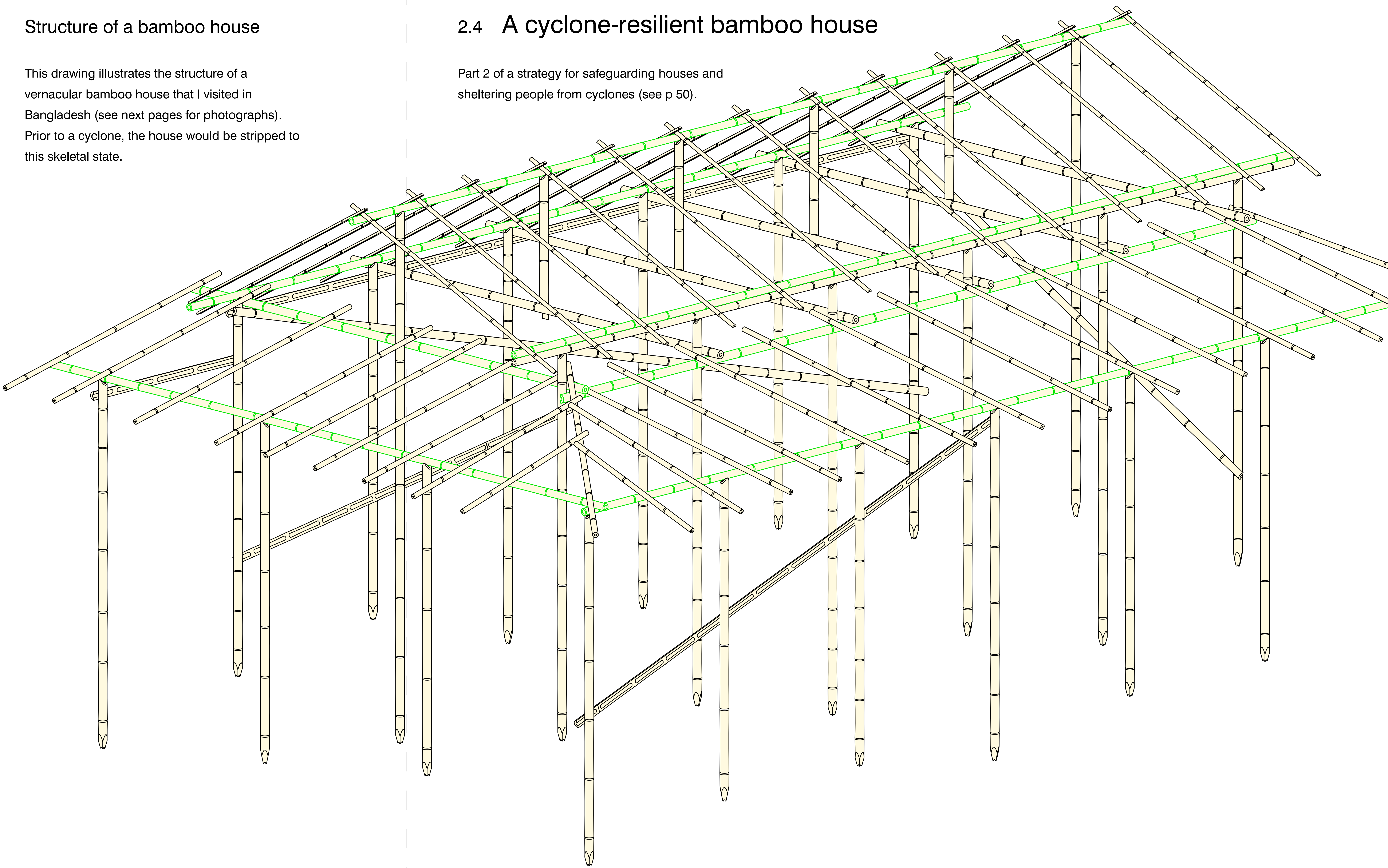
Bogi near Sarankhola, Bangladesh

Structure of a bamboo house

This drawing illustrates the structure of a vernacular bamboo house that I visited in Bangladesh (see next pages for photographs). Prior to a cyclone, the house would be stripped to this skeletal state.

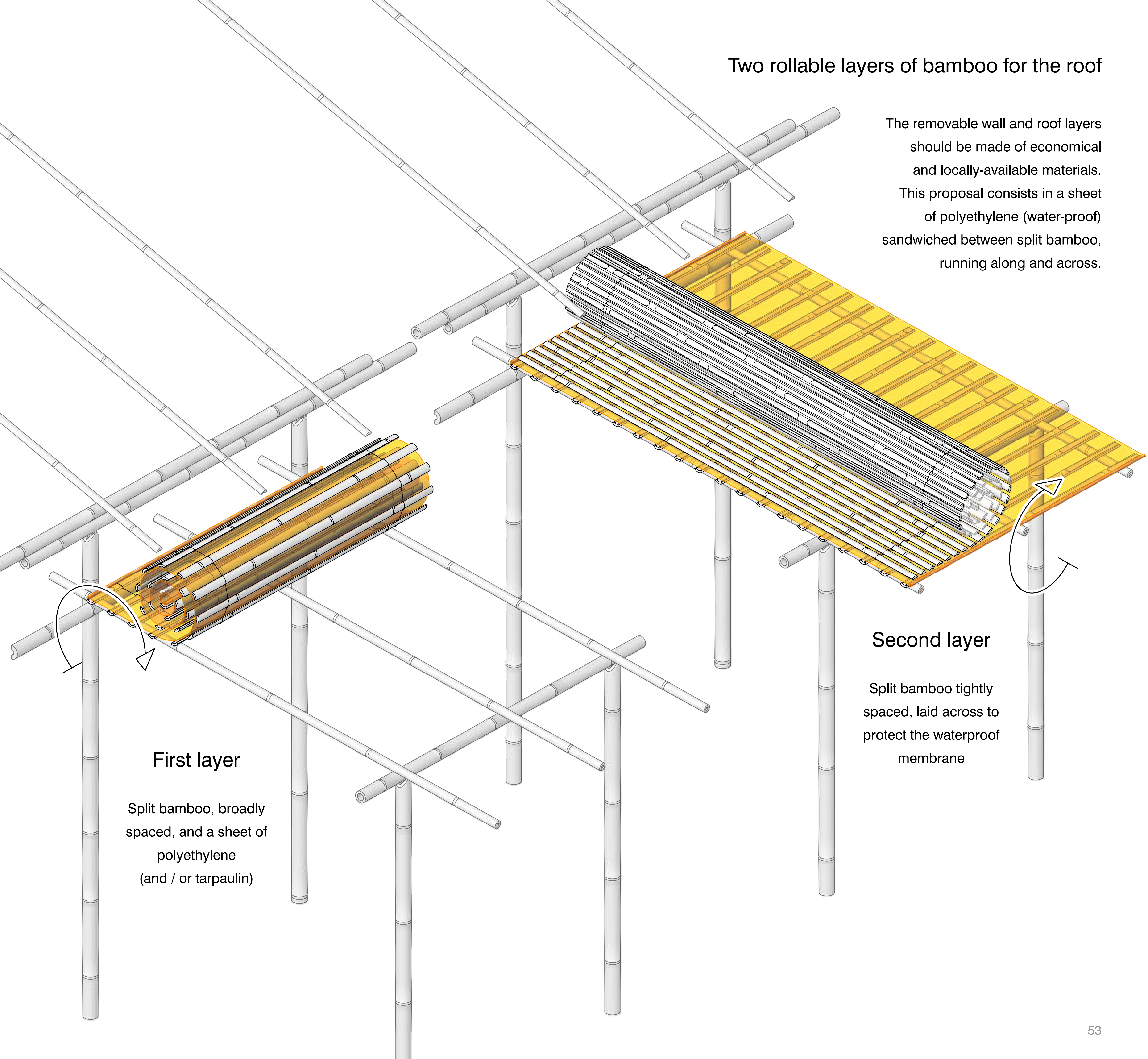
2.4 A cyclone-resilient bamboo house

Part 2 of a strategy for safeguarding houses and sheltering people from cyclones (see p 50).



Two rollable layers of bamboo for the roof

The removable wall and roof layers should be made of economical and locally-available materials. This proposal consists in a sheet of polyethylene (water-proof) sandwiched between split bamboo, running along and across.

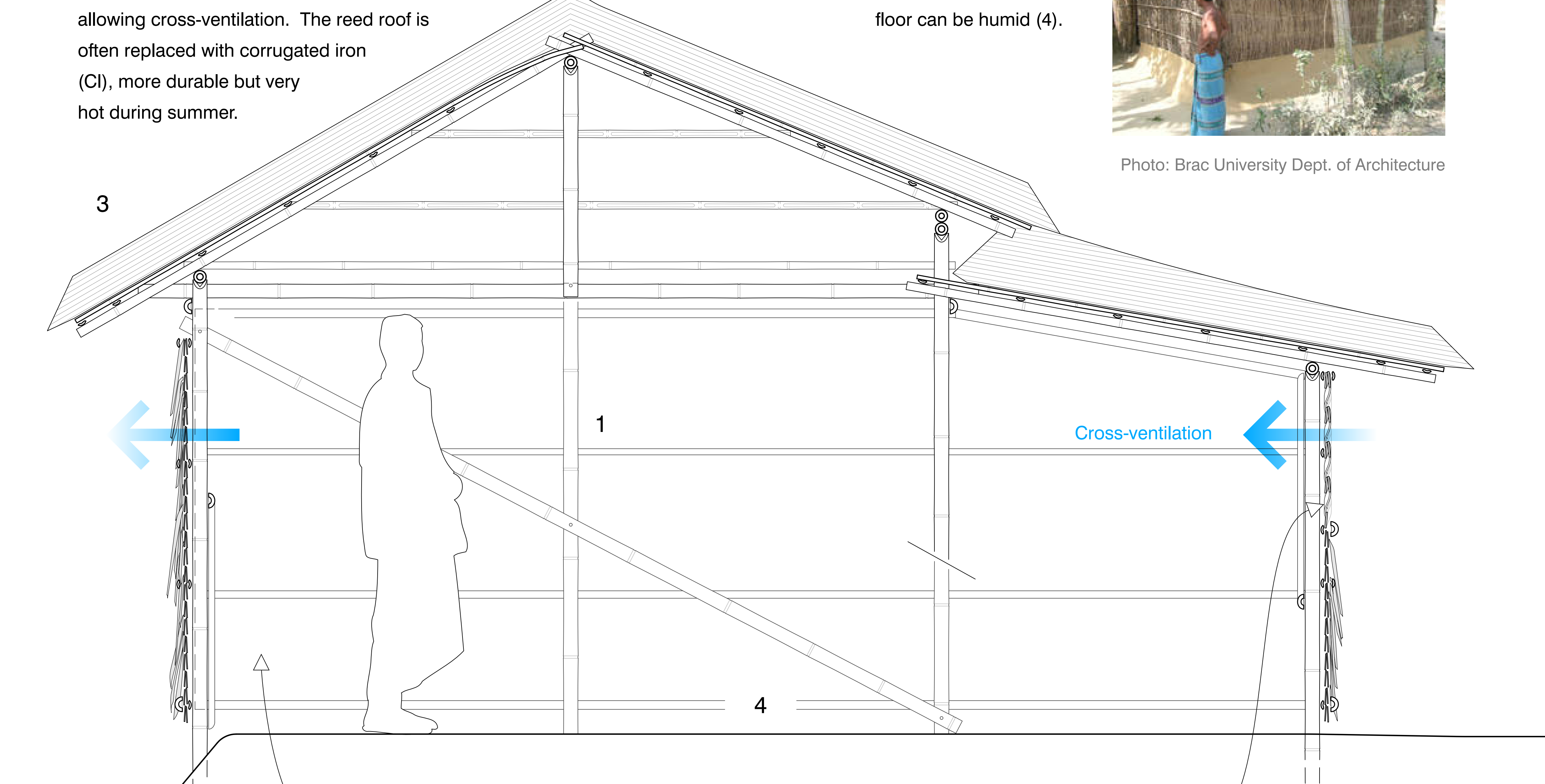


A vernacular bamboo house, as it is

The house is economical and well adapted to its environment: it is on podium to stand above the monsoon rain, and its walls create deep shade while allowing cross-ventilation. The reed roof is often replaced with corrugated iron (CI), more durable but very hot during summer.

During a cyclone, the house is likely to be blown away, because it is not anchored (2) and its walls and roof catch the wind (3). The earth floor can be humid (4).

Photo: Brac University Dept. of Architecture



Full bamboo weave

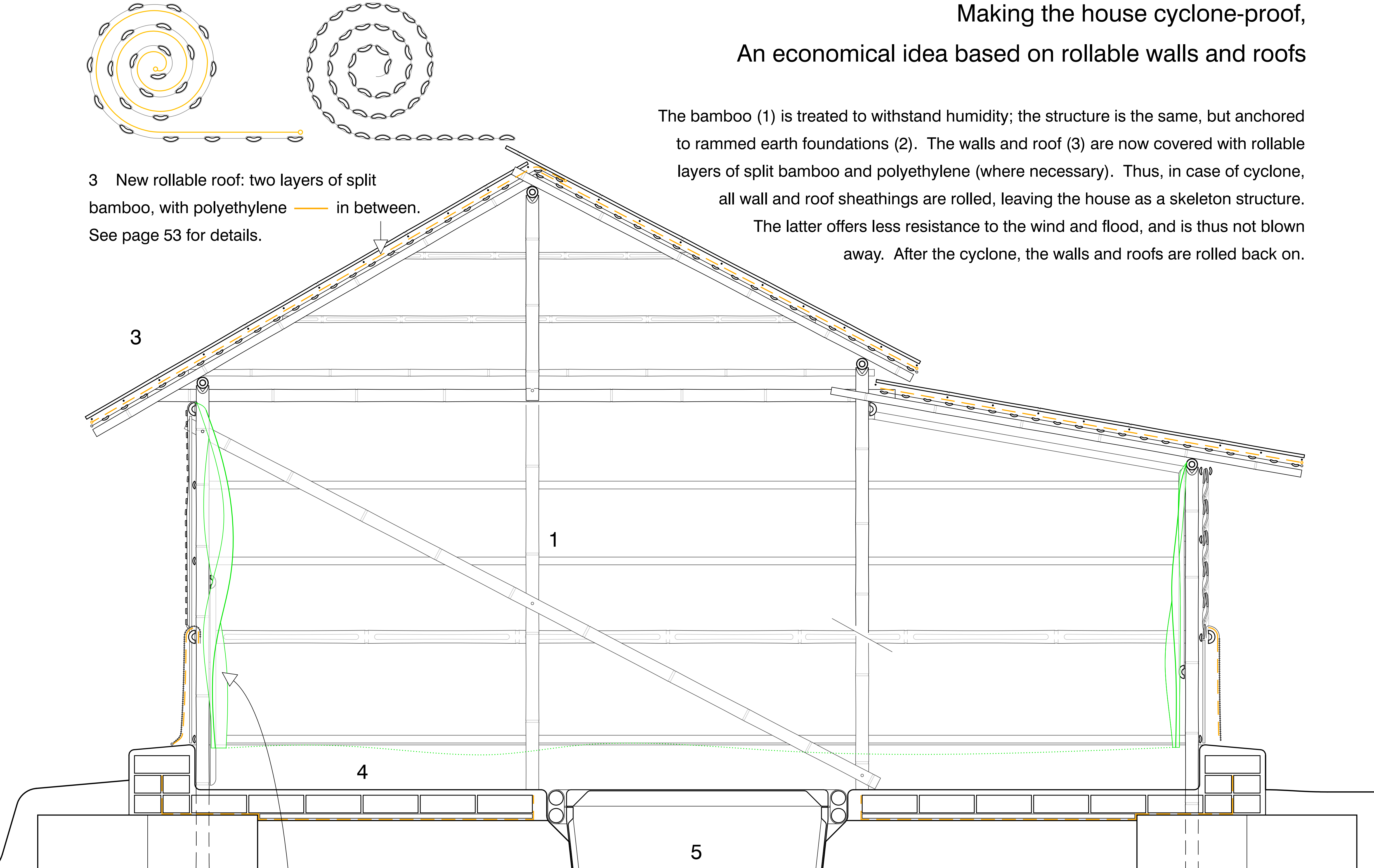
Interior (roof damaged by cyclone)

Half bamboo weave

Photos and drawing by the author

Making the house cyclone-proof,
An economical idea based on rollable walls and roofs

The bamboo (1) is treated to withstand humidity; the structure is the same, but anchored to rammed earth foundations (2). The walls and roof (3) are now covered with rollable layers of split bamboo and polyethylene (where necessary). Thus, in case of cyclone, all wall and roof sheathings are rolled, leaving the house as a skeleton structure. The latter offers less resistance to the wind and flood, and is thus not blown away. After the cyclone, the walls and roofs are rolled back on.



3 New rollable roof: two layers of split bamboo, with polyethylene —— in between. See page 53 for details.

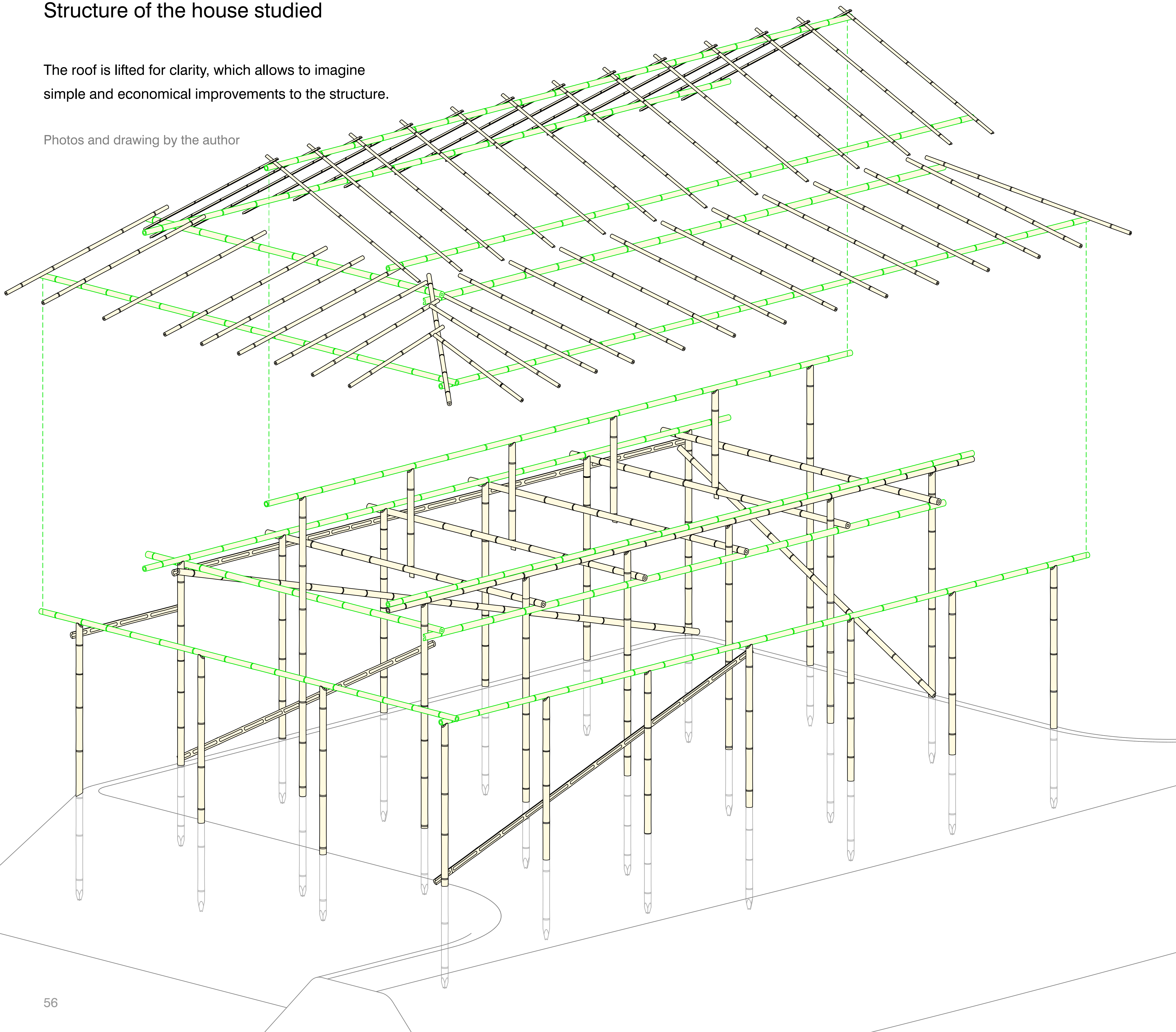
The floor (4) is covered in polyethylene, cement-stabilized earth blocks, and polished lime, for a drier and more hygienic interior. The house could be equipped with a water-proof lockable tank (5) where the owners would store their valuables.
Sari could be used as curtains, creating privacy while allowing cross-ventilation (Bangladesh is a large producer of sari).

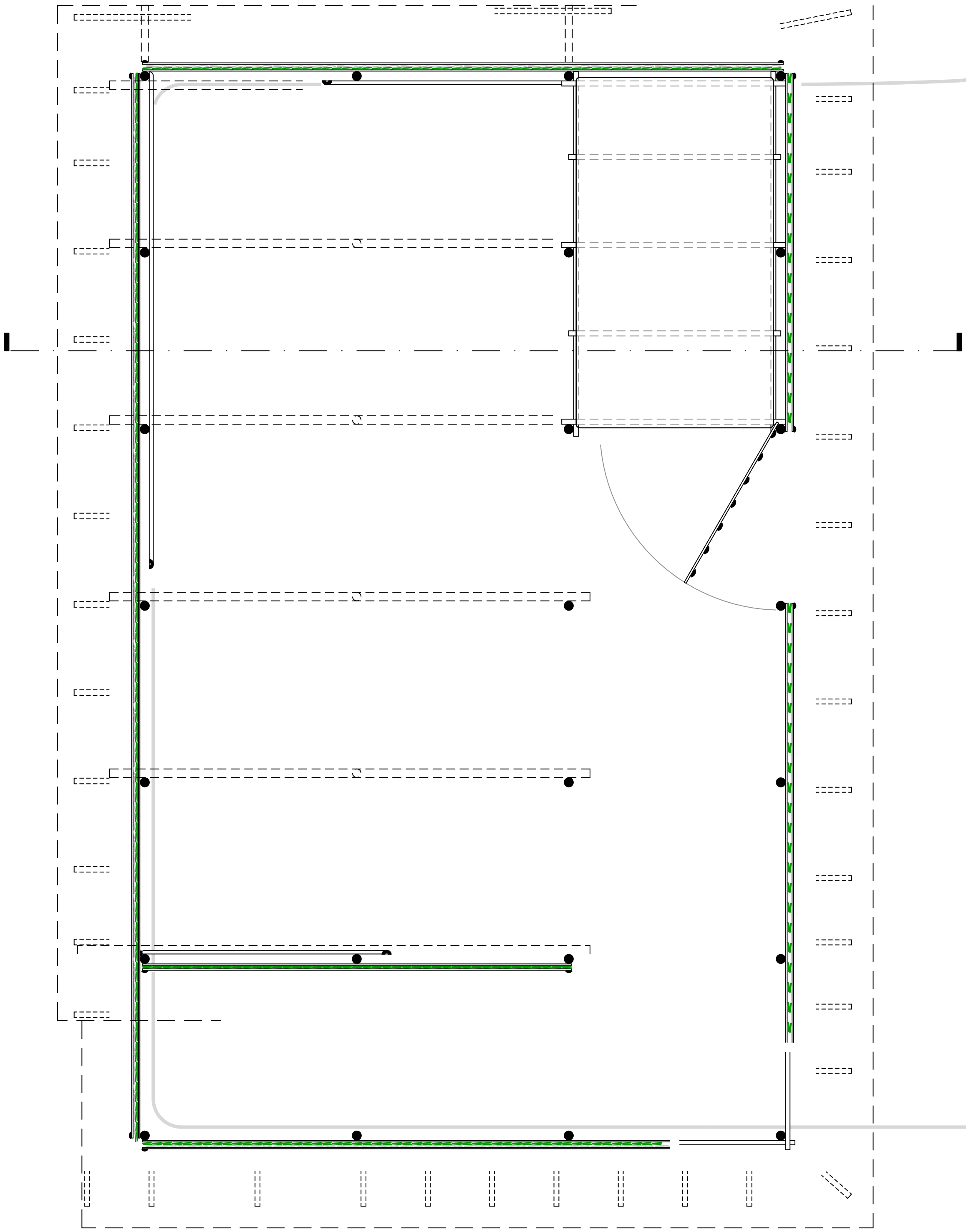
Photo: Flickr user Claude Renault

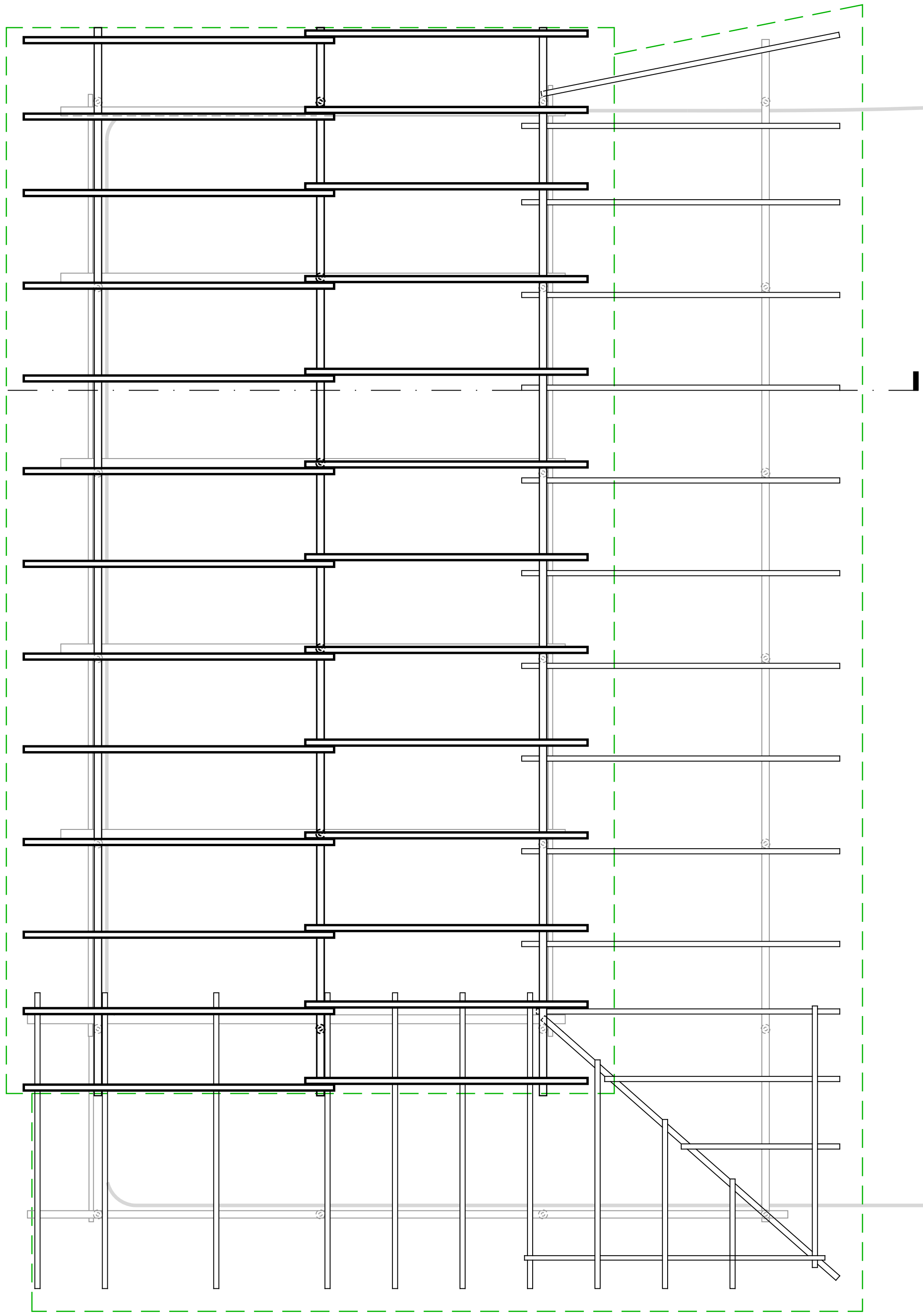
Structure of the house studied

The roof is lifted for clarity, which allows to imagine simple and economical improvements to the structure.

Photos and drawing by the author



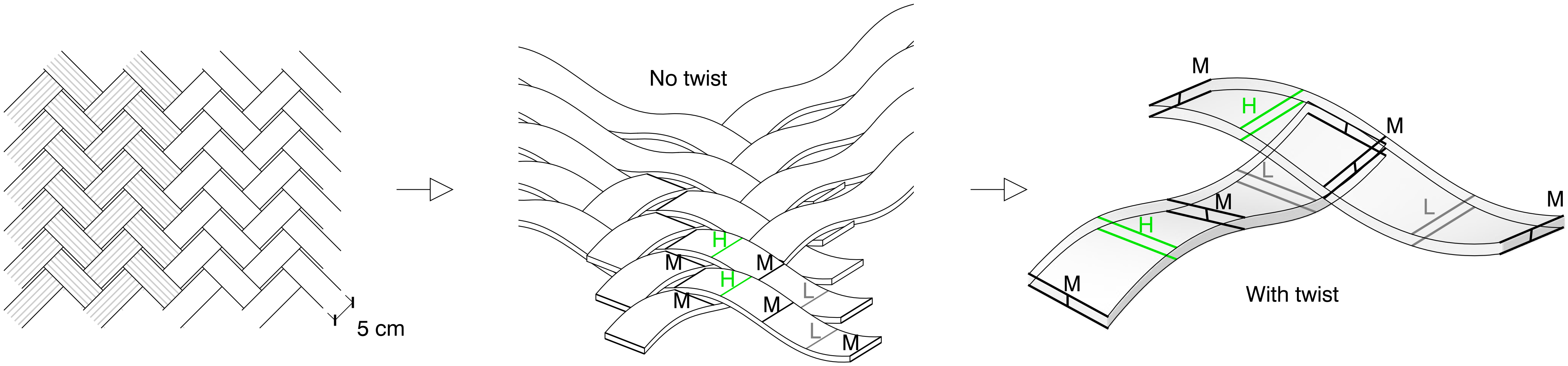


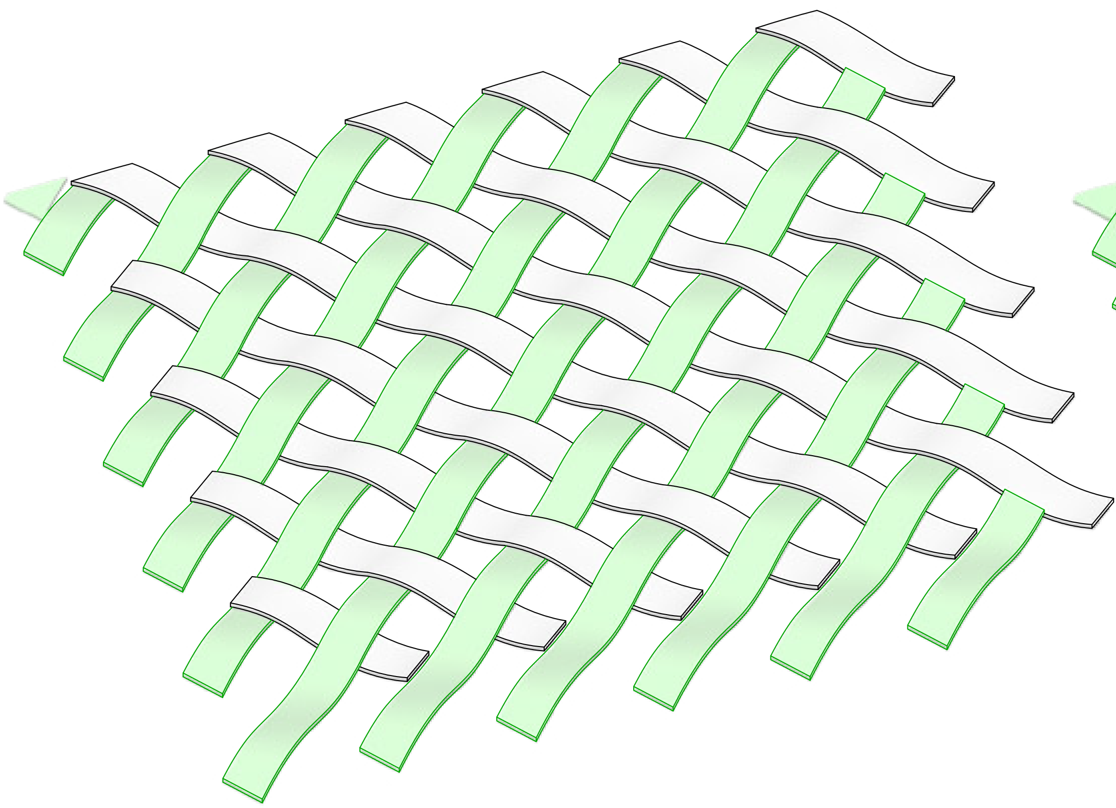


Study of a woven bamboo pattern found in Bangladesh

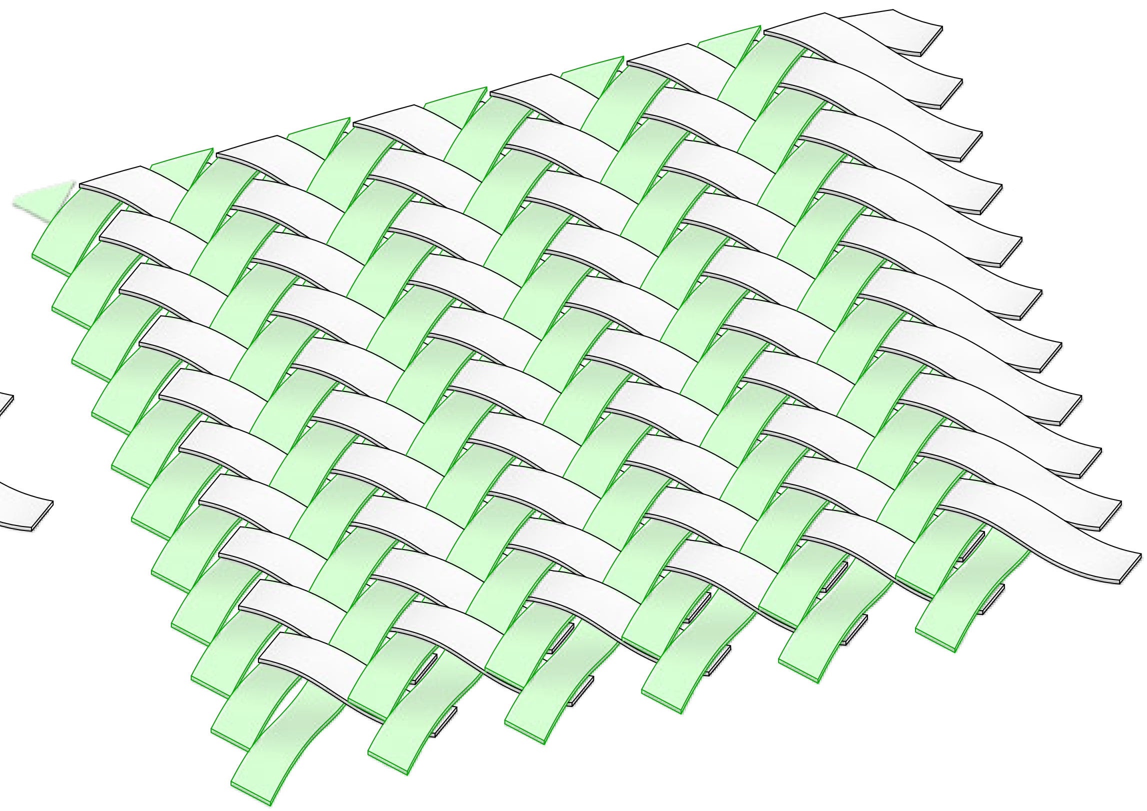
All drawings by the author

Woven bamboo is a common and distinctive wall material in Bangladesh. The fibre is obtained manually by shredding bamboo poles with a blade. It is then woven by hand, usually to sheets about 5 feet wide and as long as desired. Woven bamboo has the advantage concealing the interior of a house and fending off rainwater, while letting the wind pass. It insulates from direct sunlight, as opposed to corrugated iron which warms up in the sun. Meanwhile, it is fragile (especially at the edges) and prone to decay (especially near the ground).

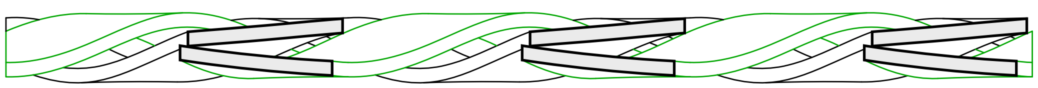


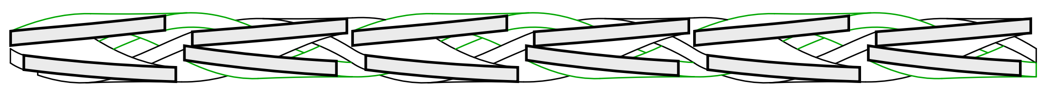


Open weave for greater ventilation

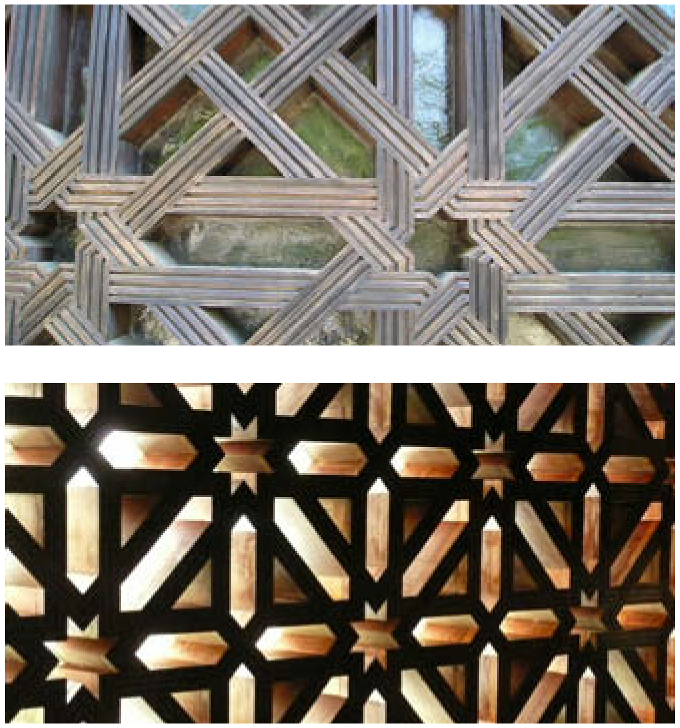


Full weave for greater privacy

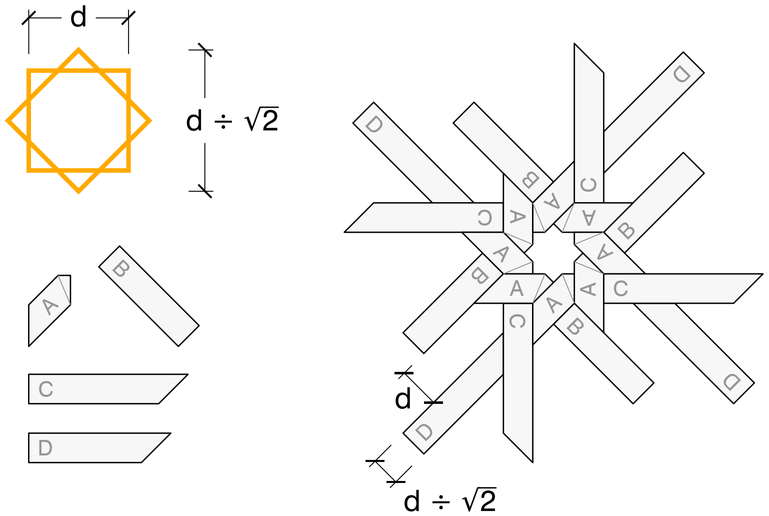


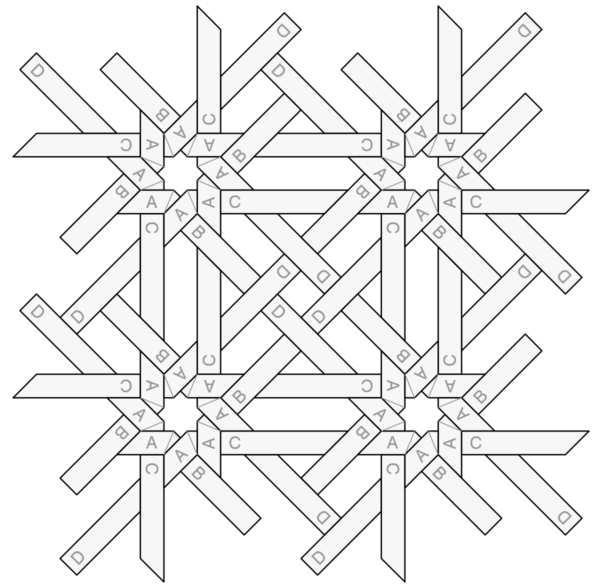


Comparative study of a star pattern at the Great Mosque of Córdoba



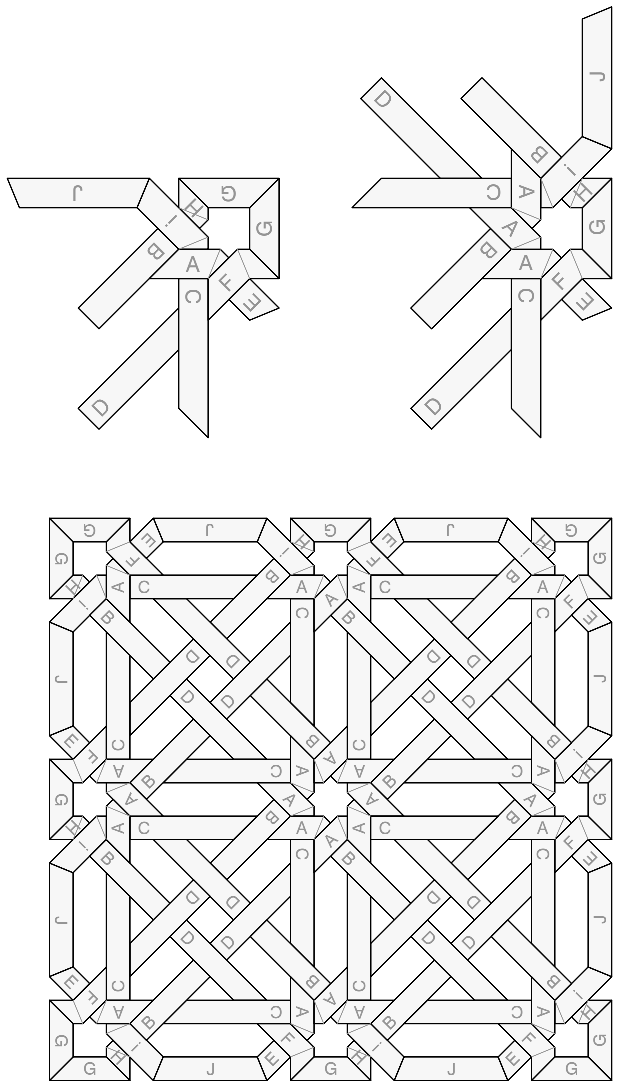
Photos: Flickr users Adam Benjamin and Maria Lopez





As in many Muslim patterns, the geometry begins with the 8-pointed star, drawn with two squares. Here, the design suggests a continuous ribbon which would pass under and over itself. There are no variables: the entire pattern, including the width of the ribbon, is related to the star.

The base pattern is made of 4 repetitive wood blocks (A B C D). To lay it flat on the window sill, the artisan introduced 6 other blocks (E F G H I J, drawing 1). Here we speculate on two other ways of closing the pattern (2, 3).



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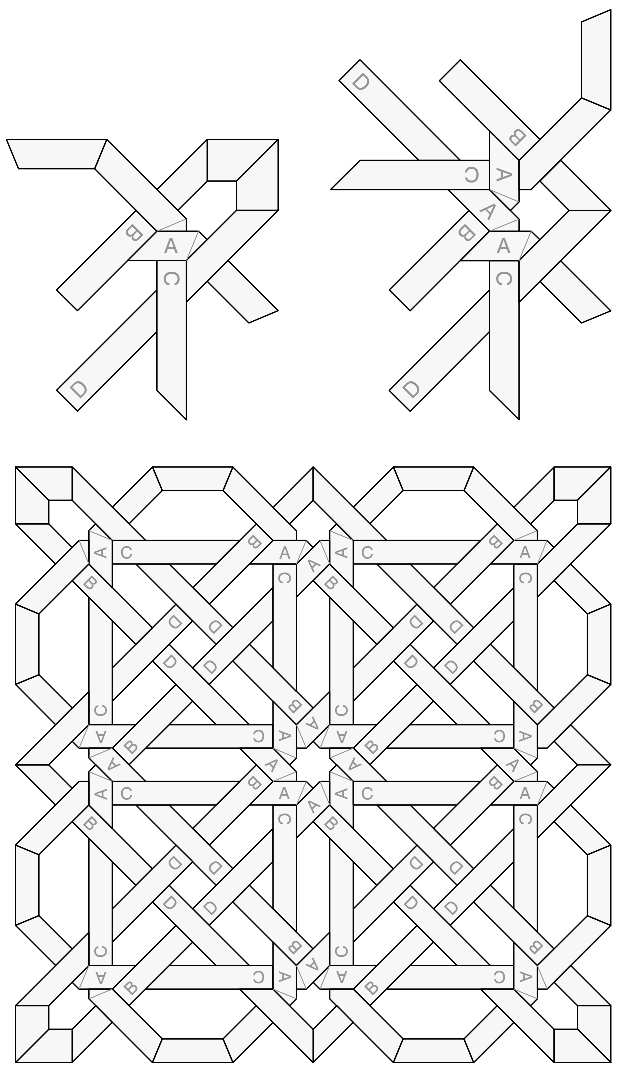

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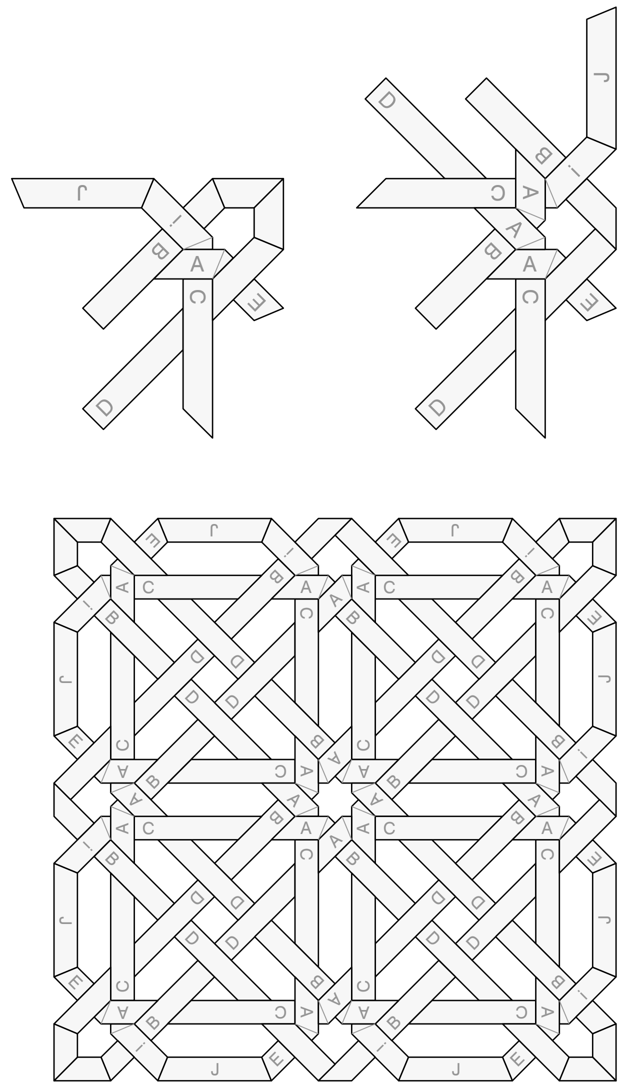

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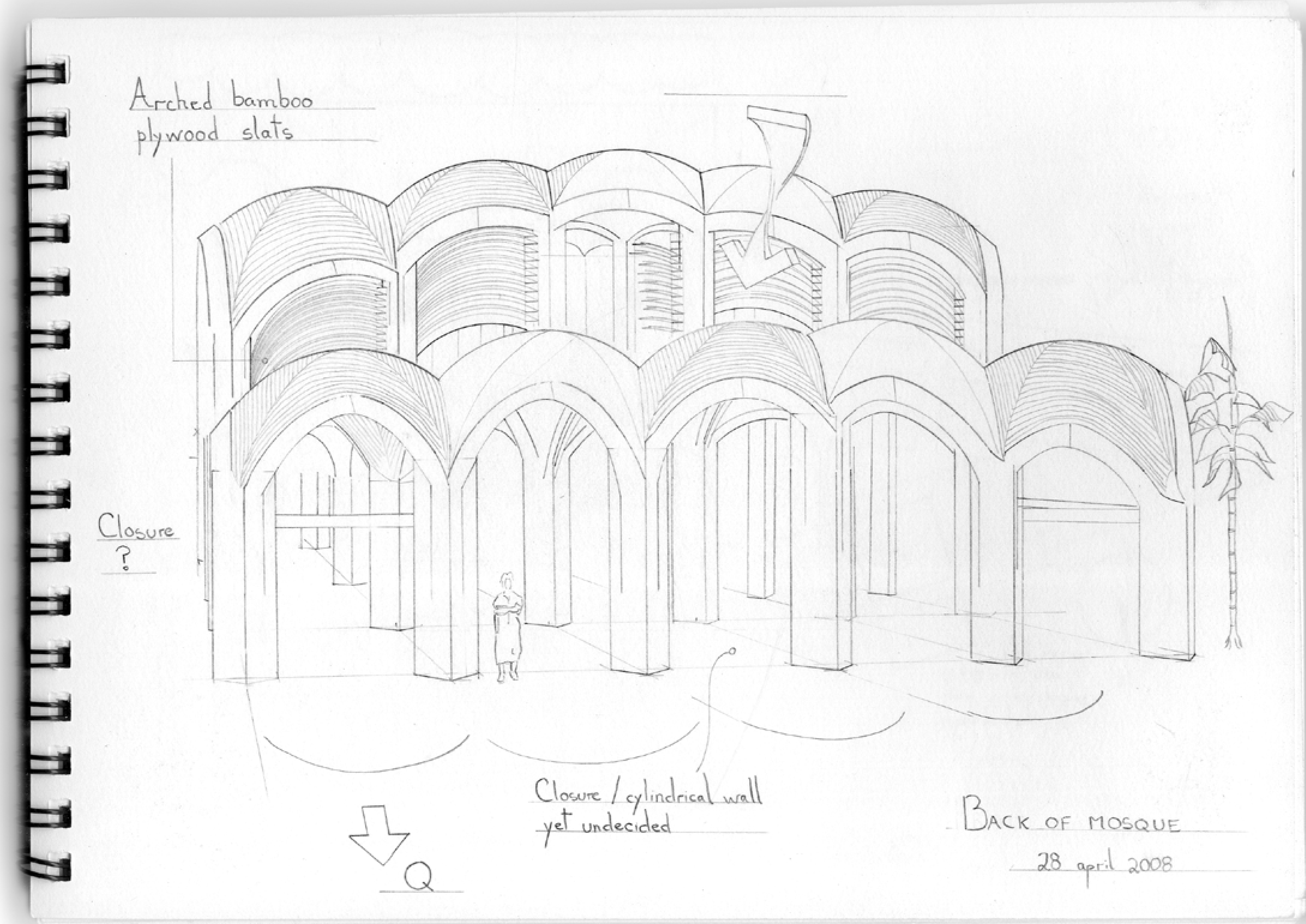
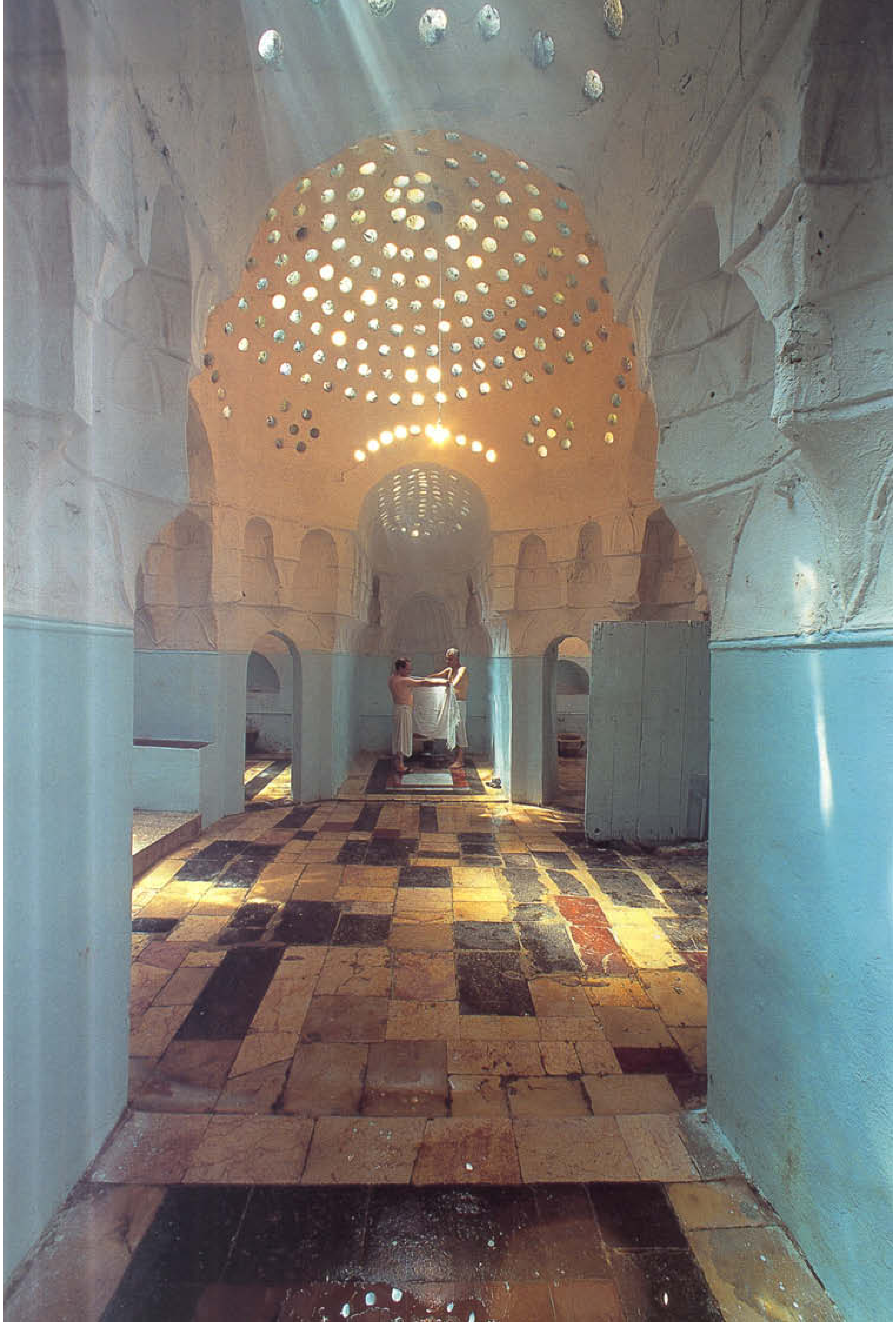

Arched bamboo
plywood slats
Closure
?
Closure / cylindrical wall
yet undecided
Q
BACK OF MOSQUE
28 april 2008



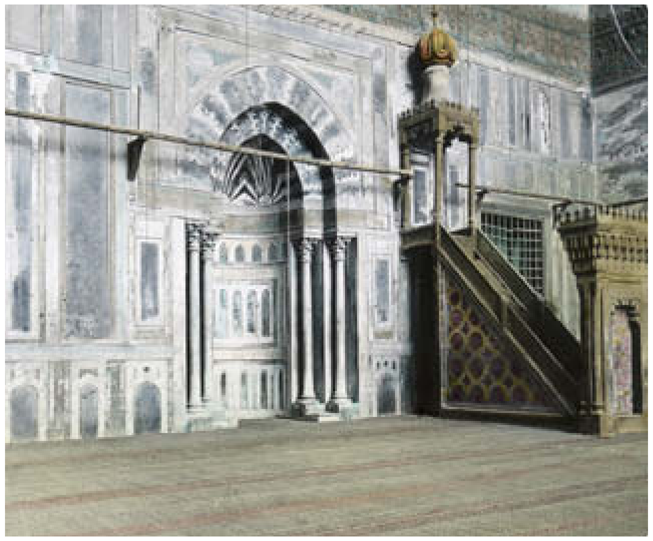
Chapter 3

A mosque and a cyclone shelter

Part 3 of a strategy for safeguarding houses and sheltering people from cyclones (see p 50).

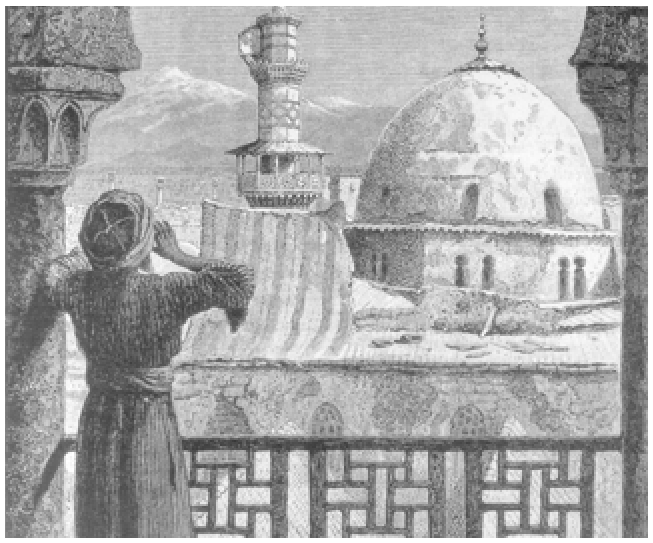
This photograph of the Al-Tawrizi hammam in Damascus presents qualities of architecture – massive, lime-white, vaulted – which inspired this project.

Source: Gerard DEGEORGE. “Damascus”. Éditions Flammarion, Paris. 2004.



Mihrab and minbar in the Mosque of Sultan Hasan, Cairo. Source: Brooklyn Museum Lantern Slides

Courtyard and portico of the Star Mosque, Dhaka, Bangladesh. Source: Flickr user Zenman



Muezzin calling the faithful to prayer. Source: Gerard DEGEORGE, “Damascus”, Éd. Flammarion, Paris.

3.1 Essential knowledge for designing a mosque

The courtyard, the prayer hall, and the prayer wall

The first mosque was the house of the Prophet Muhammad, in Medina. Muhammad gathered his followers there to pray the God of Abraham. This house had the following characteristics:

> “A simple rectangular gravel courtyard surrounded by a wall of sun-dried brick and stone measuring about 50 metres square and just over 3 metres high. ... There were two sheltered areas of palm trunks supporting a thatched roof of palm fronds plastered with mud. ... The sheltered area inside the south *qibla* wall was known as the *zulla*, and it functioned as a prayer hall.” (Yeomans p 21)

Thus originated the sequence of courtyard, prayer hall and prayer wall, which characterizes nearly all mosques. At the end of the prayer hall, the prayer wall, named *qibla* wall, is usually blank and bare, since Muhammad considered windows and decoration to be a distraction.

Of the leaders of the prayer, the mihrab, and the minbar

Muhammad would lead the prayer by chanting in the direction of the qibla, that is, the direction of the Ka’aba in Mecca, facing the wall, with the crowd behind him. Then, he would take a seat on an elevated platform, accessed by a staircase, facing the crowd to address matters of community.

These practices, re-enacted by the *imams*, the leaders of the prayer and the faith, lead to the appearance of two architectural features: the *mihrab*, an alcove in the qibla wall designed to reflect the voice of the imam to the congregation, during the prayer; and the *minbar*, the staircase from which to address a sermon to the attendance.

Other liturgical elements appeared as well: the *kursi*, a lectern for holding the *Qur’an*; the minaret, a tower where a *muezzin* or singer would call the faithful to prayer; the *dikka*, a platform in the middle of large mosques where muezzins would repeat the chant of the imam in unison, so that those at the back of the prayer hall – and in especially large gatherings, those praying in the courtyard – would hear the chant as well.

In addition, mosques usually have a clock on the qibla wall, to mark the time of the prayers; a window above the mihrab, to light the alcove; a door in the qibla wall, leading to a vestry for the imam; an elaborate system of artificial lights, to illuminate the prayer hall during the early morning and evening prayers; and a carpet throughout the prayer space, to make the movements of prostration more comfortable. Often, this carpet is illustrated with an array of rectangles, each about 60 by 120 cm, delineating a person’s space.

These liturgical elements are not present in all mosques. The dikka platform for signers has been antiquated by the appearance of sound amplification. Similarly, the minaret rarely serves its traditional purpose as a chanting tower since in most places, the signers have been replaced by loudspeakers. Meanwhile, in certain traditional mosques, perhaps according to local architectural customs, the minaret is a minor feature or is simply absent. In parallel, one can think of ancient churches, built before the bell became the way of calling the faithful to mass, which never had a bell tower.

Additional facilities: the ablution fountains and the office of the imam

The Prophet Muhammad said that "Cleanliness is half the faith"; accordingly, the Muslims perform ablutions before prayer: to wash one's face and head, arms and hands, feet and ankles, and to brush one's teeth. This light wash, called *wudu*, is different from the *ghusl or* full body wash, required notably after sexual intercourse. These ablutions traditionally called for the design of fountains, often located in the courtyard; and public baths, often in an adjoining building. Most fountains, whether elaborate or a simple array of taps, feature blocks upon which each person can stand above the soiled water. Most mosques also include an office where the imam can work and meet lay people for confessions.

Considerations on the prayer hall and courtyard

During the prayer, the Muslims do not need to see the imam, since they are looking towards Mecca; but during the sermon, it is preferable that they would see the imam on the minbar. However, during both prayer and sermon, they should be able to hear the imam. The prayer hall should accommodate regular rows of people, primarily since the Muslim prayer sequence involves blessing the person to one's left and one's right.

The persons who pray at the front of the mosque are said to be more pious and blessed. This would encourage a wide mosque; but the width is limited by the ability to see and hear the imam. Accordingly, most prayer halls have a square plan. The columns are often laid in a grid adjusted to the rows of prayer spaces, or done away with long-span structures such as domes. The openness of the space contributes to the feeling that the congregation prays together. In conclusion, about the courtyard, we can read:

> "*Hadith* sources also reveal less formal uses of the courtyard – hospice, sanctuary and refuge. The sick and wounded were cared for, as testified in one hadith, where Sa'd, one of Muhammad's injured companions, had a tent erected for him so that he could be visited by the Prophet and receive medical attention. … Noisy behaviour, however, was not generally tolerated … the Prophet strictly forbade any commercial activity inside [the courtyard]." (Yeomans p 21)

"Architecture of the Islamic World". Edited by George MICHELL. Thames and Hudson. 1978, reprinted 1987.
YEOMANS, Richard. "The Story of Islamic Architecture". Garnet Publishing, Reading, UK. First edition, 1999.

London Central Mosque, view towards the qibla wall.
Source: Wikipedia

Shatgumbad Mosque, Bagerhat, Bangladesh, c. 1450
Source: Flickr user Joiseyshowaa

The ablutions fountains at the Yeni Mosque, Istanbul.
Source: Flickr user Aviana2

3.2 Compressed soil blocks and domes

Photos by the author

Bangladesh. Compressed soil blocks are stacked prior to firing.

An artisanal brick-maker built this dome (a kiln) without formwork or cintering.

Unfired bricks in Bangladesh: an economical option

Bangladesh produces a lot of bricks which, as everywhere, are relatively expensive because of amount of fuel required to fire them. Furthermore, they can hardly be delivered to coastal villages which are not connected by road; this is the case in southern Bangladesh, where most localities can only be reached by boat.

This project along the coast of Bangladesh could be built in unfired bricks, made with the local soil and stabilized with cement (delivered by boat). Cement-stabilized compressed soil blocks are waterproof, durable, and more economical by volume than fired brick (even produced locally), concrete masonry units, or poured concrete (which requires and aggregates not locally available in coastal Bangladesh).

Most civic buildings in Southern Bangladesh which have stood for more than 100 years are built in bricks, with multiple domes, and have withstood numerous cyclones.

A portable press with interchangeable moulds, like the *Ceraman*, can compress blocks to about 10 MPa. With 10% cement, the resulting block's compressive strength is 10 MPa. A fired brick typically has a strength of 20 - 40 MPa.

Source: Anthony Geoffrey KERALI. "Durability Of Compressed And Cement-Stabilised Building Blocks". University of Warwick, School of Engineering, 2001.

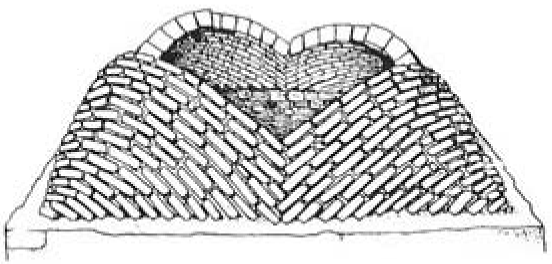
Experimenting with traditional domed architecture

In this project, the arguments in favour of using bricks (crude or fired) lead me to consider building the architecture entirely in bricks. This challenge implied an architecture of vaults and domes. The difficulty was double: first, to learn how masonry vaults work, and second, to improve upon them, without reinventing the wheel. The drawing on the right was a first effort in this direction (see p 86).

This challenge also came with exciting possibilities. From the start, domed architecture is curved (at least in section) and thus a step away from the cyclone-shelter concrete bunker so familiar to Bangladesh. Thanks to its double curvature, a dome is more efficient than a slab, and presumably poses less resistance to the wind. Domes can also be built without cintering, which makes them economical. One method (2) simply requires to incline the bricks 10 - 15° backwards of the angle that they should have radially (4); an arm on a pivot (3), and some scaffold for the worker to stand upon, are all that is required.

1 “Architecture of the Islamic World”, ed. George Michell, Thames and Hudson, 1987.

2 3 4 CRATerre, “Traité de construction en terre”, Éditions Parenthèses, 2006.



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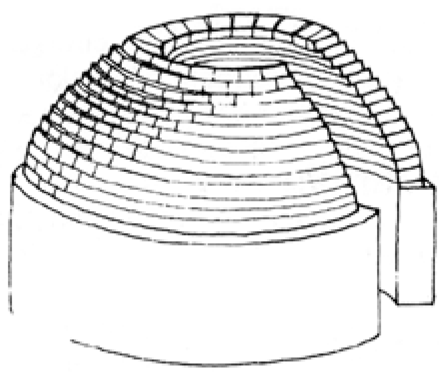

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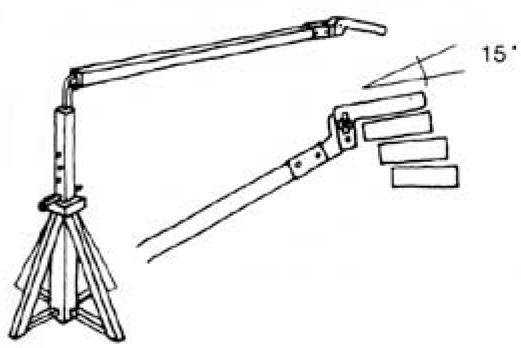

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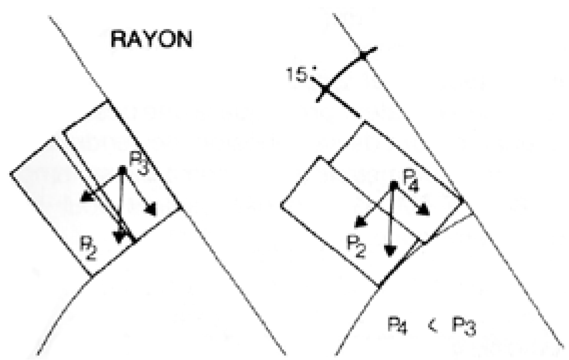

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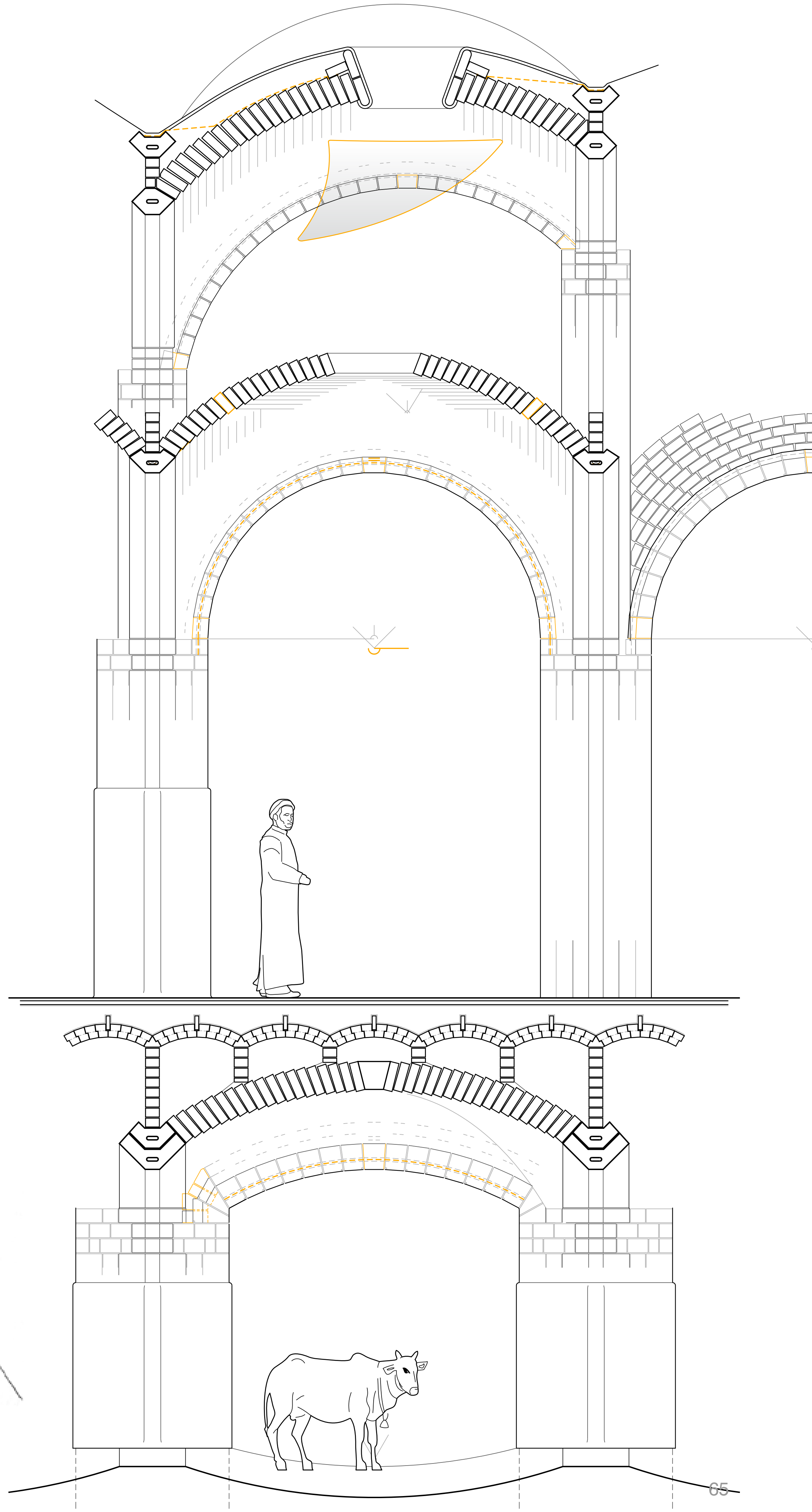
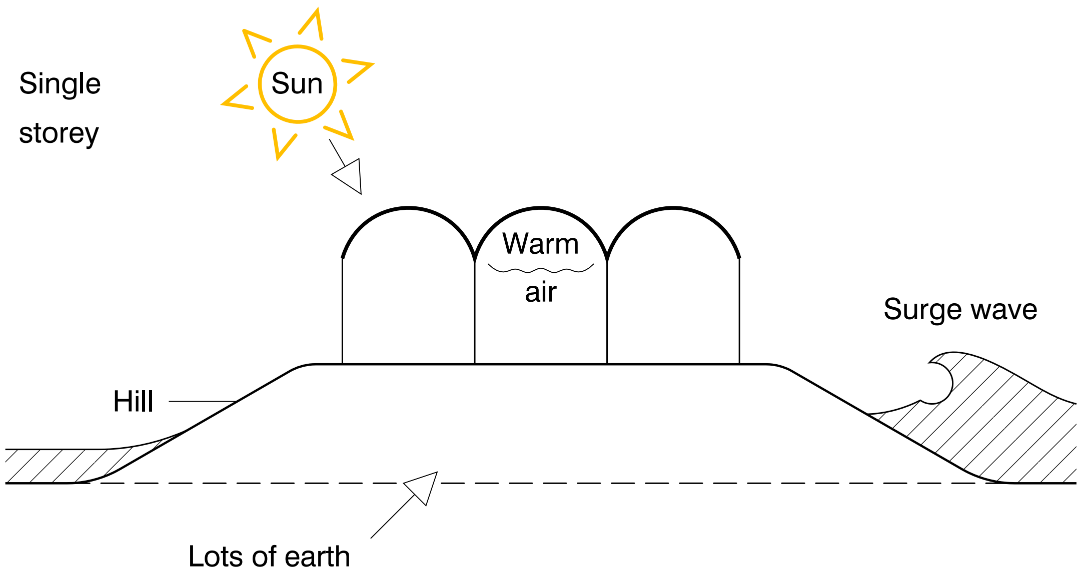
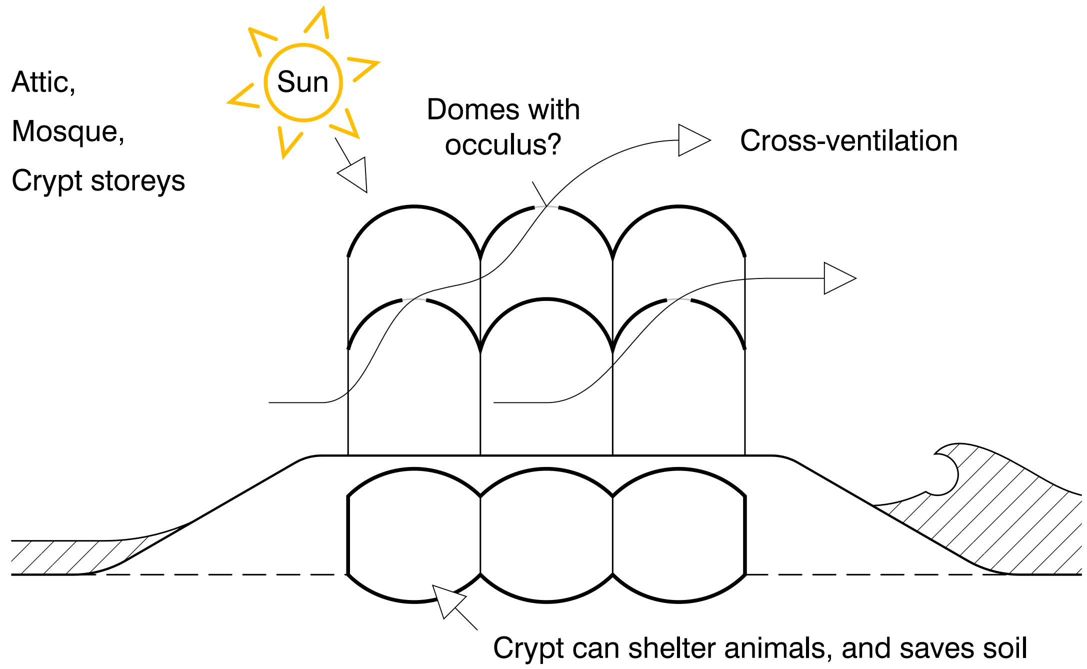


3.3 Four ideas for a shelter with domes



1 Stack the domes to create three spaces

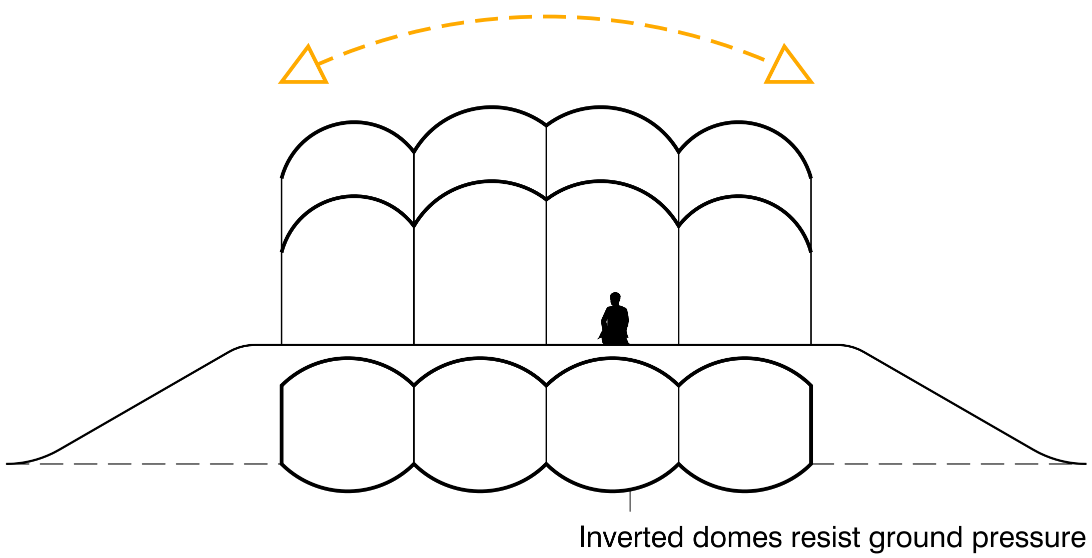
On a daily basis, the attic buffers the heat of the sun;
during a cyclone, the crypt shelters the livestock.



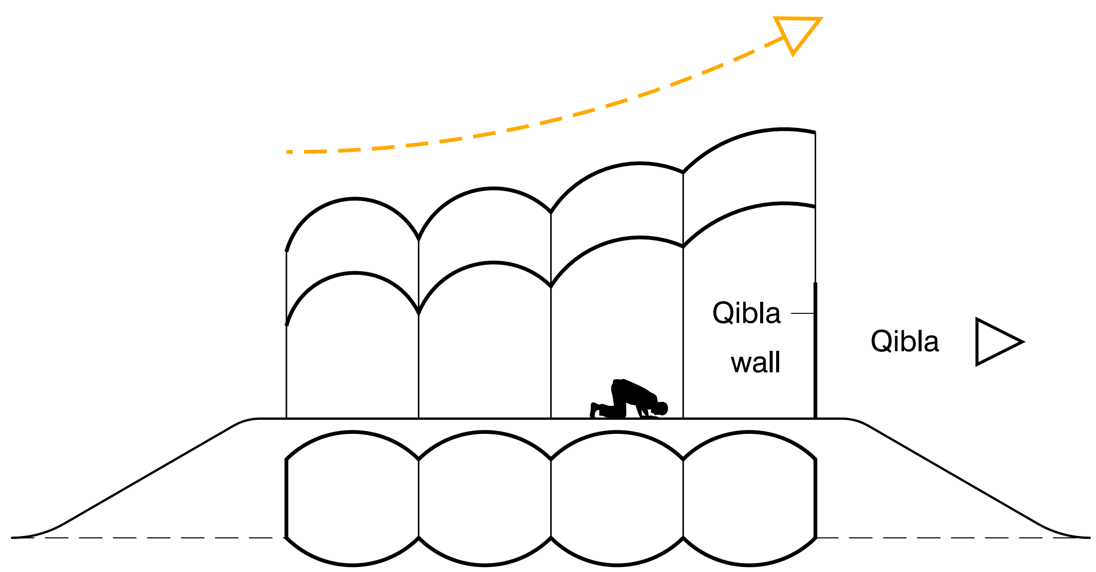
2 Vary the radius and height of the domes

Note: in Bangladesh, the Qibla (direction of Mecca) is about 9° north of west.

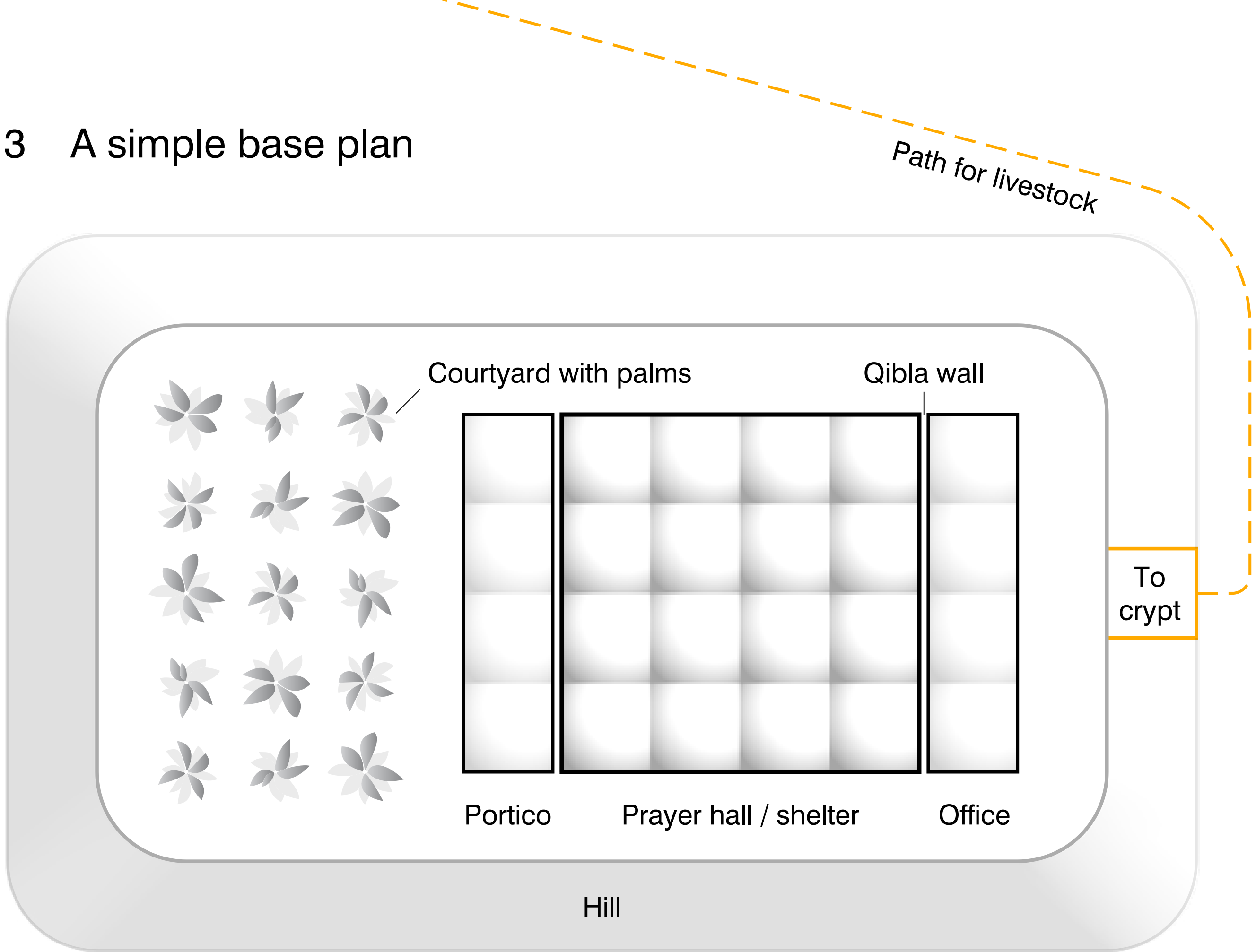
North – south section
Ample space at the center; feeling of protection



East – west section
Ascension of the domes towards the sacred

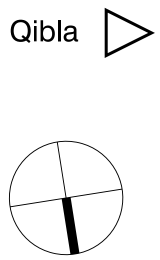


3 A simple base plan



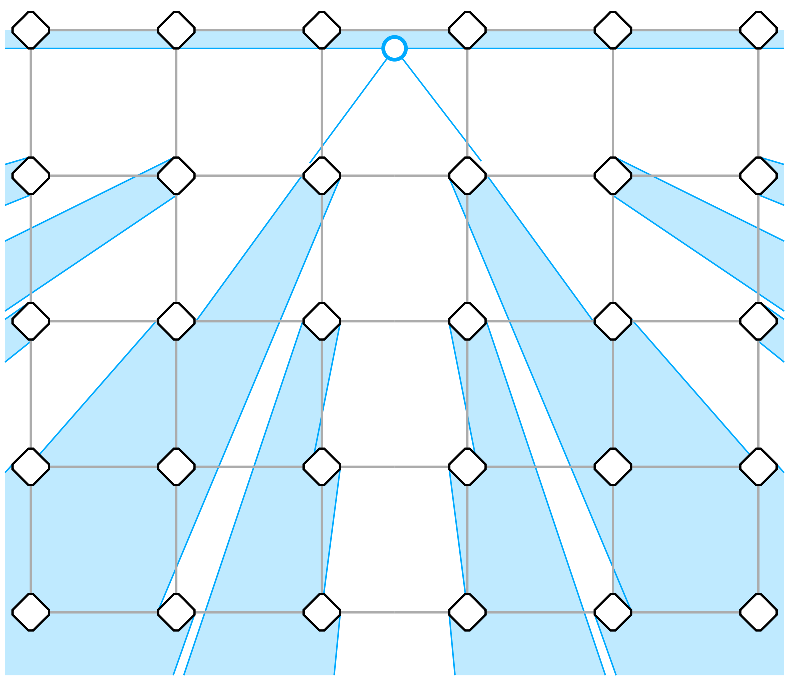
The base plan is simple: a broad hill elevates the shelter above a cyclone flood; a courtyard, shaded by palm trees, is a public place; a portico covers an area for light ablutions; and behind the qibla wall is the imam's office.

The plan will be transformed by its relationship with the site.

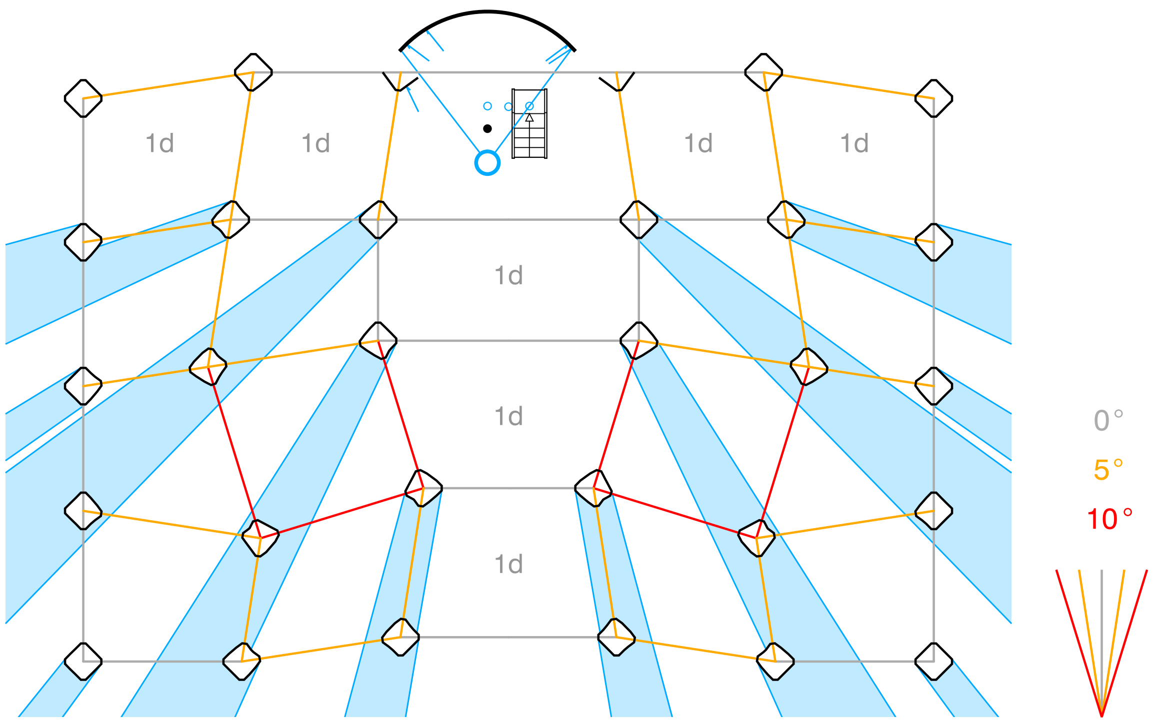


4 Shift columns to improve sight and sound lines

Here, the imam ○ speaks in a hall where big columns are arranged in square bays. The columns create large areas of shadow.

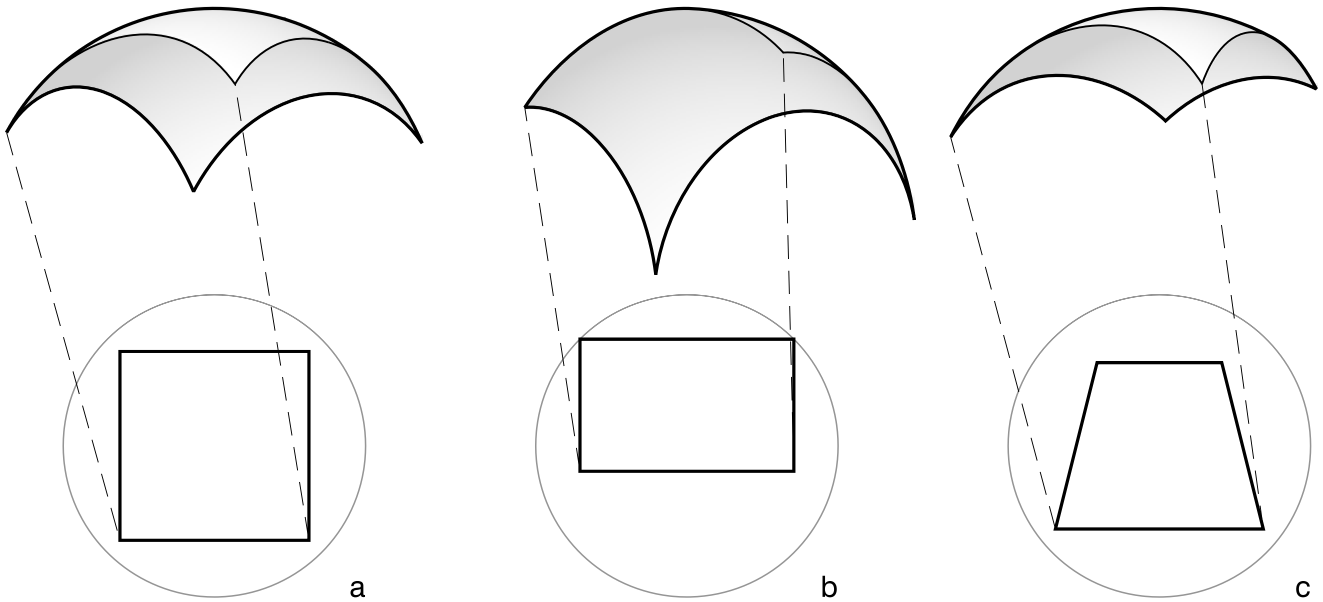


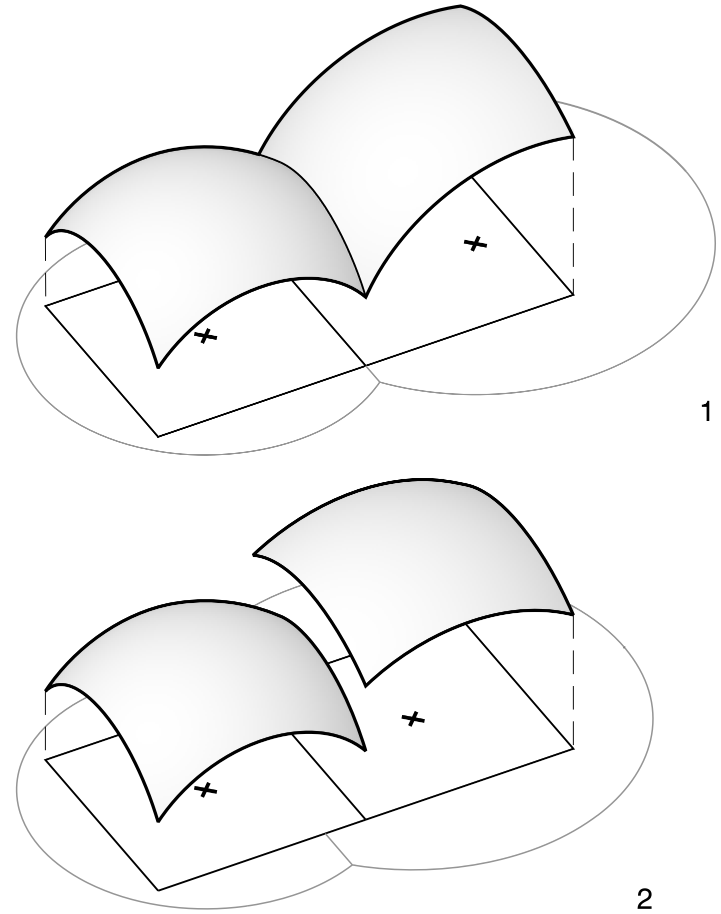
Here, the imam ○ speaks towards a sound mirror which reflects his voice radially towards the hall. The columns are shifted to create less shadow.

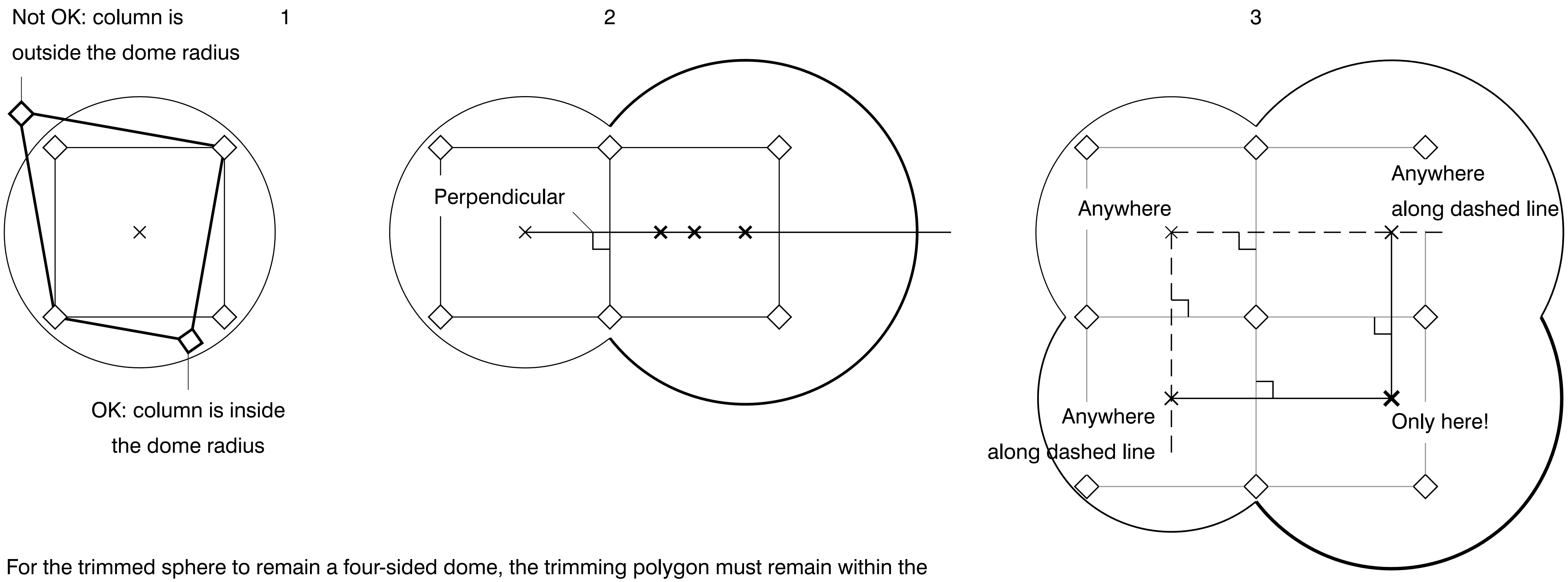


3.4 Contiguous bubble domes

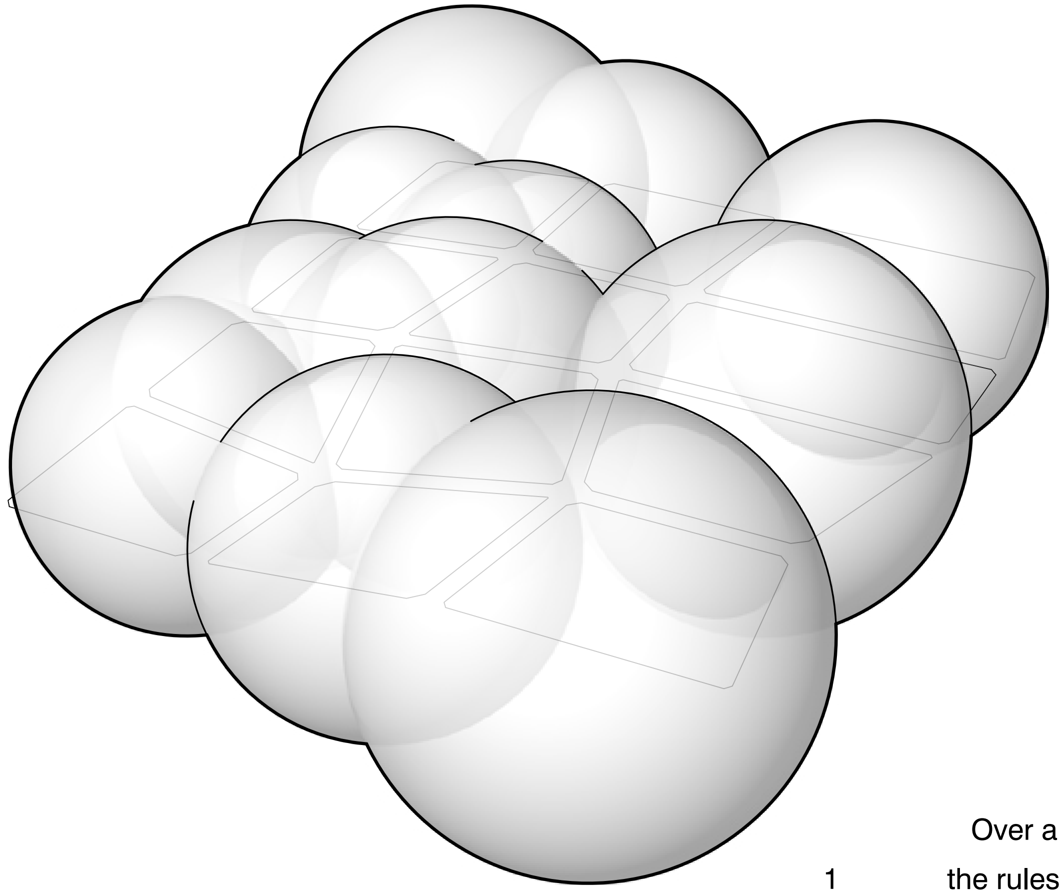
The domes began with the following questions: What happens when a sphere is trimmed by a four-sided polygon (a b c) ? And in which conditions do adjacent trimmed spheres share an edge (1) or none (2) ?







For the trimmed sphere to remain a four-sided dome, the trimming polygon must remain within the sphere's radius (1). To share an edge, an adjacent sphere must be centered on a line perpendicular to the shared polygon edge (2). An array of contiguous 'bubble domes' can be created by repeating this condition (3), and others drawn on pages 74 - 82.



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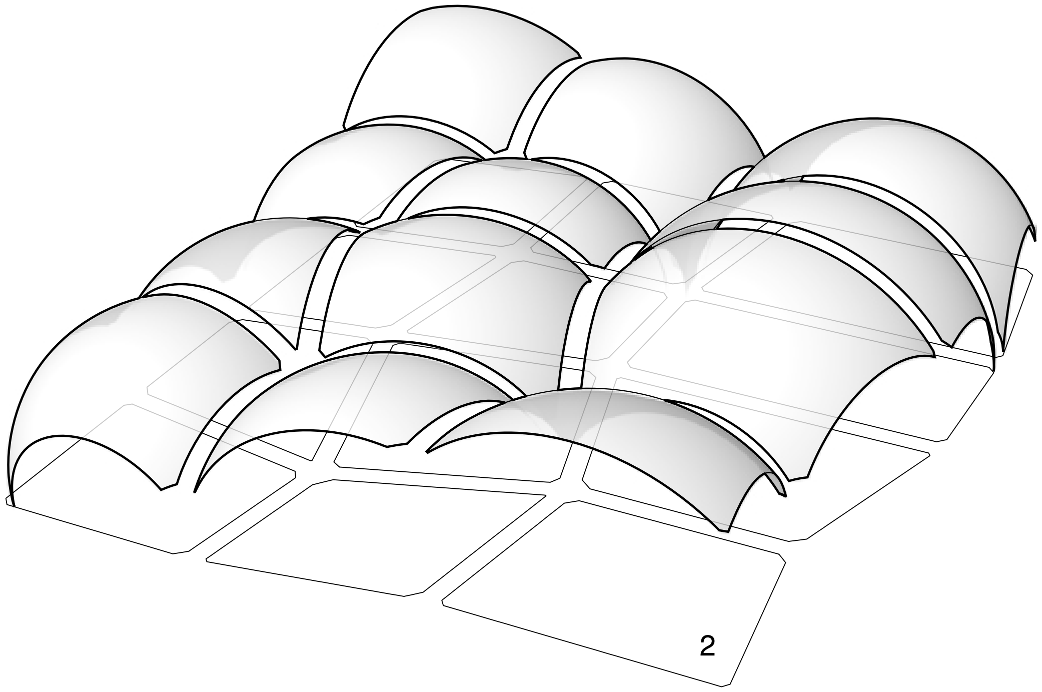


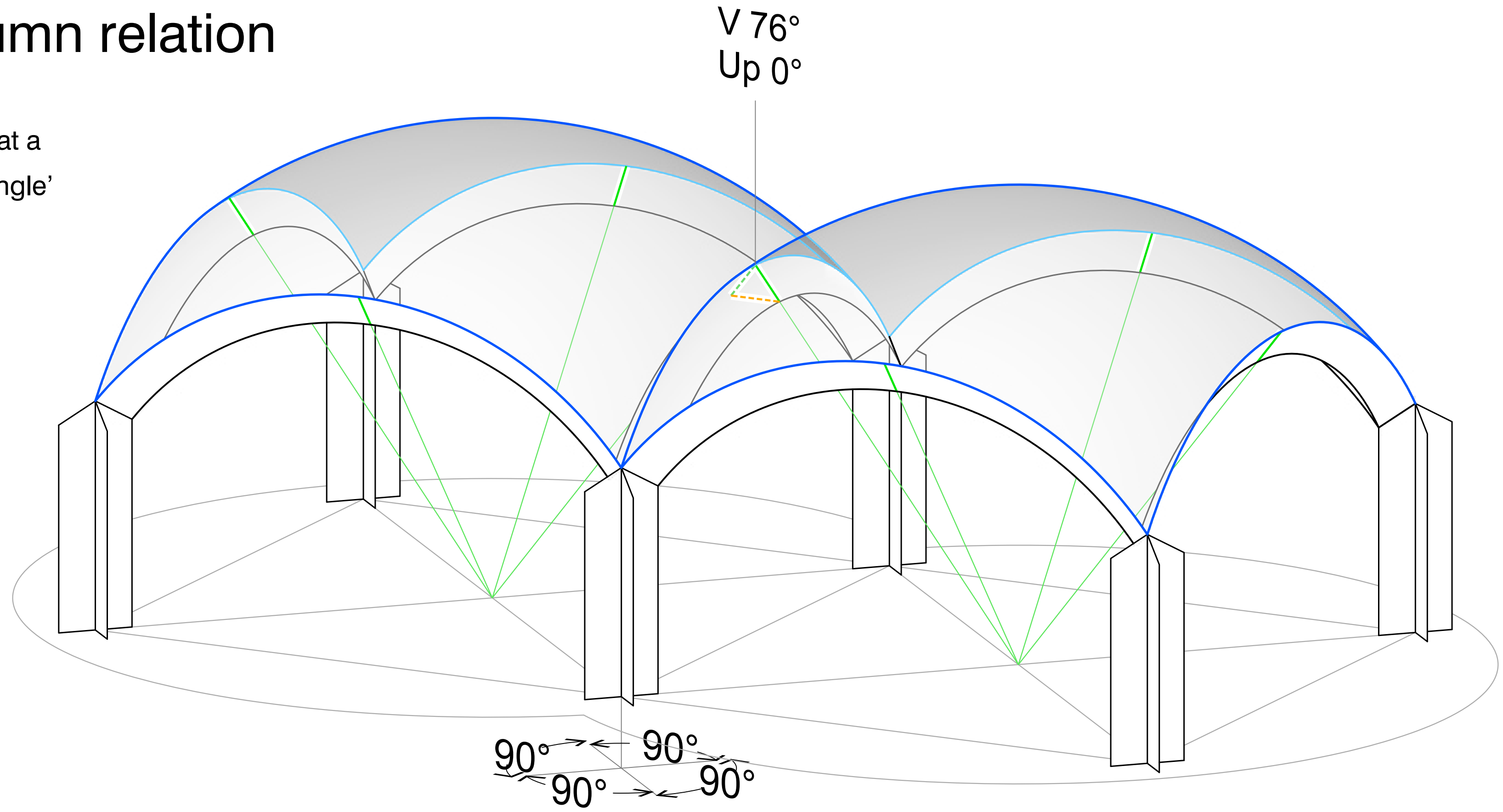
2

Over a plan with randomly angled, four sided polygons, spheres are drawn (1) which follow the rules on pages 74 - 82. When the spheres are trimmed, they yield contiguous domes (2).

3.5 Dome, arch, column relation

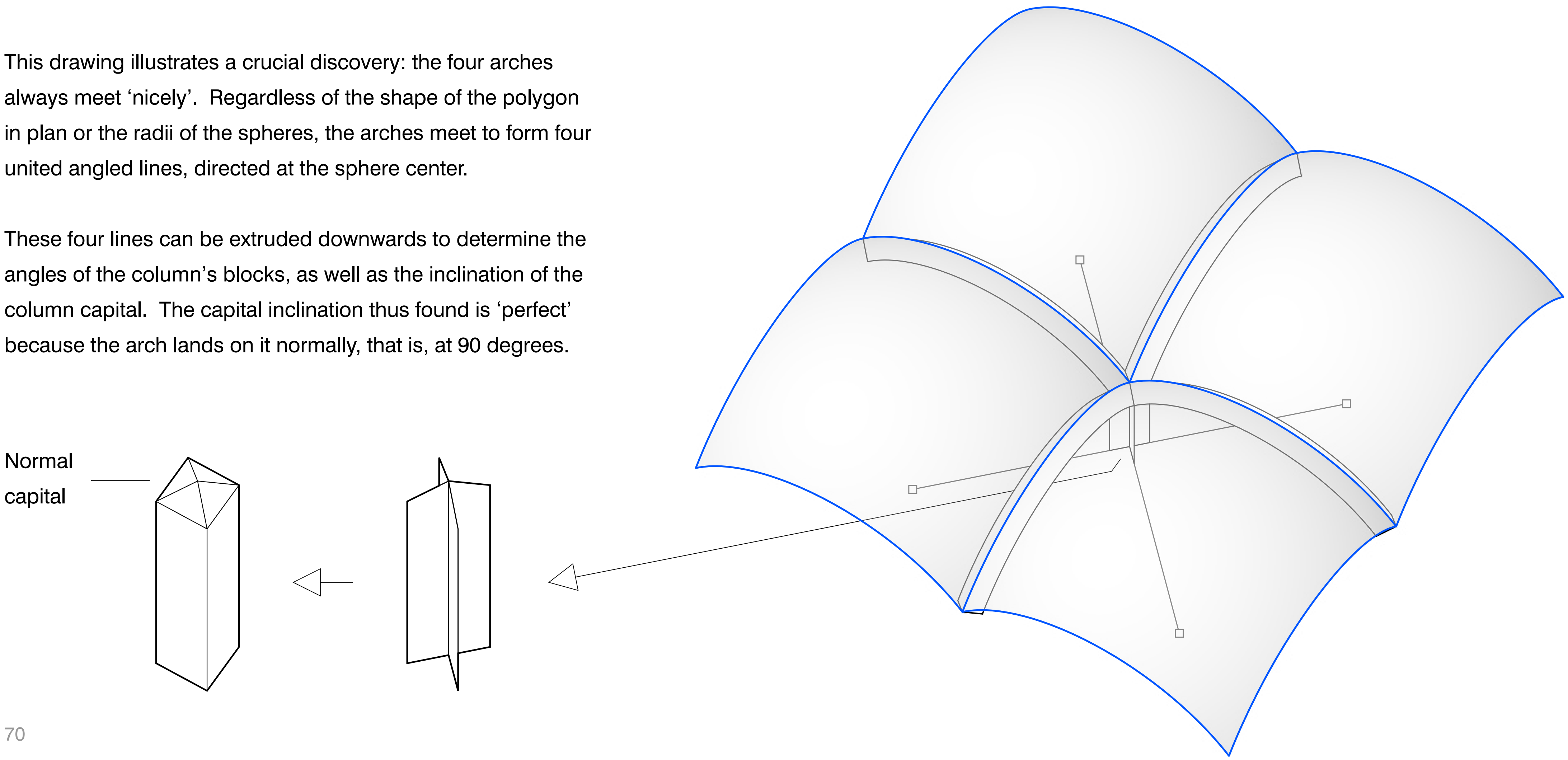
Two spherical domes, side by side, meet at a circular arch. This arch has a certain 'V-angle' and 'Up-angle', measurable at the apex.

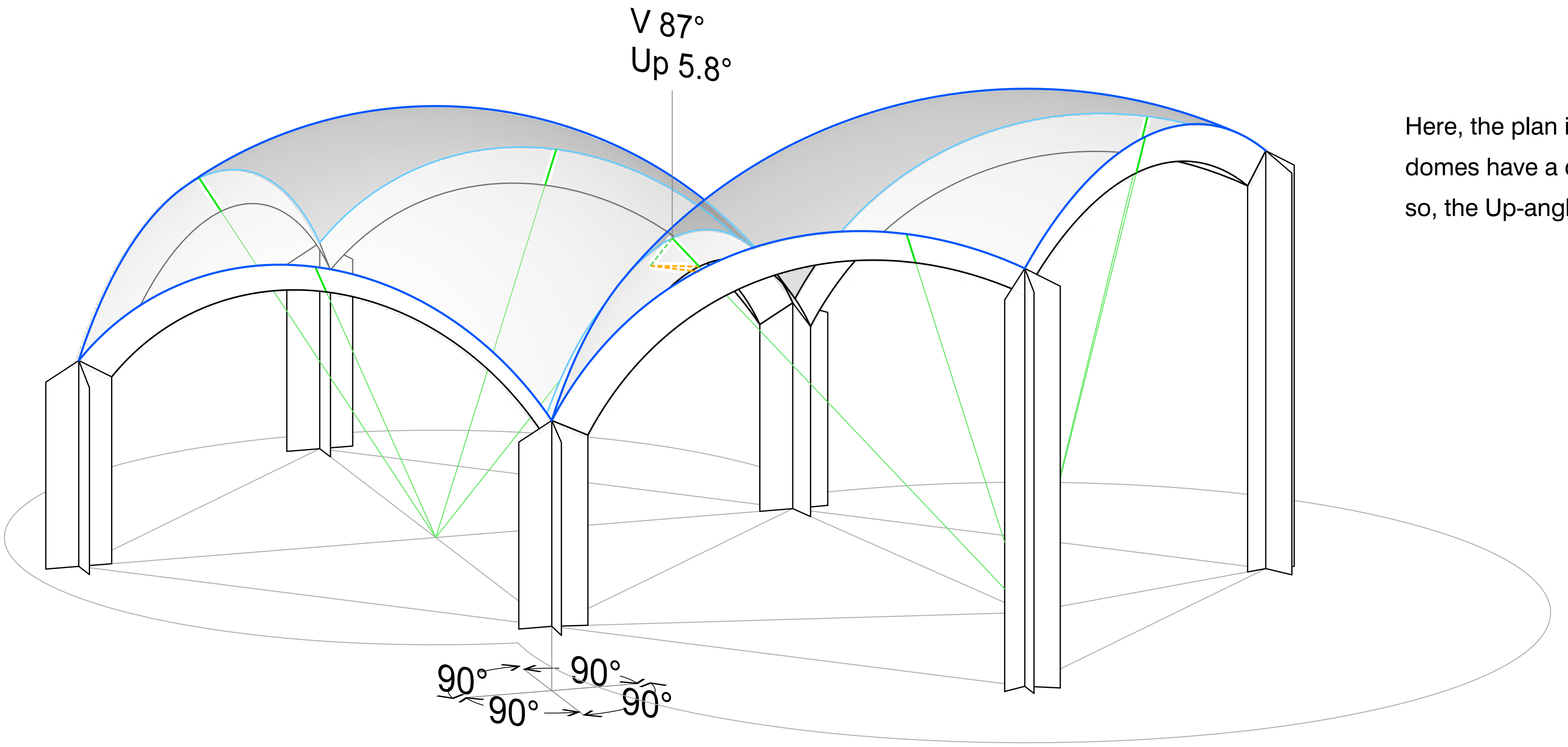
In this case, the V-angle is 76 degrees and, since the domes have the same radius, the Up-angle is zero.



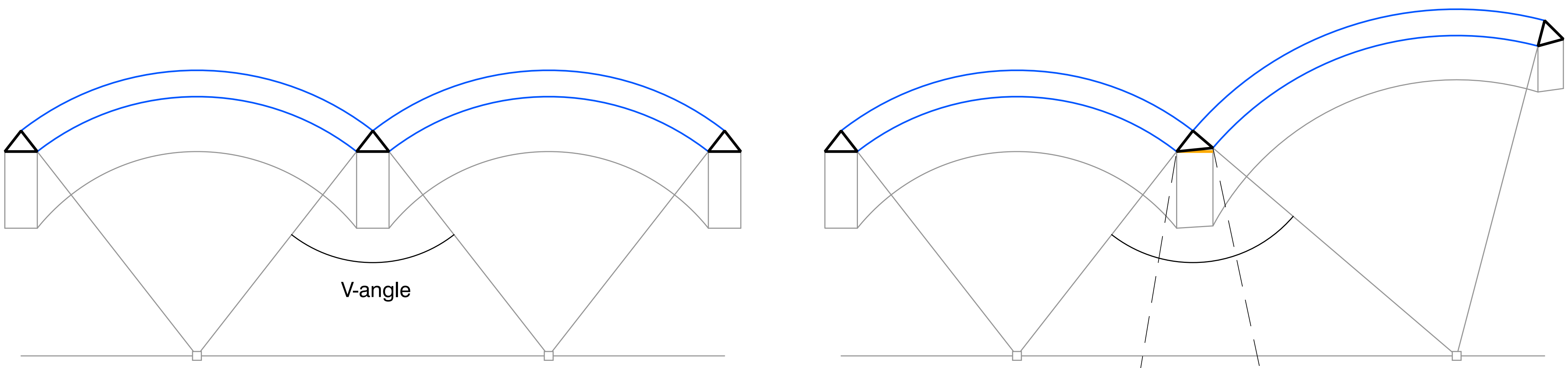
This drawing illustrates a crucial discovery: the four arches always meet 'nicely'. Regardless of the shape of the polygon in plan or the radii of the spheres, the arches meet to form four united angled lines, directed at the sphere center.

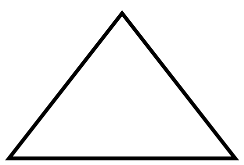
These four lines can be extruded downwards to determine the angles of the column's blocks, as well as the inclination of the column capital. The capital inclination thus found is 'perfect' because the arch lands on it normally, that is, at 90 degrees.



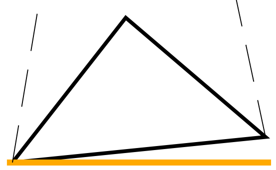


Here, the plan is the same, but the domes have a different radius and so, the Up-angle is not zero.





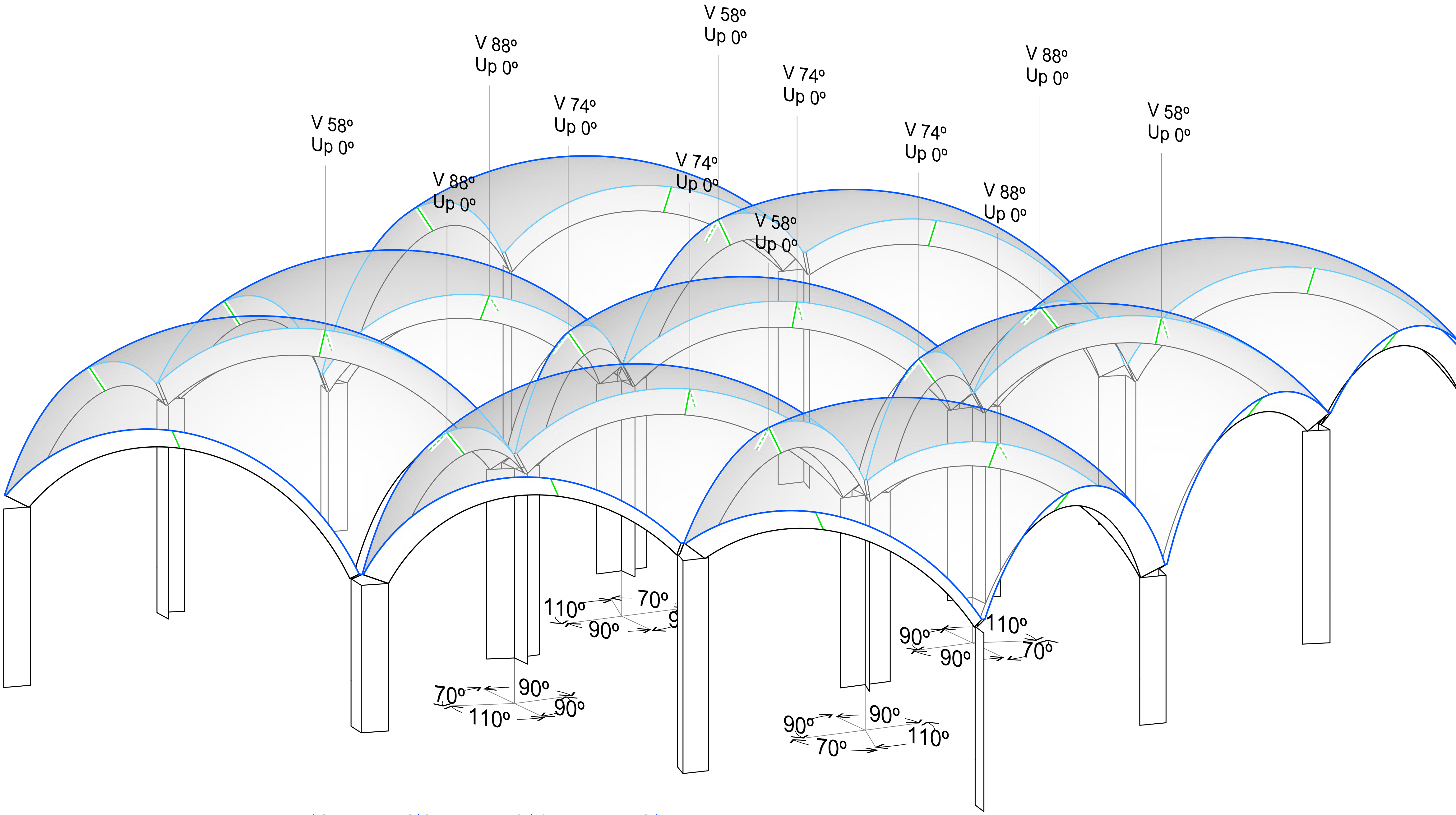
No up-angle

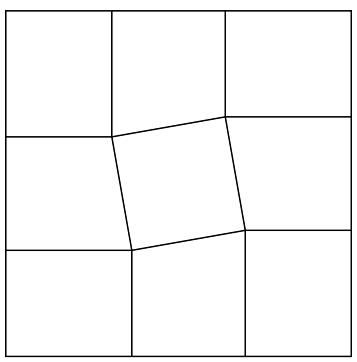


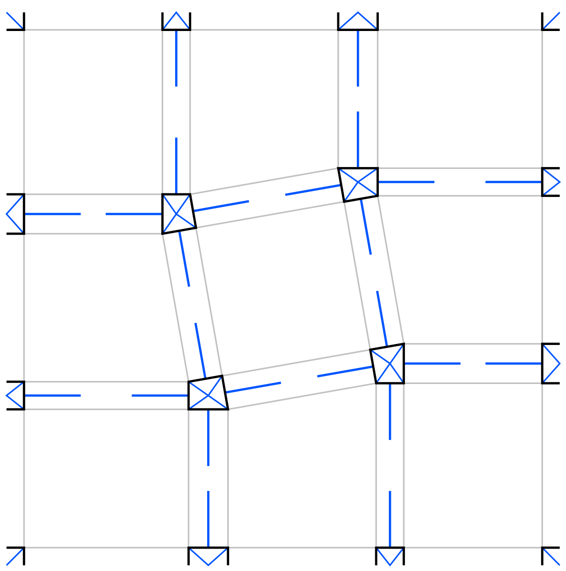
The Up-angle exists because the arch (here drawn simplistically) is made of an isosceles triangle. It has direct repercussions on the columns, explained on the following pages.

Up-angle

Example of dome, arch, column relation: no up-angle



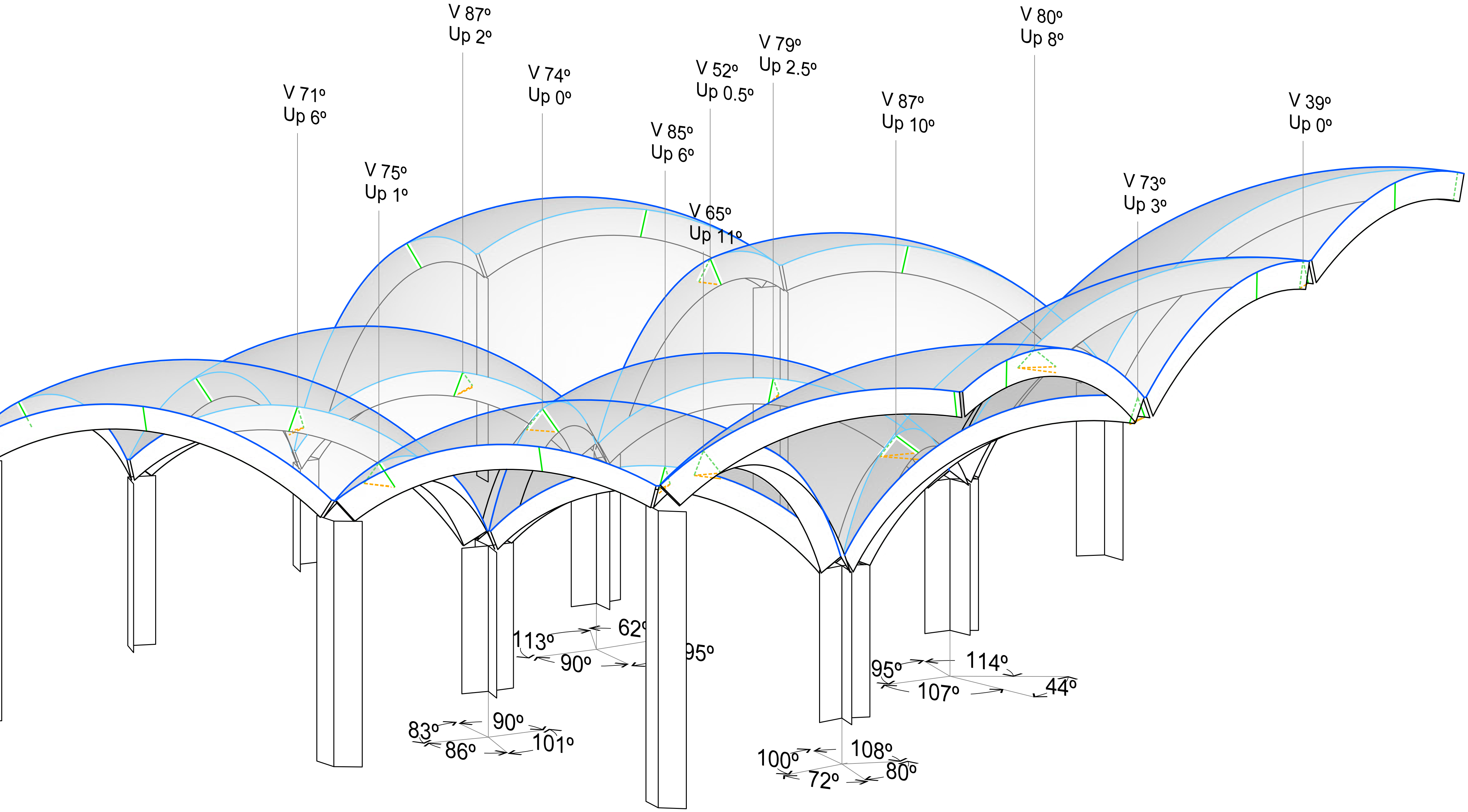


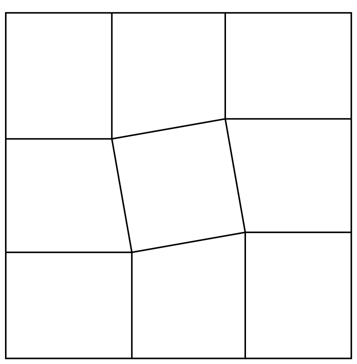


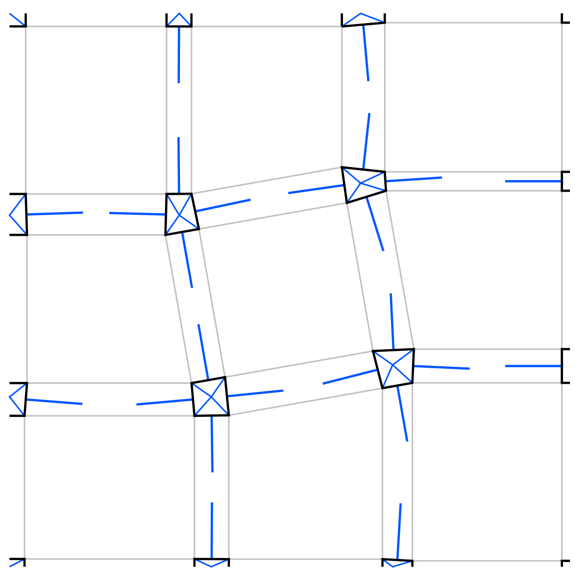
In this example, nine domes with the same radius cover a plan with a simple twist. Following the dome - arch - column geometry specific to ‘bubble domes’ (see previous page), the columns are found by projecting in plan the meeting lines of four arches.

We note that the column blocks, thus found, face their counterparts. This is indicated on the left by the blue perpendicular lines which point at each other.

Example of dome, arch, column relation: with up-angle





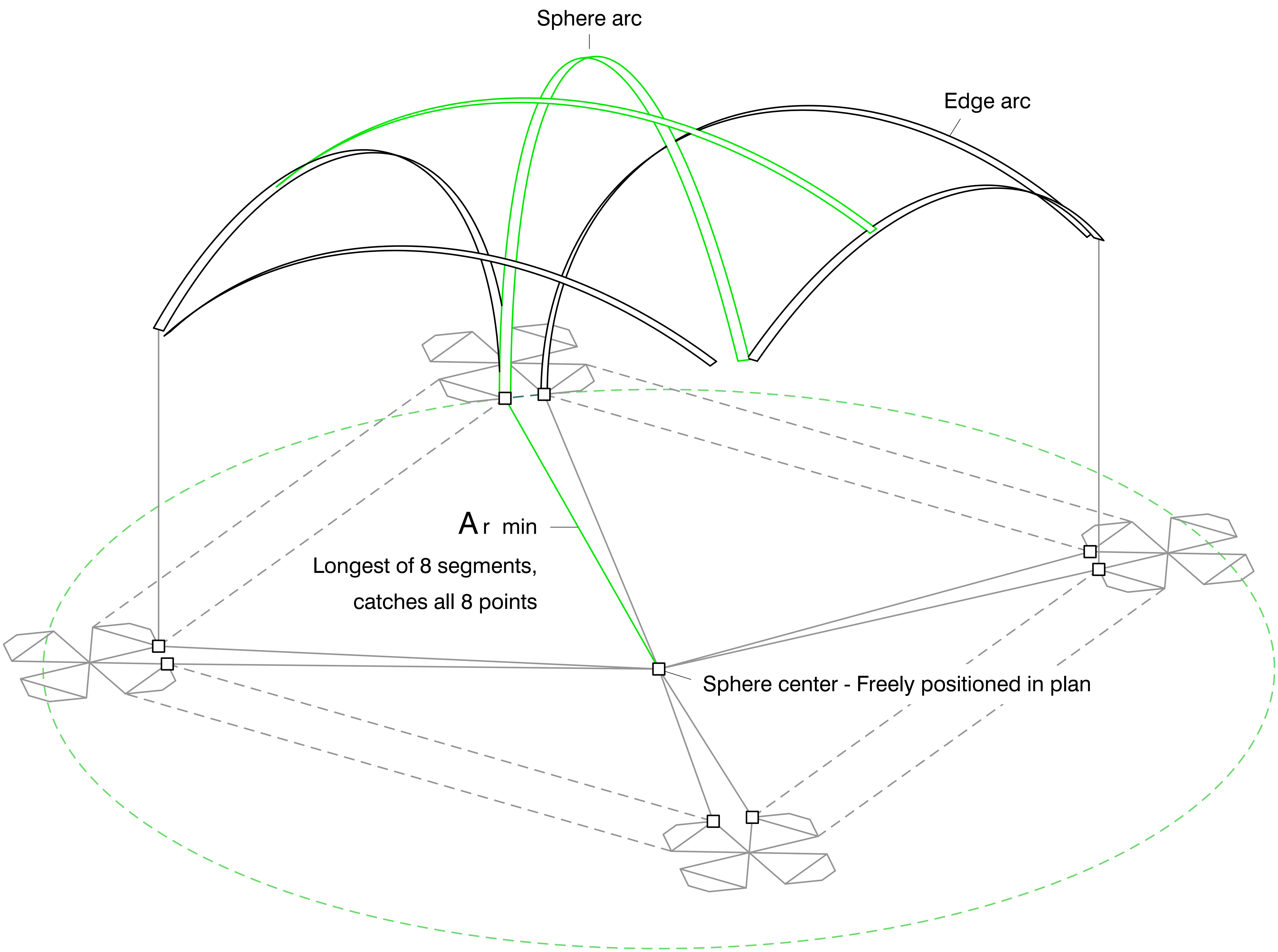


Here, the nine domes cover the same plan but have different radii. Consequently, they have up-angles, ranging from zero to 11 degrees. These up-angles transfer to the columns; the angles of the column blocks are thus different, even though the columns themselves stand in the same place as before.

As indicated by the blue lines on the left, the column blocks no longer face each other, although the arches remain perfectly straight. This will complicate the concept of superposing domes.

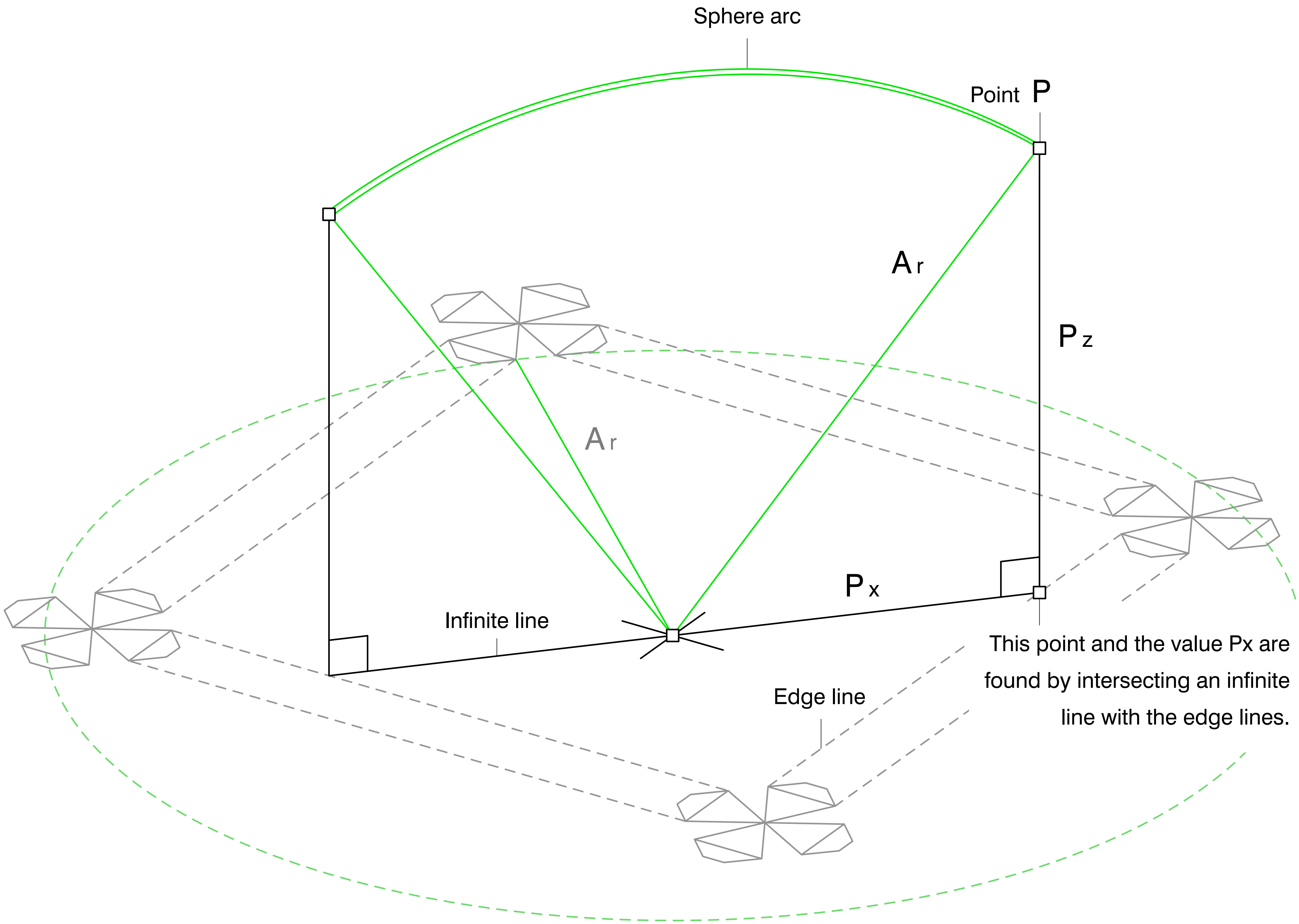
3.6 Bubble domes geometry

Spherical domes are contiguous, like bubbles, when they follow certain geometrical conditions, illustrated here. These were programmed in a GenerativeComponents (GC) script.



Sphere 2d

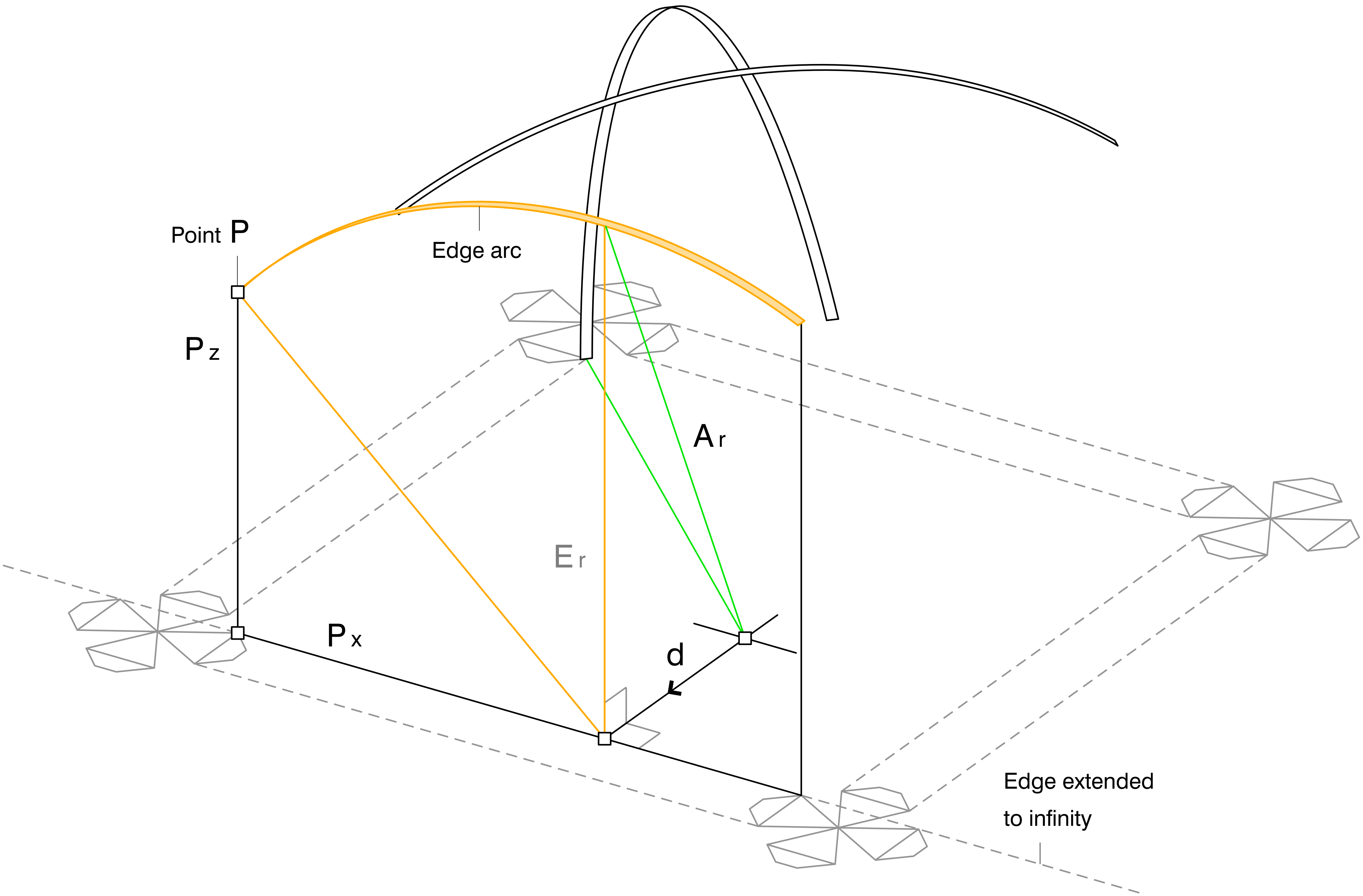
The center of the first dome can be anywhere, and its radius any value, as long as it encompasses all four columns. Because of these two degrees of liberty, it is called 'sphere 2d'.



Sphere arc

The GC script draws a ‘sphere arc’: an arc at the apex of the sphere, simply to give an idea of the dome. Drawing the actual surface of the dome would require lots of computing and thus reduce the interactivity of the script.

Given the radius and center of the sphere, GC draws the sphere arc using the center and two points P_1 and P_2. Their coordinates are found with the intersection described below, and with Pythagoras’ ratio: $Pz^2 = Ar^2 - Px^2$.

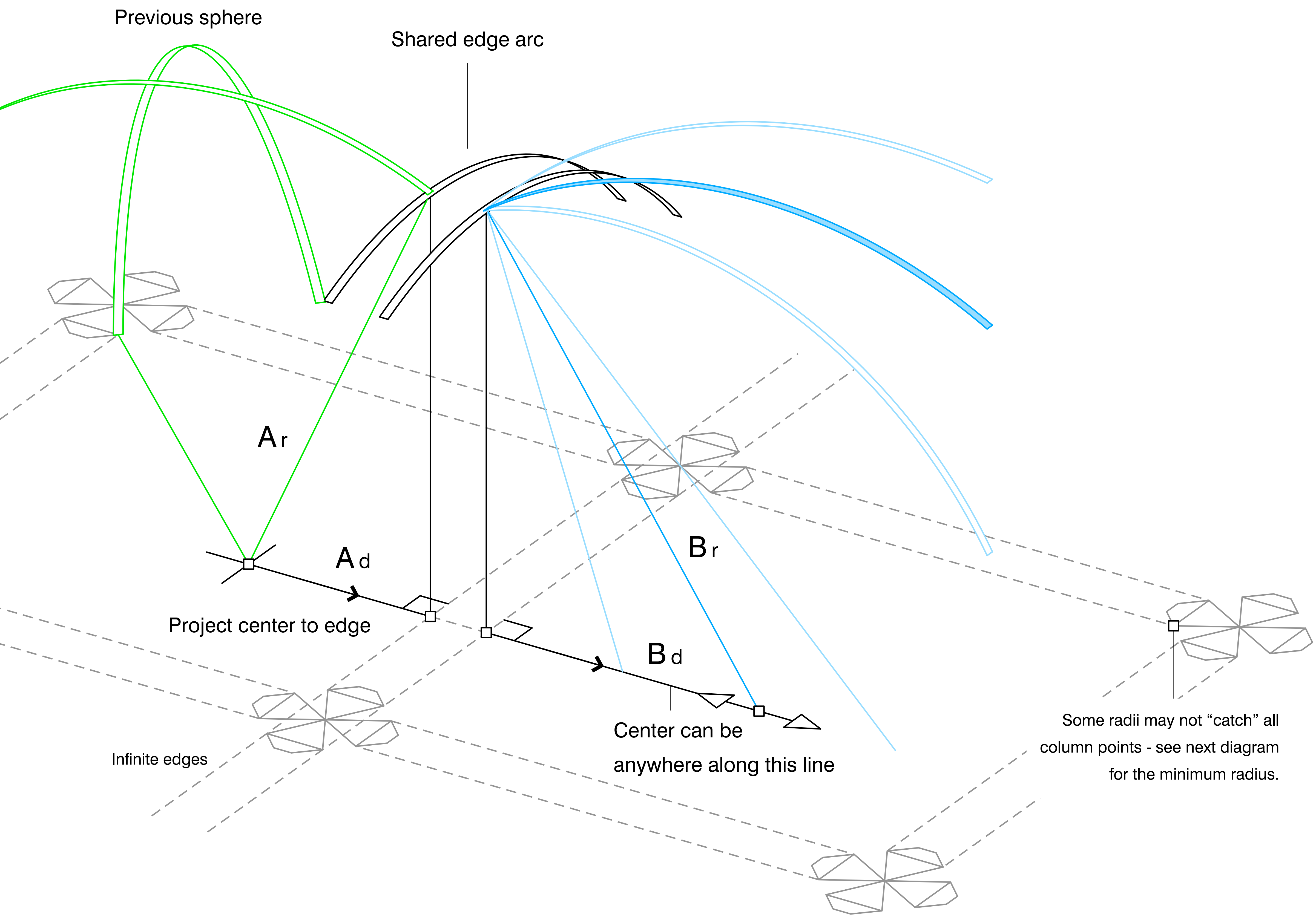


Edge arcs

The GC script draws four ‘edge arcs’ illustrating the dome at its four edges. To find the center of the arc, GC projects the center of the sphere onto the edge of the polygon. To find the ends of the arc, GC calculates Pz from Pythagoras’ ratio: $Er^2 = Ar^2 - d^2$

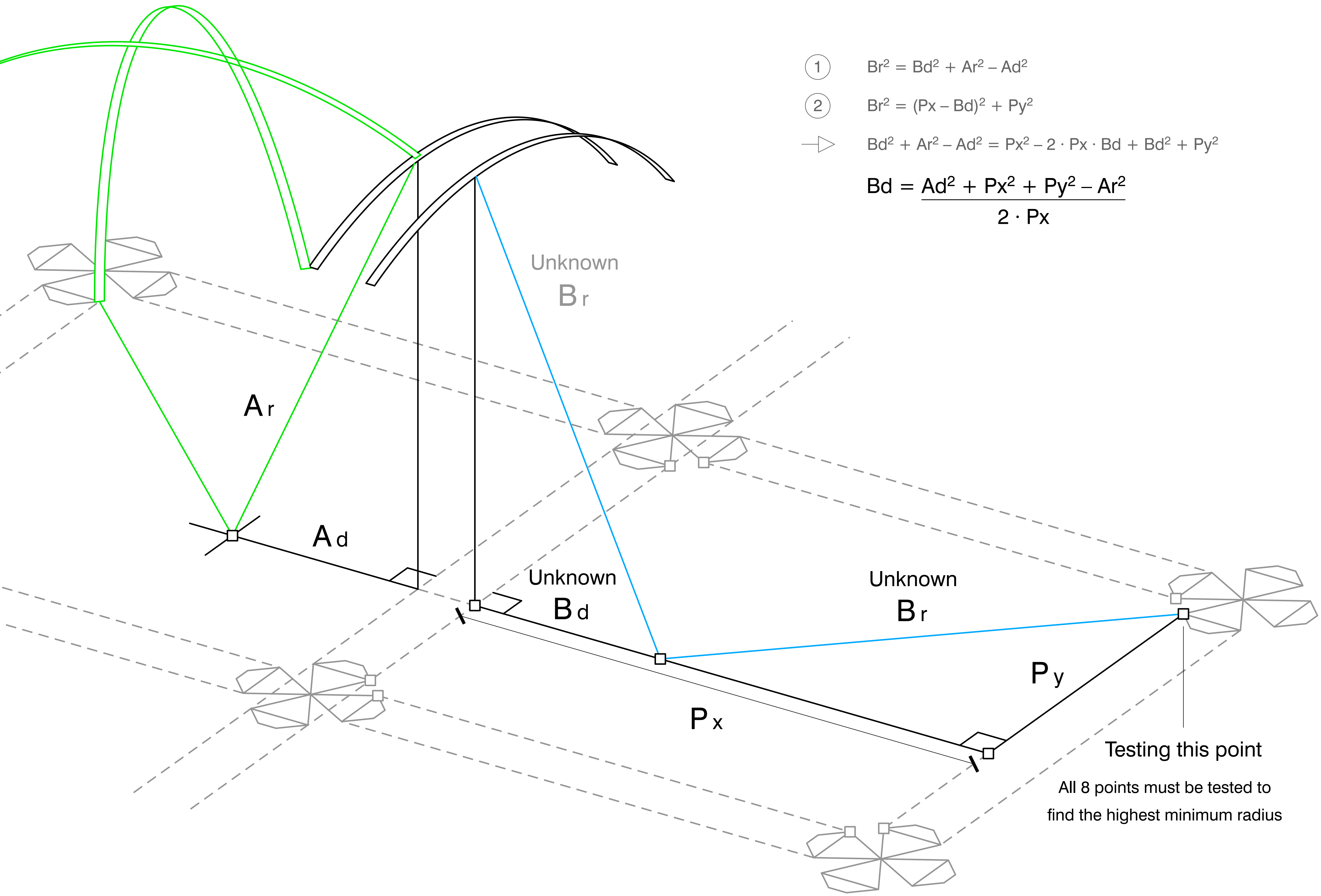
and $Pz^2 = Er^2 - Px^2$

thus $Pz^2 = Ar^2 - d^2 - Px^2$



Sphere 1d

The center of the second dome must be on a line perpendicular to the edge shared with the first dome. Because of this one degree of liberty, it is called ‘sphere 1d’. Once a center point is chosen along this line, the radius of the new dome is given by: $Br^2 = Bd^2 + Ar^2 - Ad^2$



$$\text{(1)} \quad Br^2 = Bd^2 + Ar^2 - Ad^2$$

$$\text{(2)} \quad Br^2 = (Px - Bd)^2 + Py^2$$

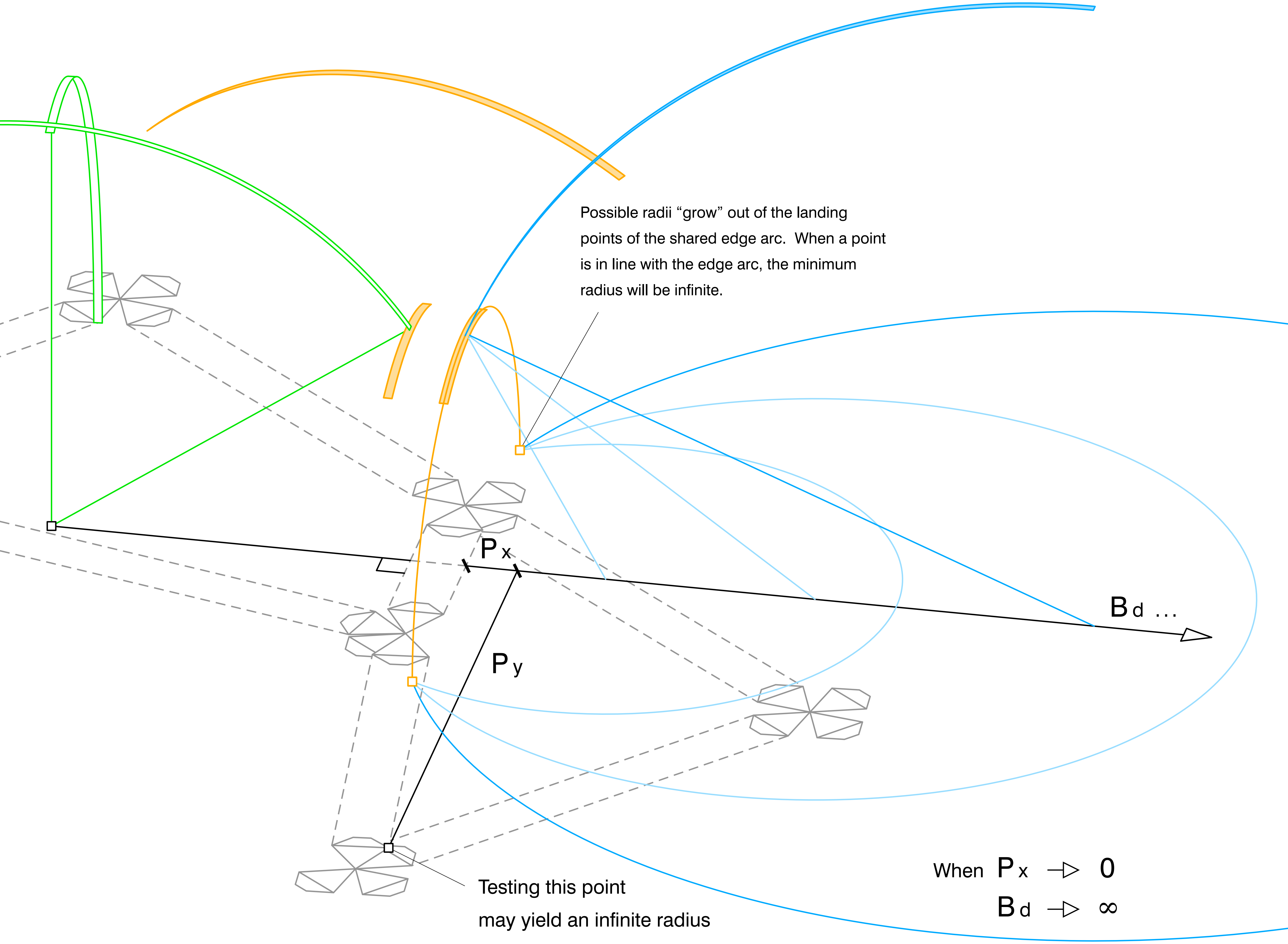
$$\Rightarrow \quad Bd^2 + Ar^2 - Ad^2 = Px^2 - 2 \cdot Px \cdot Bd + Bd^2 + Py^2$$

$$Bd = \frac{Ad^2 + Px^2 + Py^2 - Ar^2}{2 \cdot Px}$$

Sphere 1d minimum radius

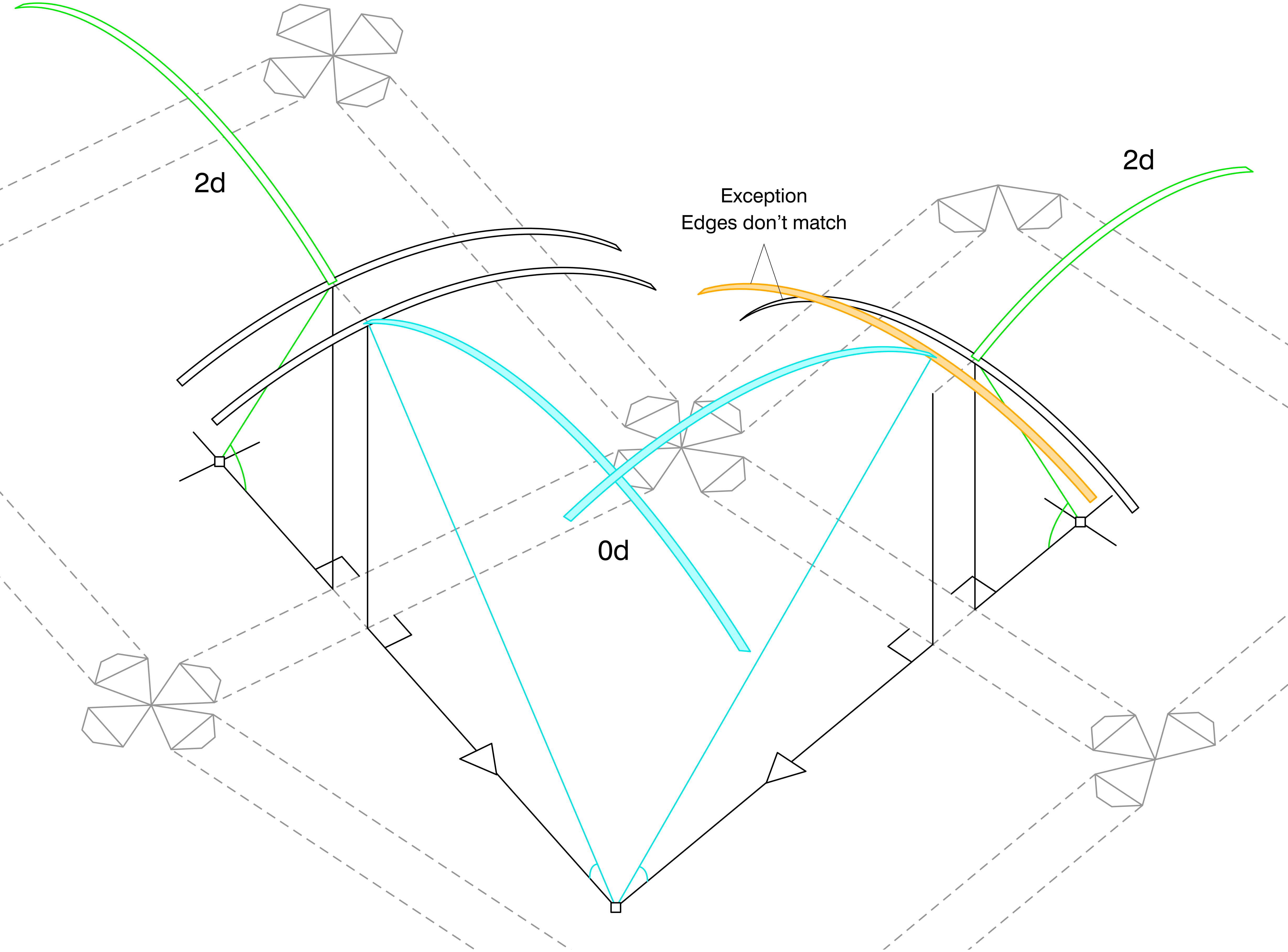
The center of a sphere 1d can be anywhere along the line; however, at some locations, the sphere is too small and no longer encompasses all four columns. There must be a minimum radius.

GC submits each of the eight points of the polygon to this test, and keeps the highest Br. Then, with the equation above, GC finds Bd to locate the center on the line.



This exception must be programmed into the GC testing script, otherwise it fails.

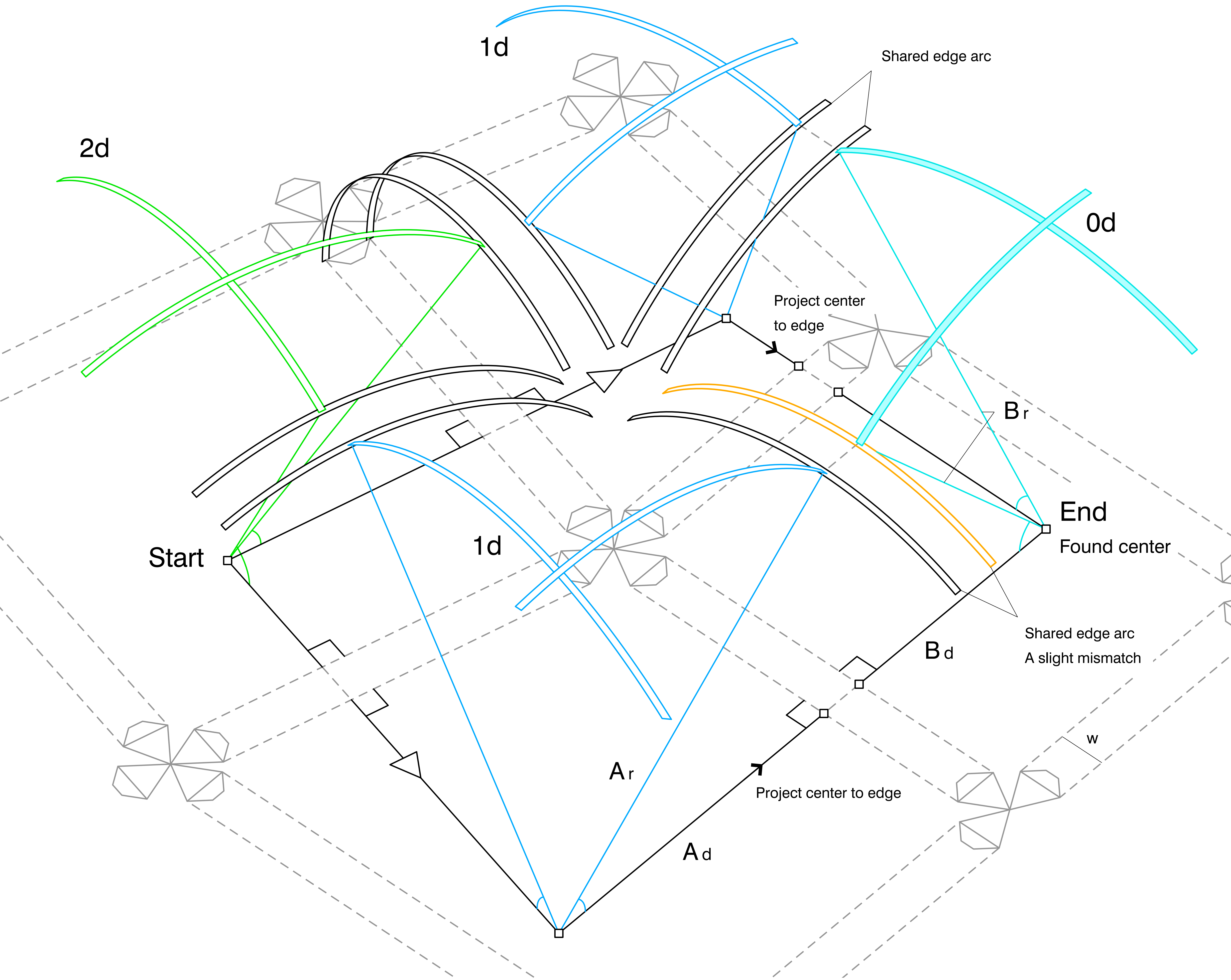
Minimum radius exception



Sphere 0d exception

When two domes already exist around a corner, the connecting dome is set: its center and radius can only have one value. It has no degree of liberty and is thus called ‘sphere 0d’.

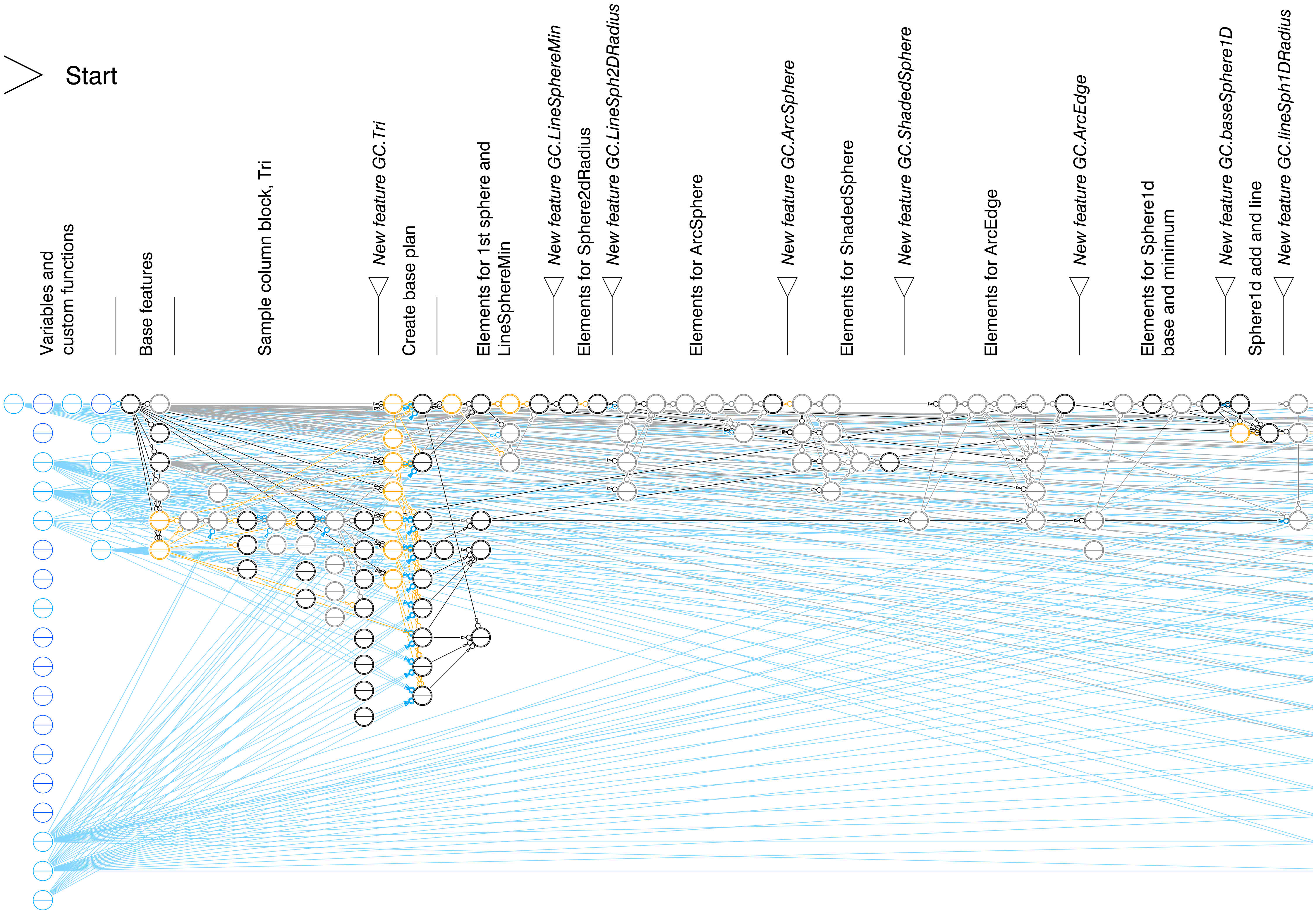
A sphere 0d can connect a sphere 2d and a 1d, or two spheres 1d, but not two spheres 2d; otherwise, the domes aren’t contiguous.



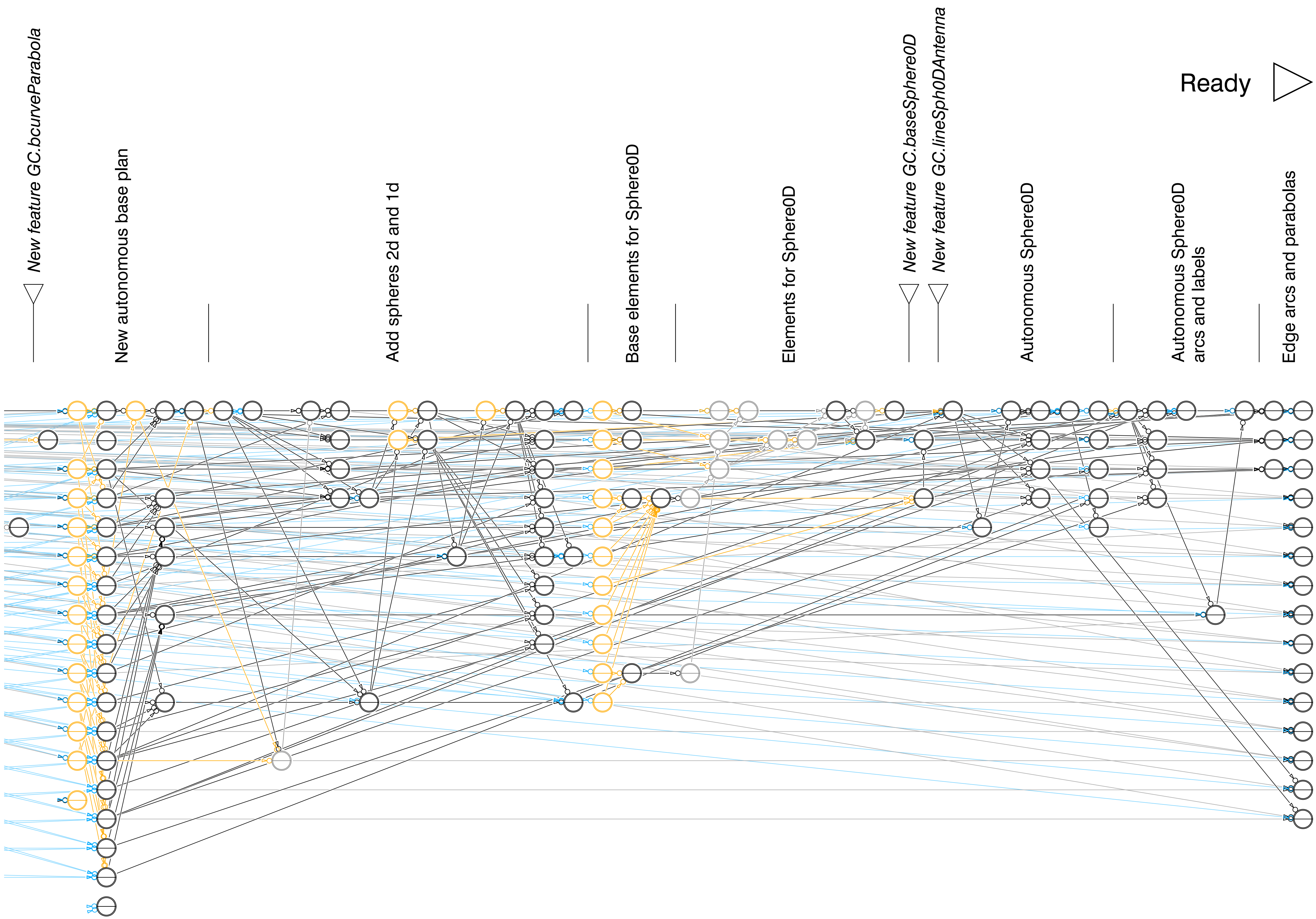
This diagram illustrates how the center of the sphere 2d (start) is projected to eventually yield the center of the sphere 0d (end).
The slight mismatch occurring at the edge arc would not occur if the arch had zero width, that is, if the domes met without an arch.

Sphere 0d

3.7 A GenerativeComponents model to vary the domes easily



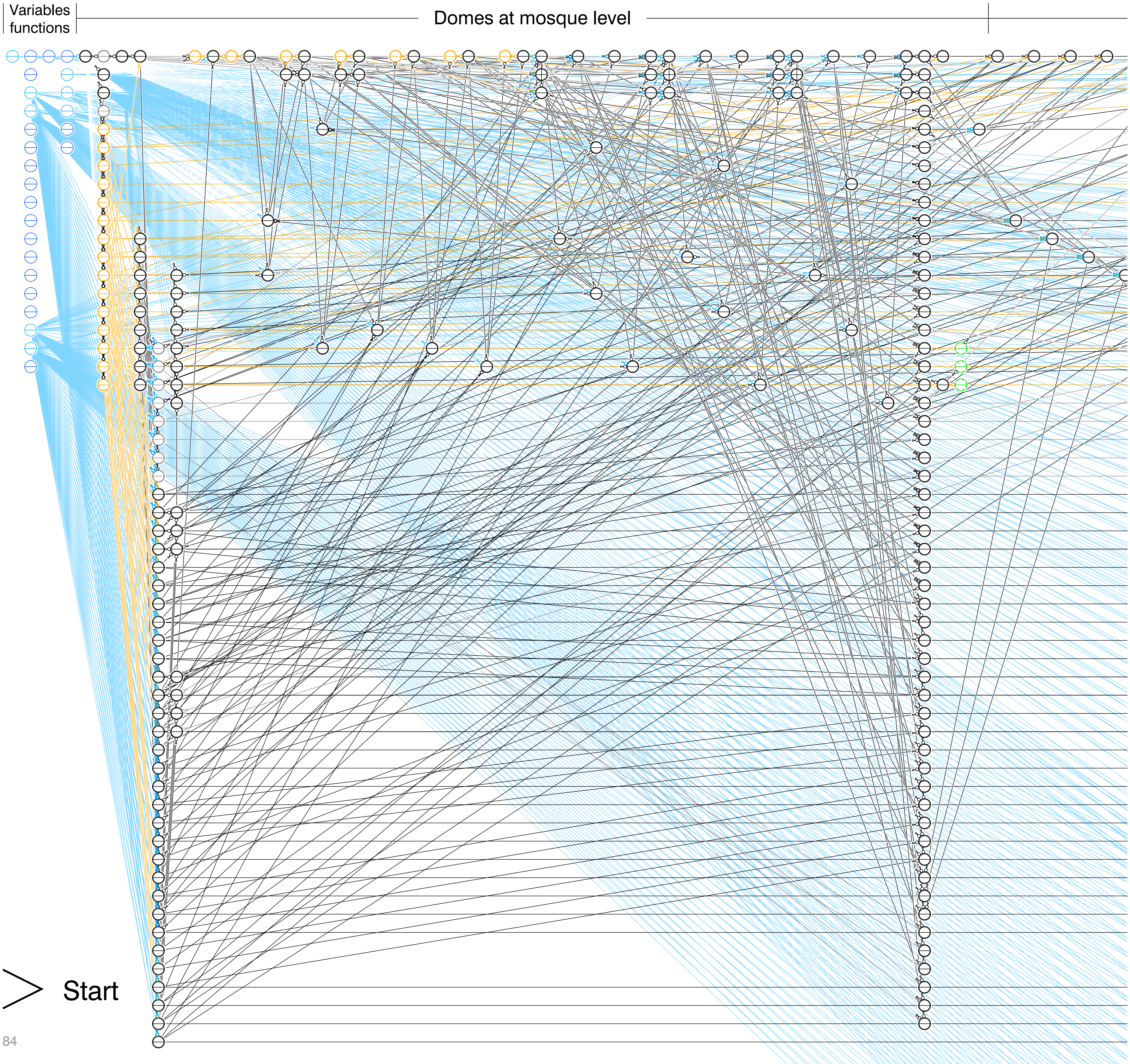
This first part of the GC script, transactions 1 to 57, generates 'custom features', that is, 3d objects which automatically adjust to changing parameters: the edge arcs, sphere arcs, spheres 2d, 1d and 0d described earlier. It becomes possible to move one column and to see all the domes reconfigure.



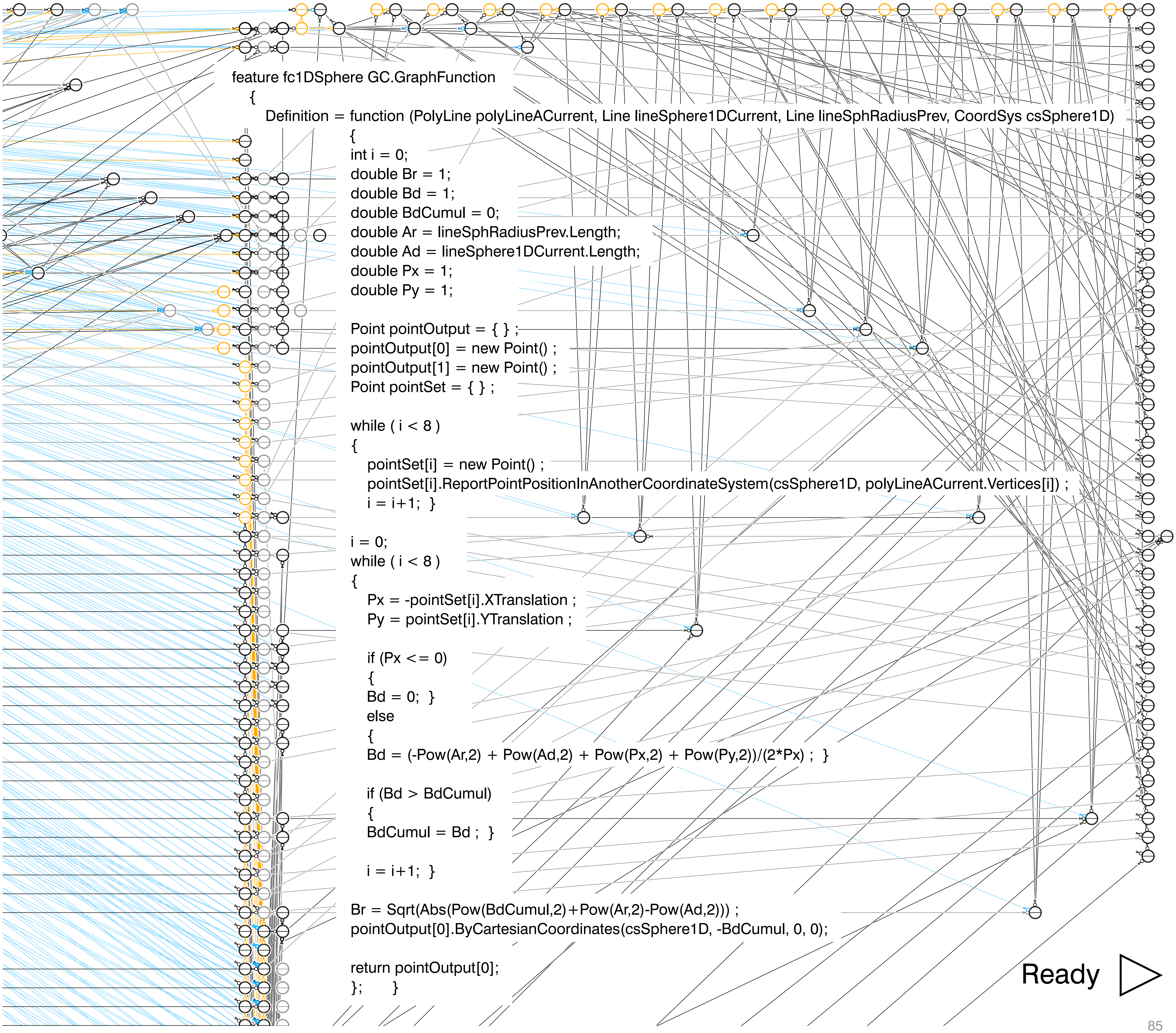
The second part of the script, transactions 58 to 112 on the next page, generates some 40 domes with the custom features. At the end, the model is 'ready': one can shift columns in the mosque and visualize the effects on the domes. However, to add or remove a dome, one must reprogram the script – a lengthy process.

These are images of the script; for an image of the model, see page 94.

Animations of the GC model are available at www.mailoci.com/jf .

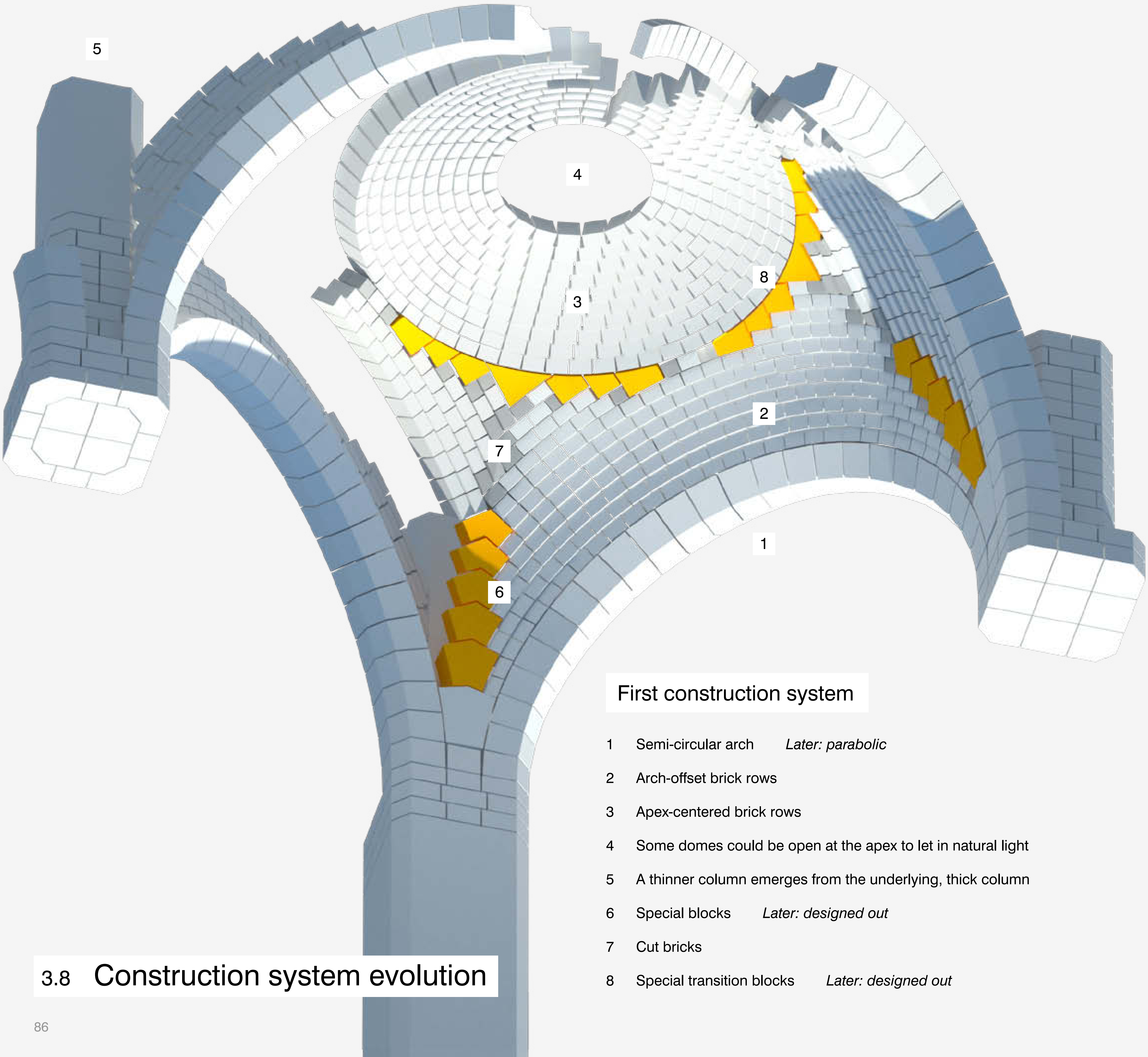

Variables
functions
Domes at mosque level
Start

Domes at roof level



```
feature fc1DSphere GC.GraphFunction
  {
    Definition = function (PolyLine polyLineACurrent, Line lineSphere1DCurrent, Line lineSphRadiusPrev, CoordSys csSphere1D)
              {
              int i = 0;
              double Br = 1;
              double Bd = 1;
              double BdCumul = 0;
              double Ar = lineSphRadiusPrev.Length;
              double Ad = lineSphere1DCurrent.Length;
              double Px = 1;
              double Py = 1;

              Point pointOutput = { } ;
              pointOutput[0] = new Point() ;
              pointOutput[1] = new Point() ;
              Point pointSet = { } ;

              while ( i < 8 )
              {
                 pointSet[i] = new Point() ;
                 pointSet[i].ReportPointPositionInAnotherCoordinateSystem(csSphere1D, polyLineACurrent.Vertices[i]) ;
                 i = i+1;  }

              i = 0;
              while ( i < 8 )
              {
                 Px = -pointSet[i].XTranslation ;
                 Py = pointSet[i].YTranslation ;

                 if (Px <= 0)
                 {
                 Bd = 0;  }
                 else
                 {
                 Bd = (-Pow(Ar,2) + Pow(Ad,2) + Pow(Px,2) + Pow(Py,2))/(2*Px) ;  }

                 if (Bd > BdCumul)
                 {
                 BdCumul = Bd ;  }

                 i = i+1;  }

              Br = Sqrt(Abs(Pow(BdCumul,2)+Pow(Ar,2)-Pow(Ad,2))) ;
              pointOutput[0].ByCartesianCoordinates(csSphere1D, -BdCumul, 0, 0);

              return pointOutput[0];
              };      }
```

Ready ▷

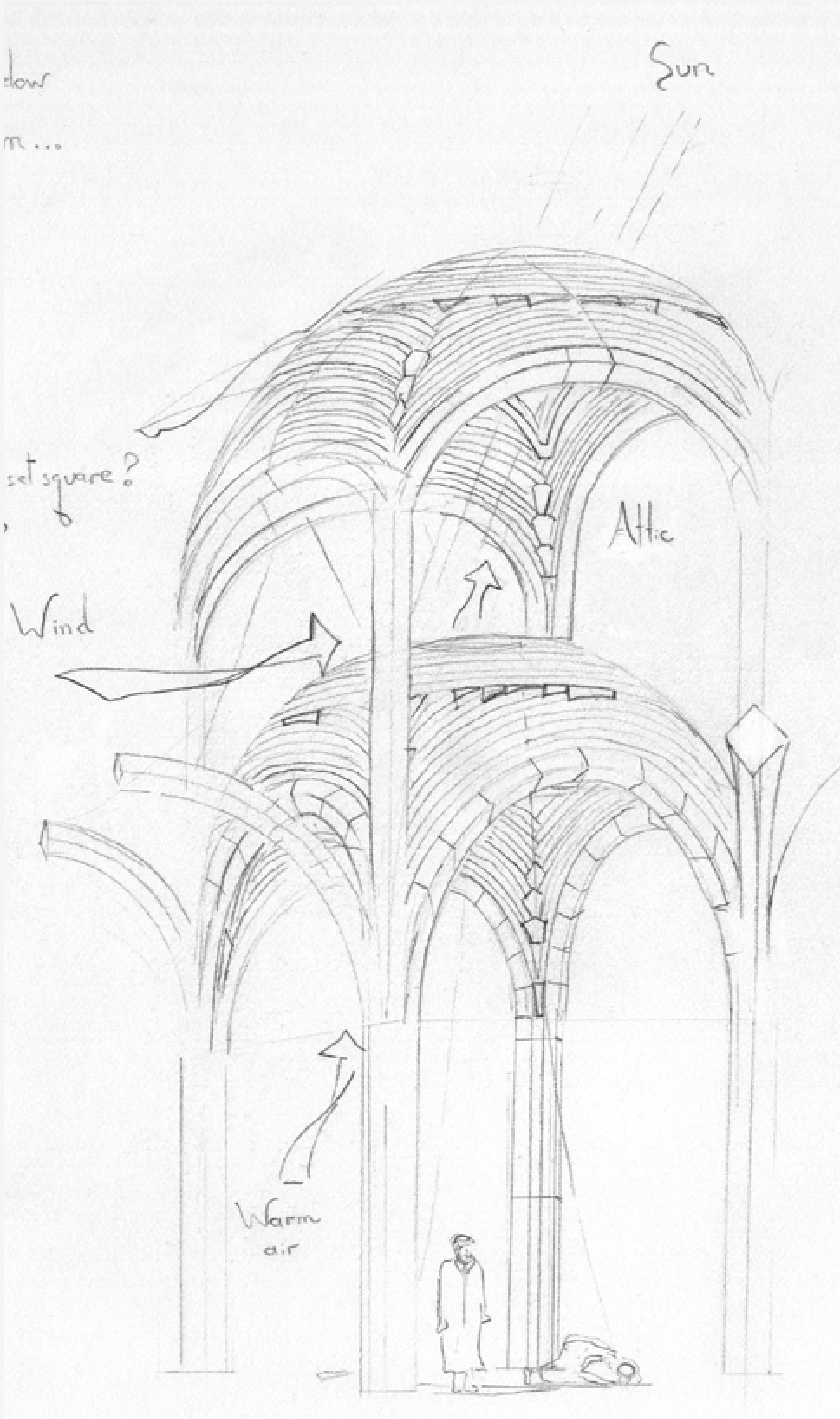


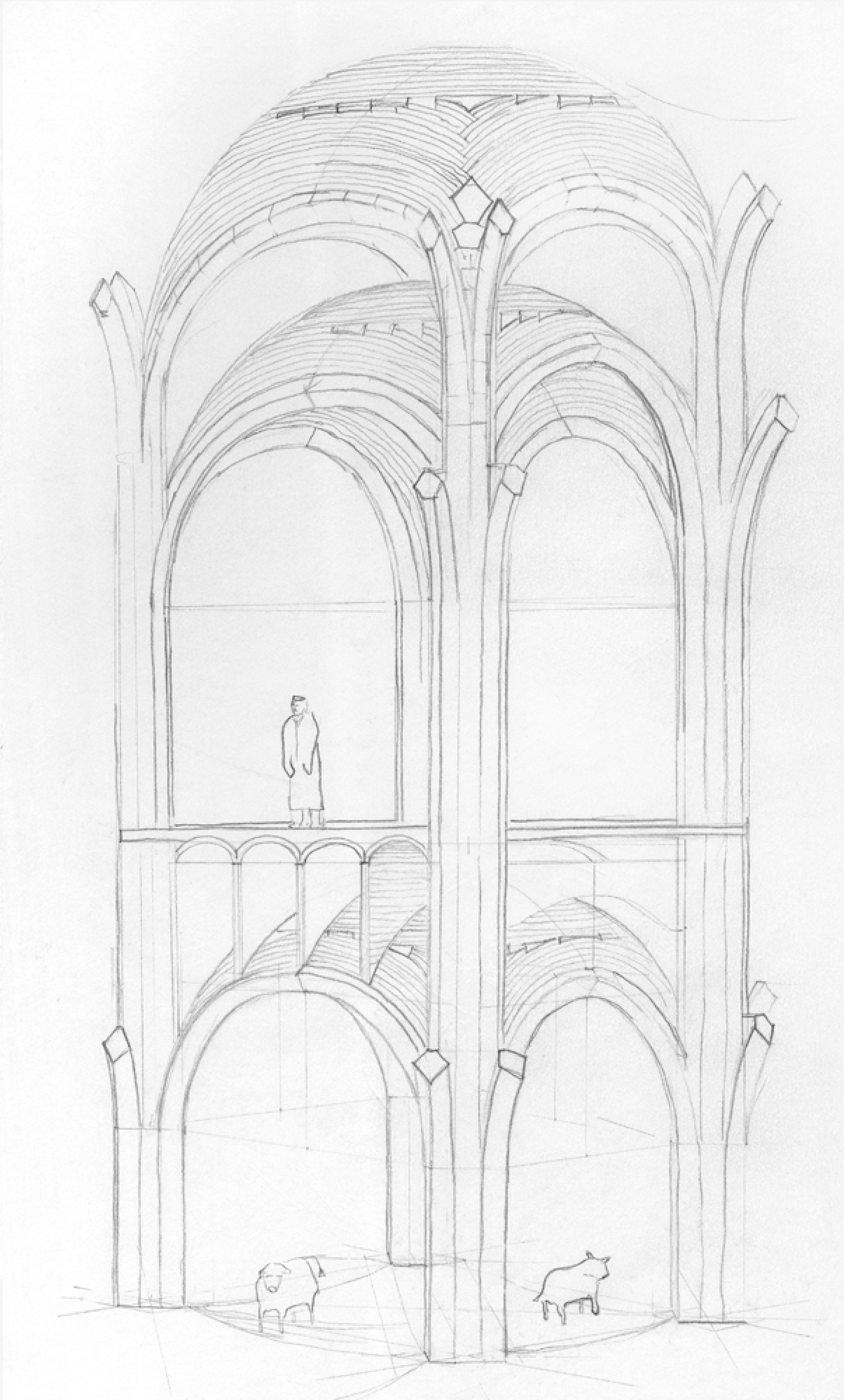
First construction system

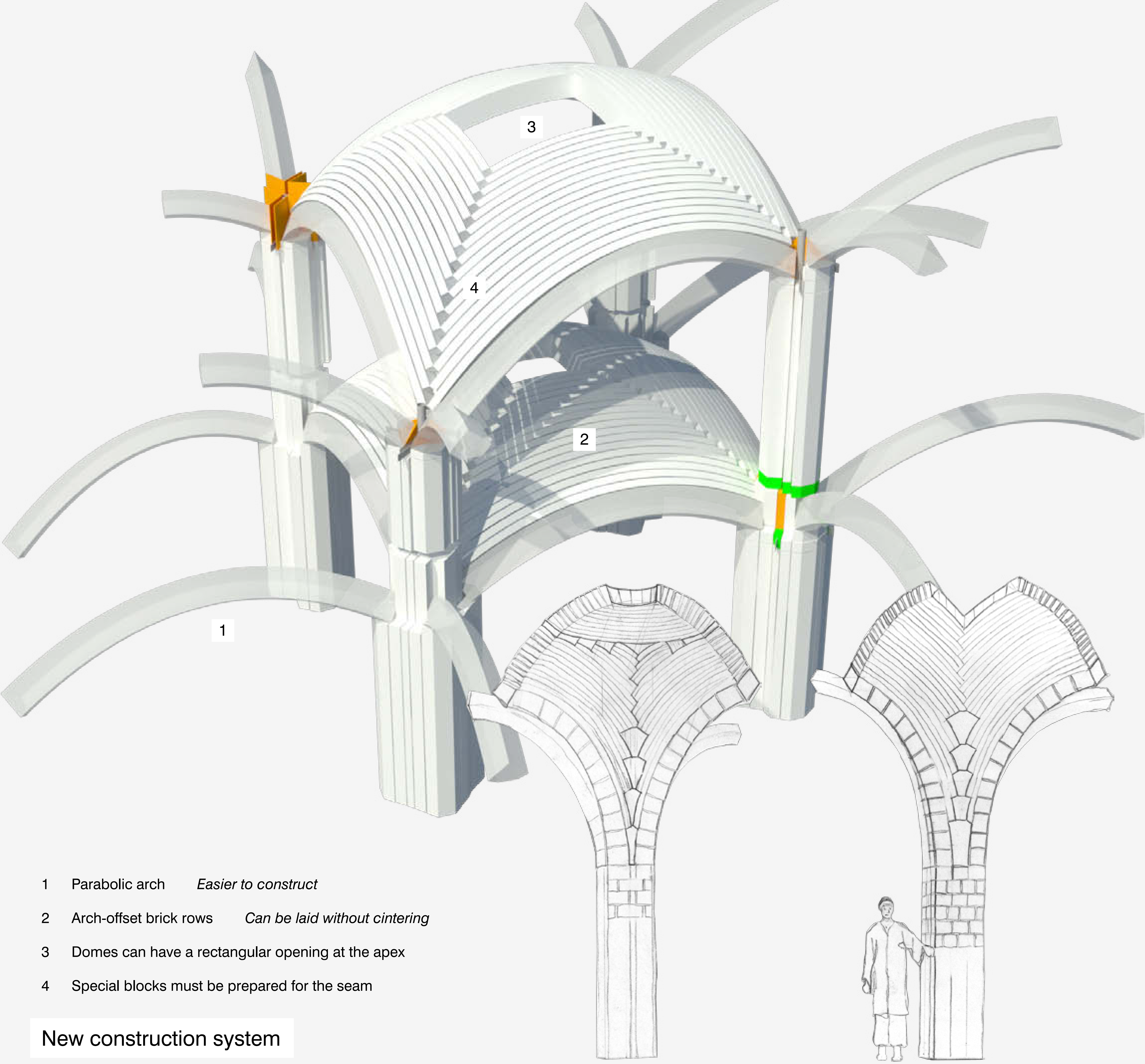
1	Semi-circular arch	*Later: parabolic*
2	Arch-offset brick rows	
3	Apex-centered brick rows	
4	Some domes could be open at the apex to let in natural light	
5	A thinner column emerges from the underlying, thick column	
6	Special blocks	*Later: designed out*
7	Cut bricks	
8	Special transition blocks	*Later: designed out*

3.8 Construction system evolution

These sketches illustrate one bay of the shelter: three domes superposed and resting on columns of decreasing breadth.







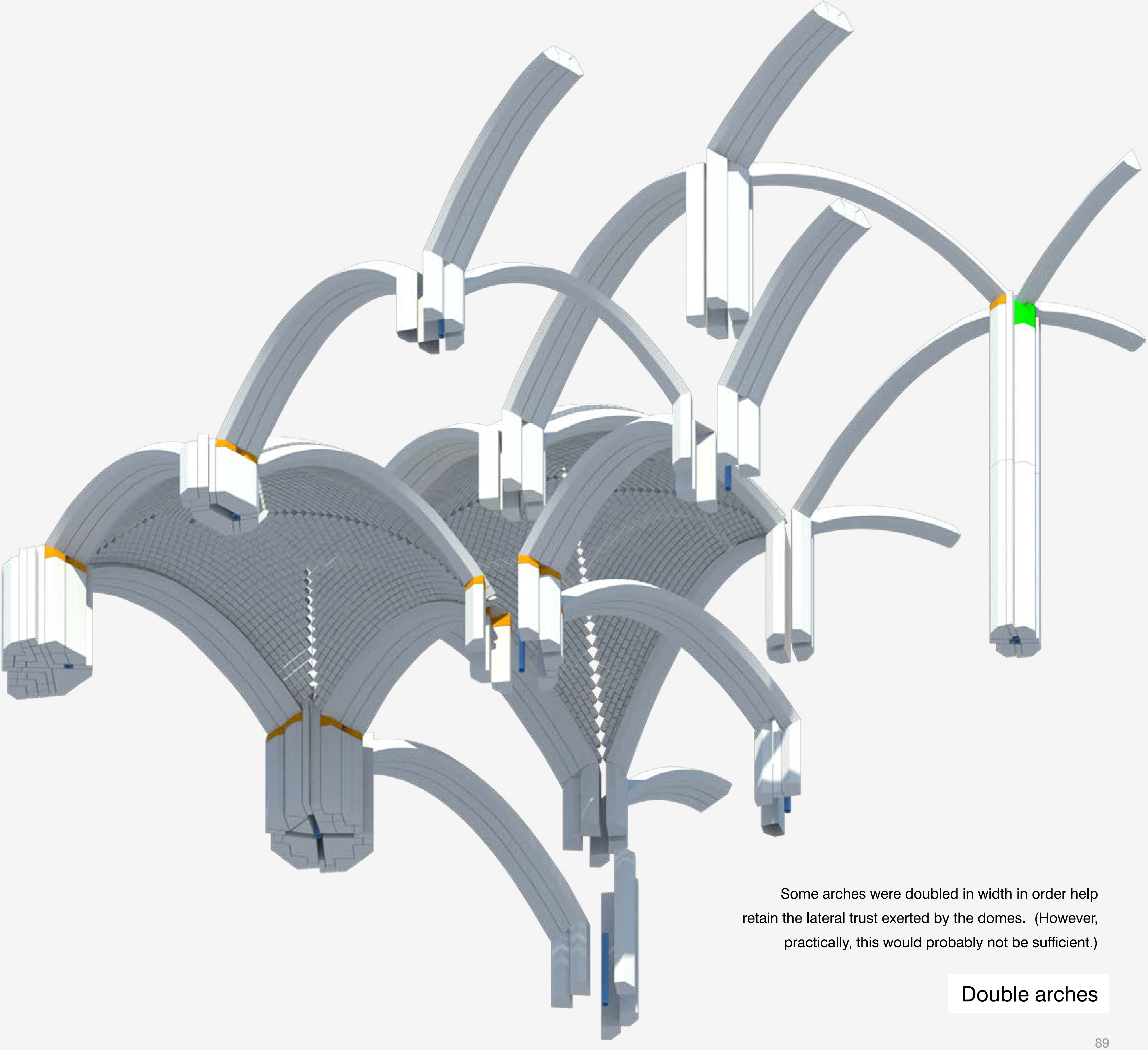
1 Parabolic arch *Easier to construct*

2 Arch-offset brick rows *Can be laid without cintering*

3 Domes can have a rectangular opening at the apex

4 Special blocks must be prepared for the seam

New construction system



Some arches were doubled in width in order help retain the lateral trust exerted by the domes. (However, practically, this would probably not be sufficient.)

Double arches

3.9 A catalogue of blocks

Calepinage

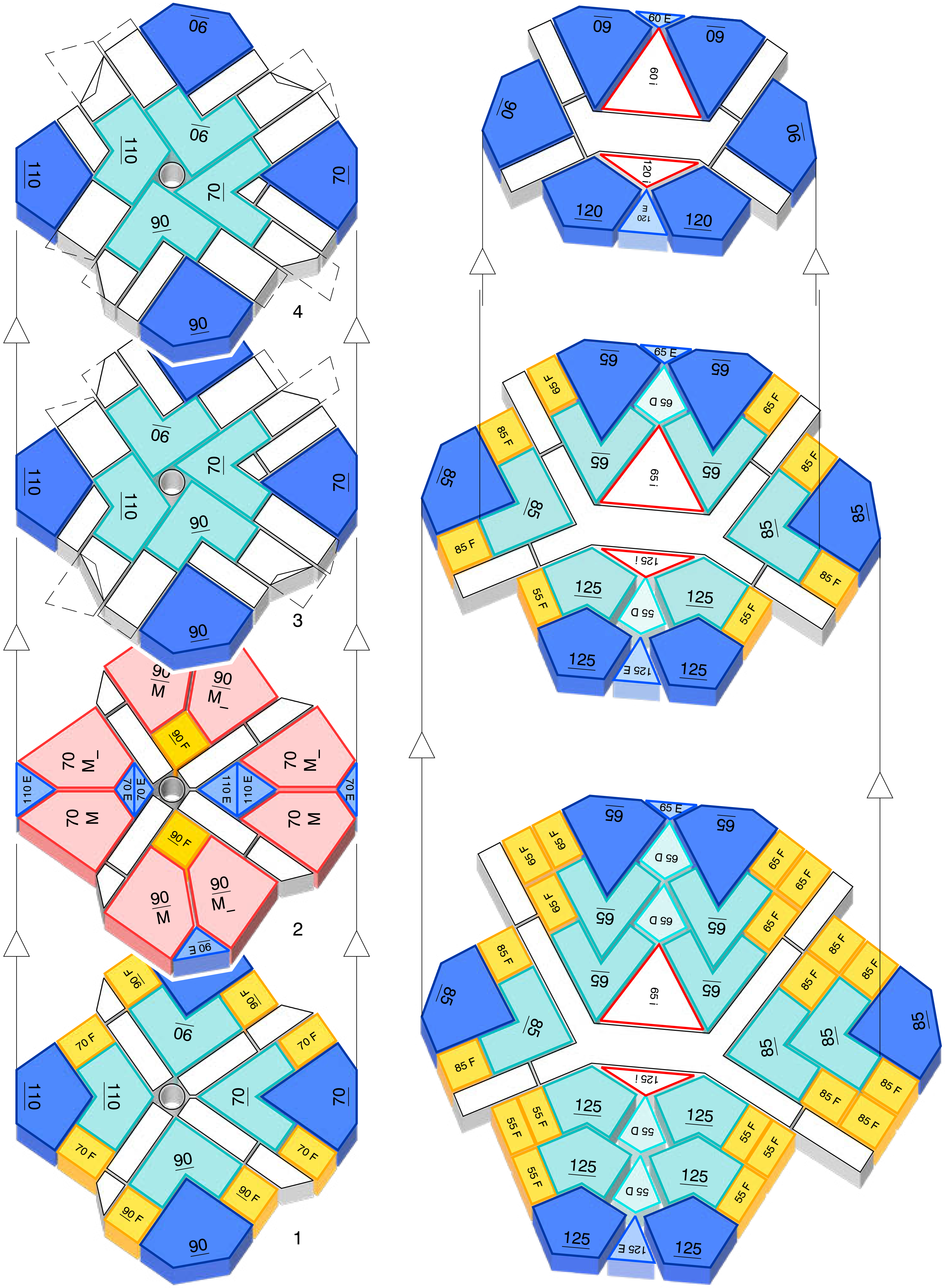
When making a structure out of blocks, one must alternate the patterns so as to cross the joints which would otherwise run vertically. In brick works, the various patterns are called bonds; in French, drawing the bond is called *calepinage*.

The idea here was to develop a system of blocks which could not only create columns of various plan-angles (1) but also their *calepinage* (2 3 4). Using the same moulds, alternative courses can be made to break the joints, regardless of the column's plan-angles (though it is necessary to cut some blocks).

Column growth

From the foundations to the roof, as the shafts become arches, the column shrinks. Because the plan-angles are related to the arches' V-angles (see p 70) and there are three storeys of domes, the angles of the shafts can change mid-way through the column (e.g. from 125° to 120°). This complicates the imbrication (a 125° shaft can't be imbricated in a 120° shaft) and requires transitions (see p 100).

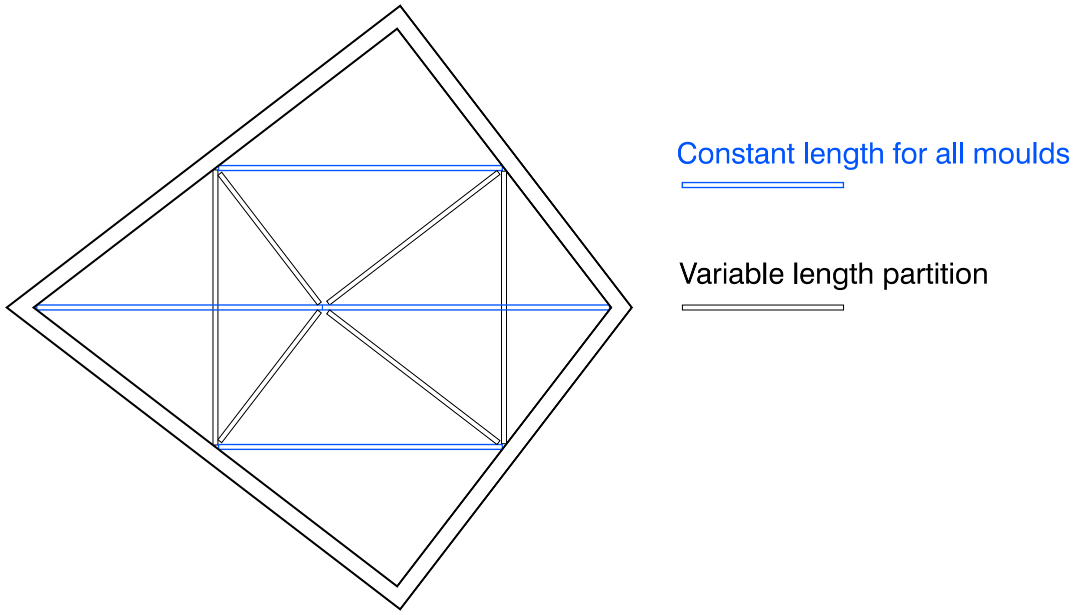
Moreover, the thickness of the column spaces the arches apart, when they should land on the same capital. This compromises their relation with the dome. For these reasons, it would have been simpler to go with concrete columns supporting a single storey of domes. Unfortunately, this only became clear during the last semester.

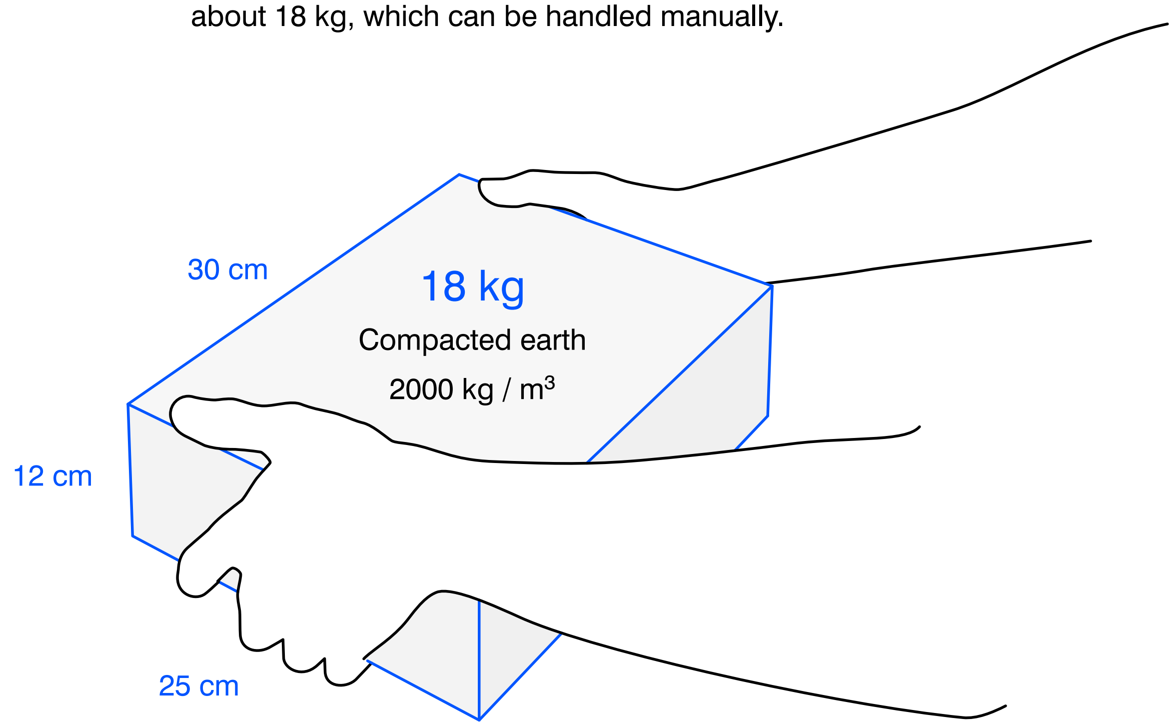


Designing moulds for compressed earth blocks

Earth block presses can be designed to work with interchangeable moulds. Ten moulds were designed to yield nineteen block angles (from 45° to 90°, in 5° increments) and a multitude of block types. The ten outer lozenges of the moulds share a constant length of diagonal: a property selected to make the blocks inter-operable.

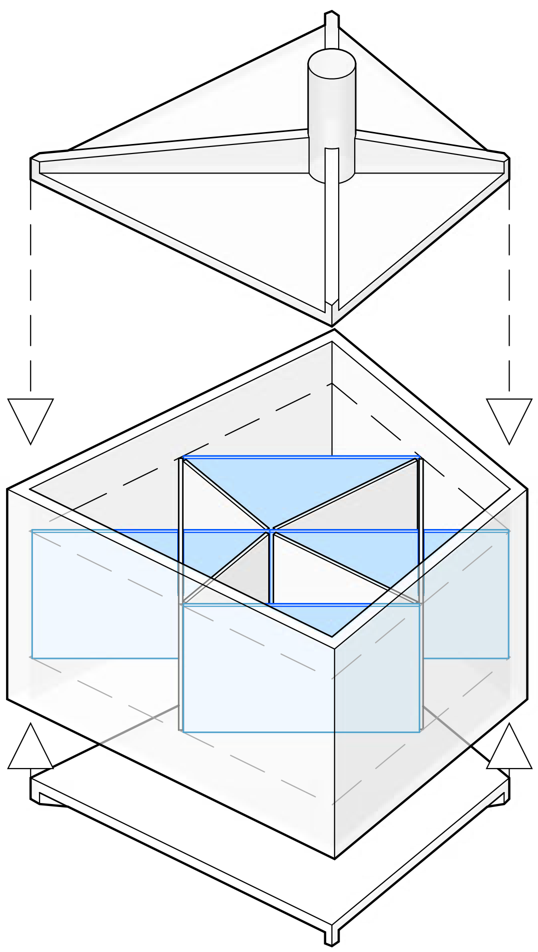
The basic size of all moulds was set to yield blocks of about 18 kg, which can be handled manually.

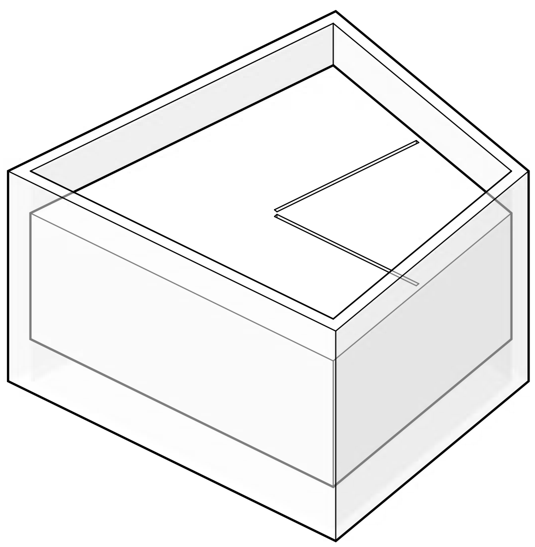


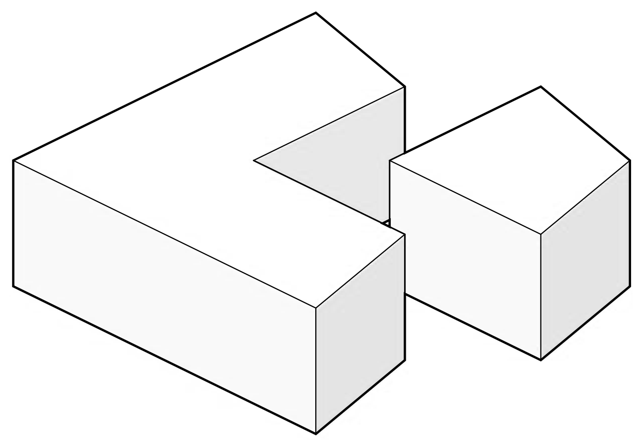


Removable partitions

The moulds were designed with removable partitions, which are used to create multiple block types (see next page).



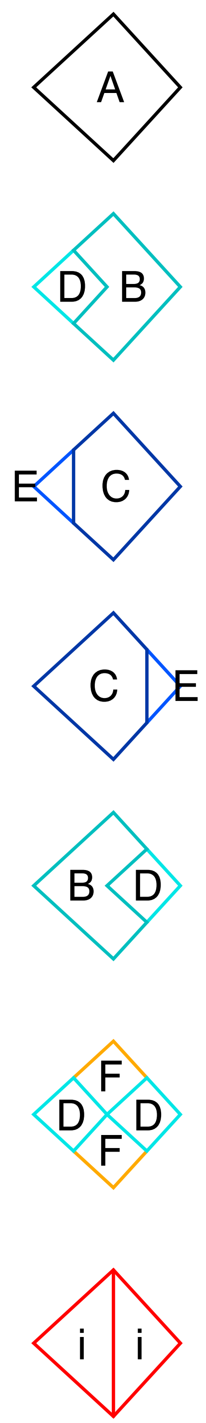


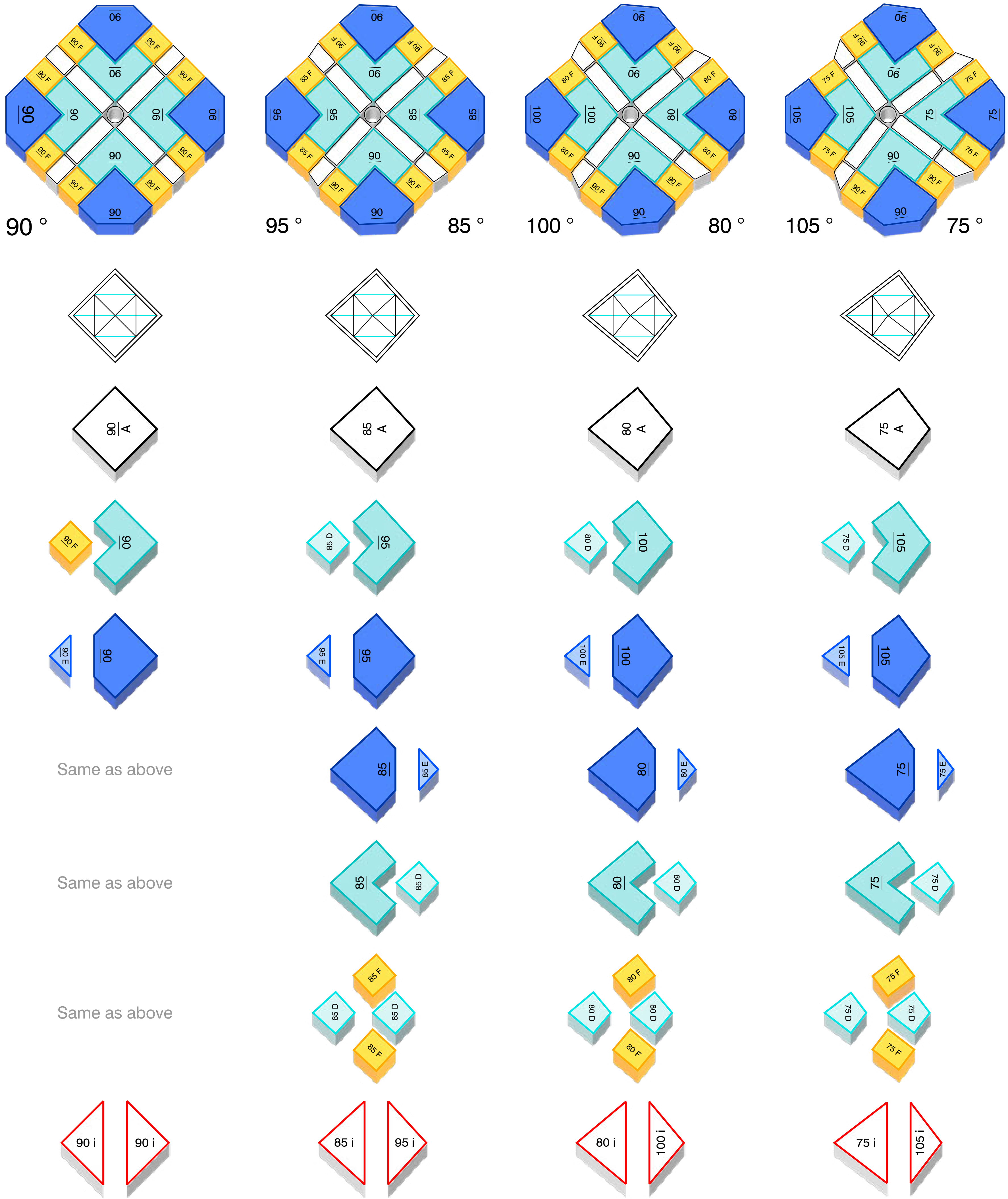


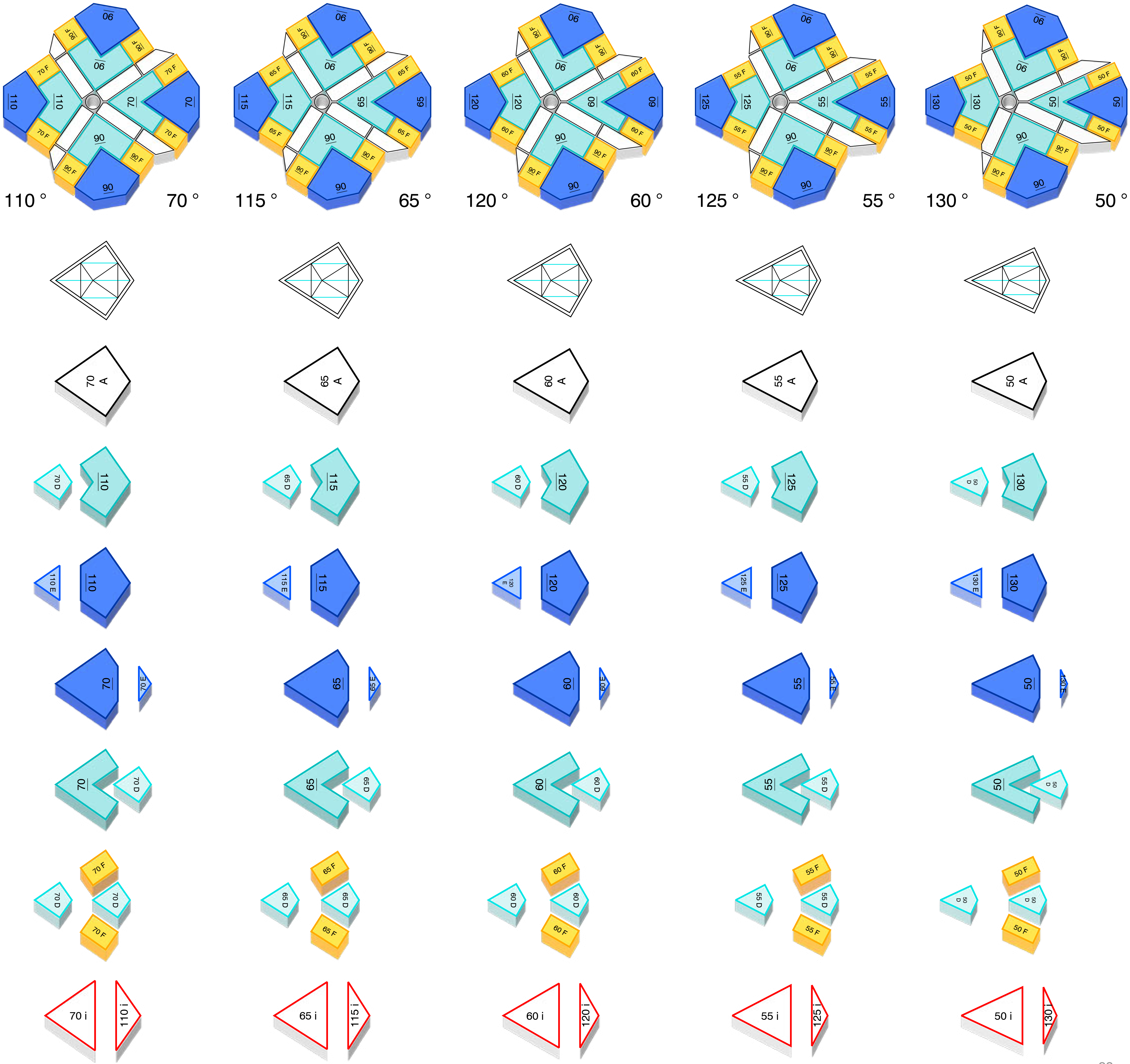
Nine moulds from 90° to 50° and the blocks they can make

Right: sample columns

Right: moulds
Below: block types



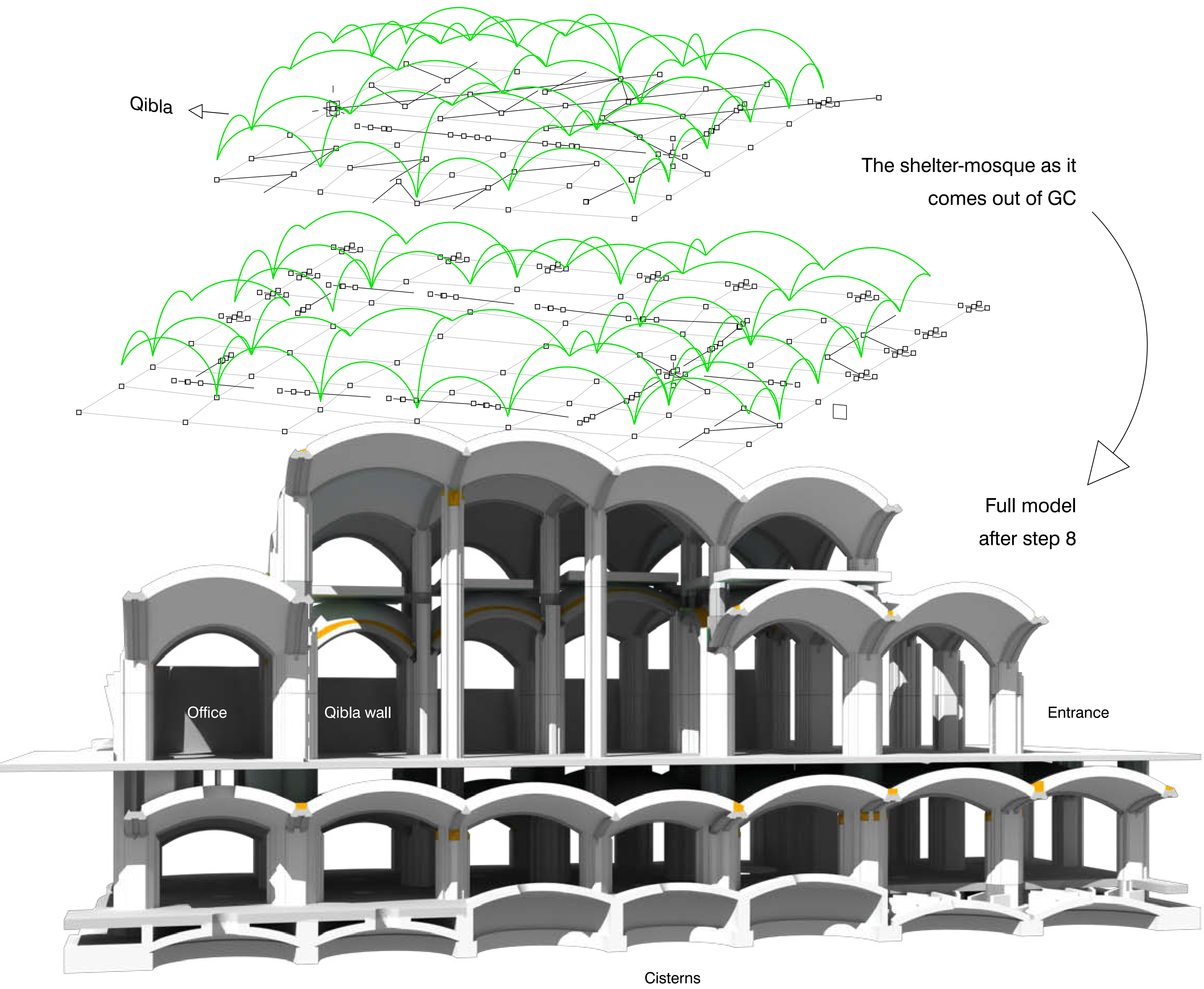



110 °
70 °
115 °
65 °
120 °
60 °
125 °
55 °
130 °
50 °
70 A
65 A
60 A
55 A
50 A
70 D
65 D
60 D
55 D
110 E
115 E
125 E
130 E
70 E
65 E
60 E
55 E
70 F
65 F
60 F
55 F
50 F
90 F
70 i
110 i
65 i
115 i
60 i
120 i
55 i
125 i
50 i
130 i

Modelling all the arches and columns

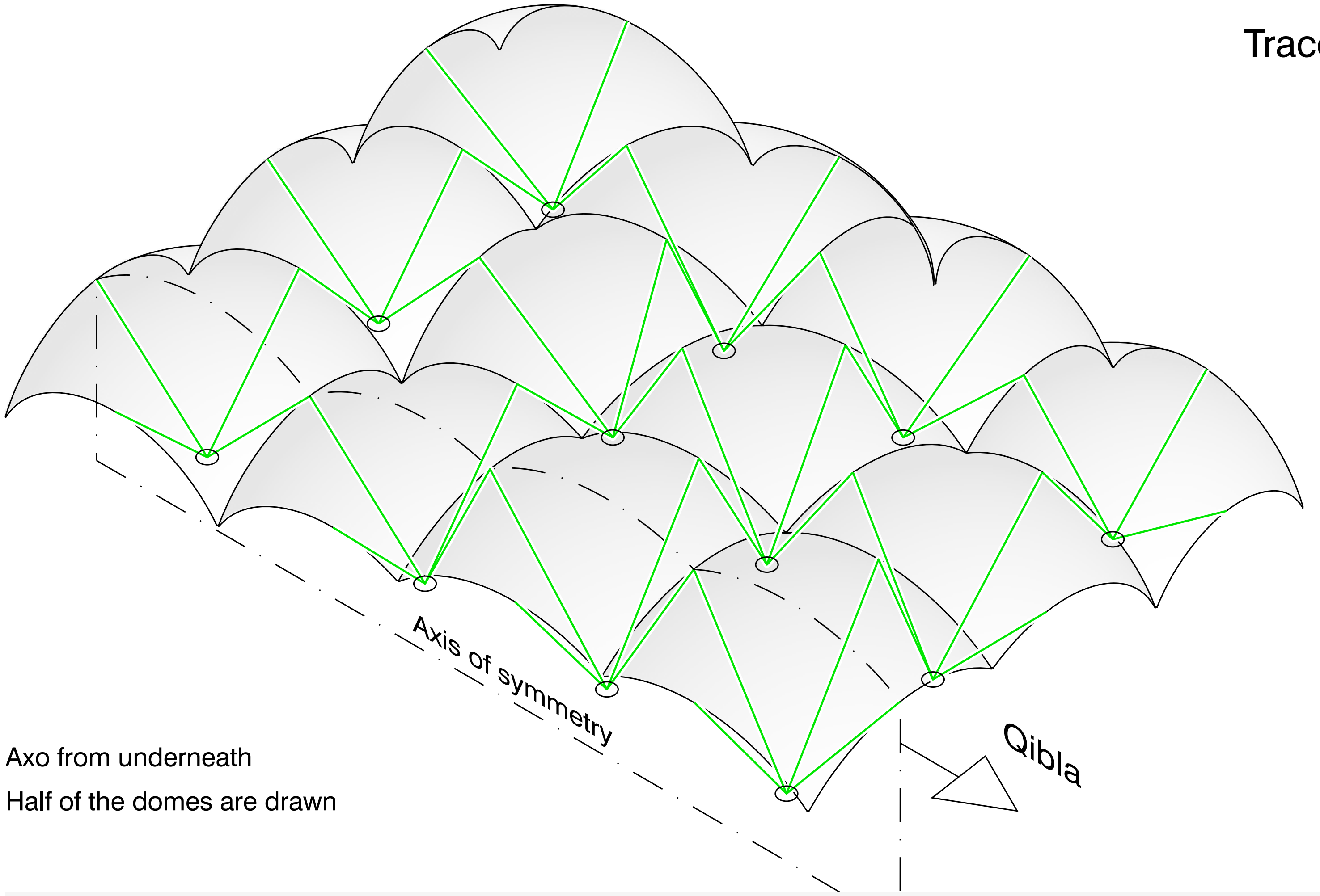
GenerativeComponents model

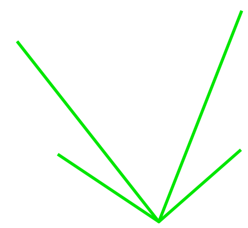
Step 1



Trace the arches’ angle lines Step 2

Step 2 consists in drawing the green lines, from the apex of the arches to the centers of the domes.



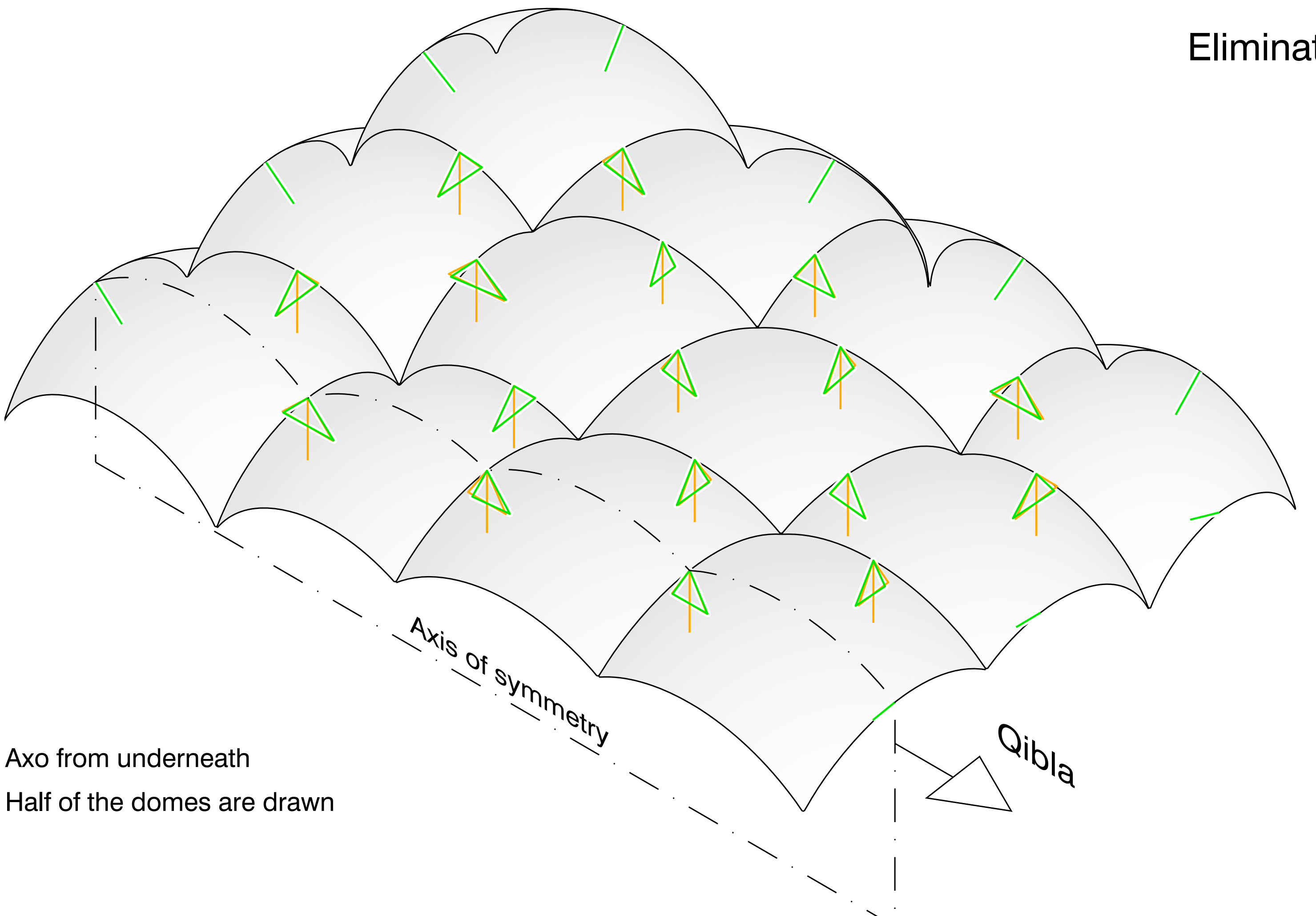


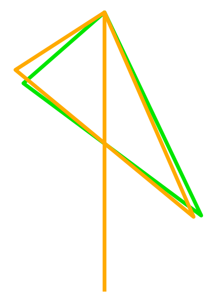
Axo from underneath
Half of the domes are drawn

Roof domes

Eliminate the arches’ up-angles Step 3

The green triangle, which has an up-angle, is rotated to yield the orange triangle, which has none.





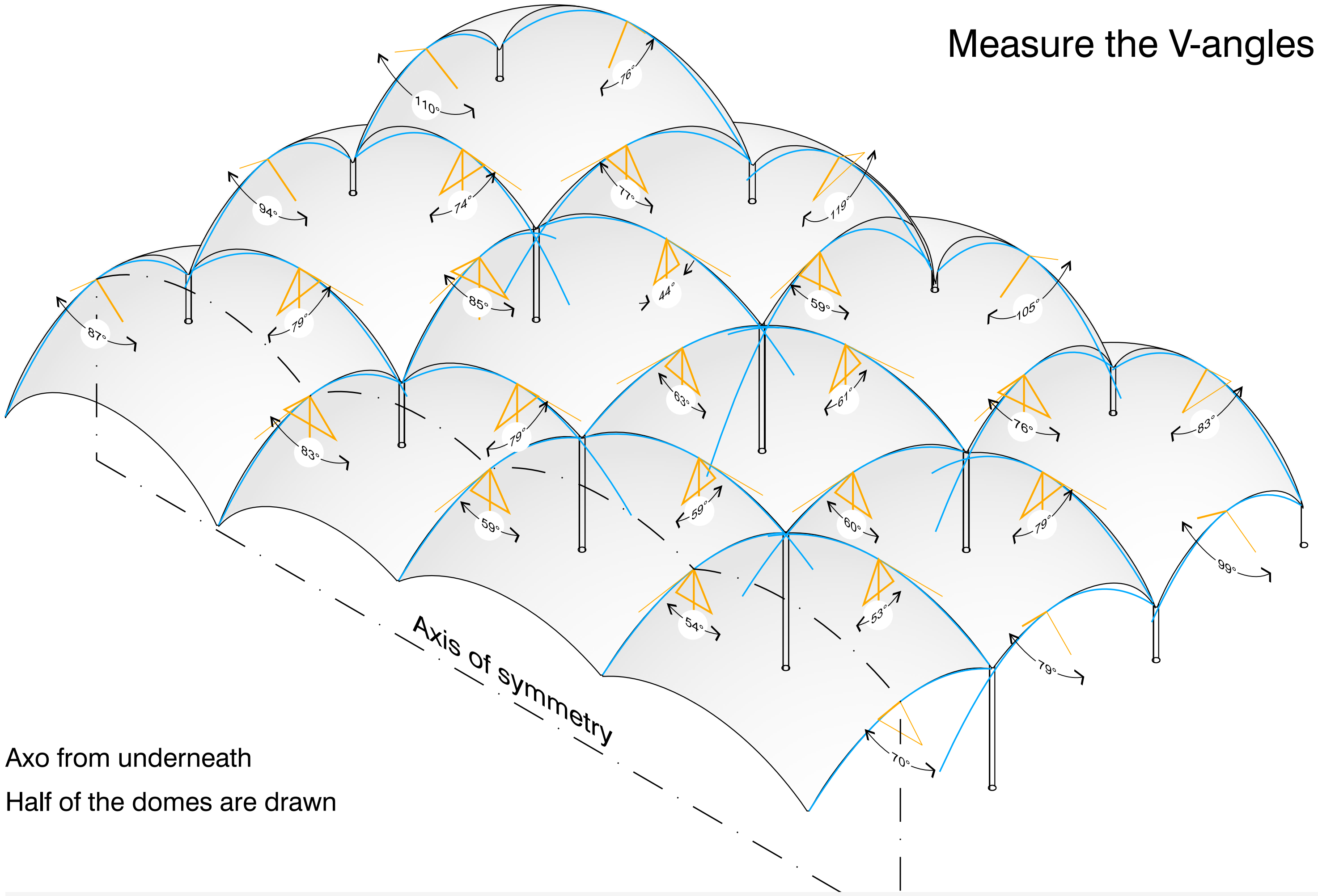
Axo from underneath
Half of the domes are drawn

Roof domes

Measure the V-angles and trace the parabolas

Step 4

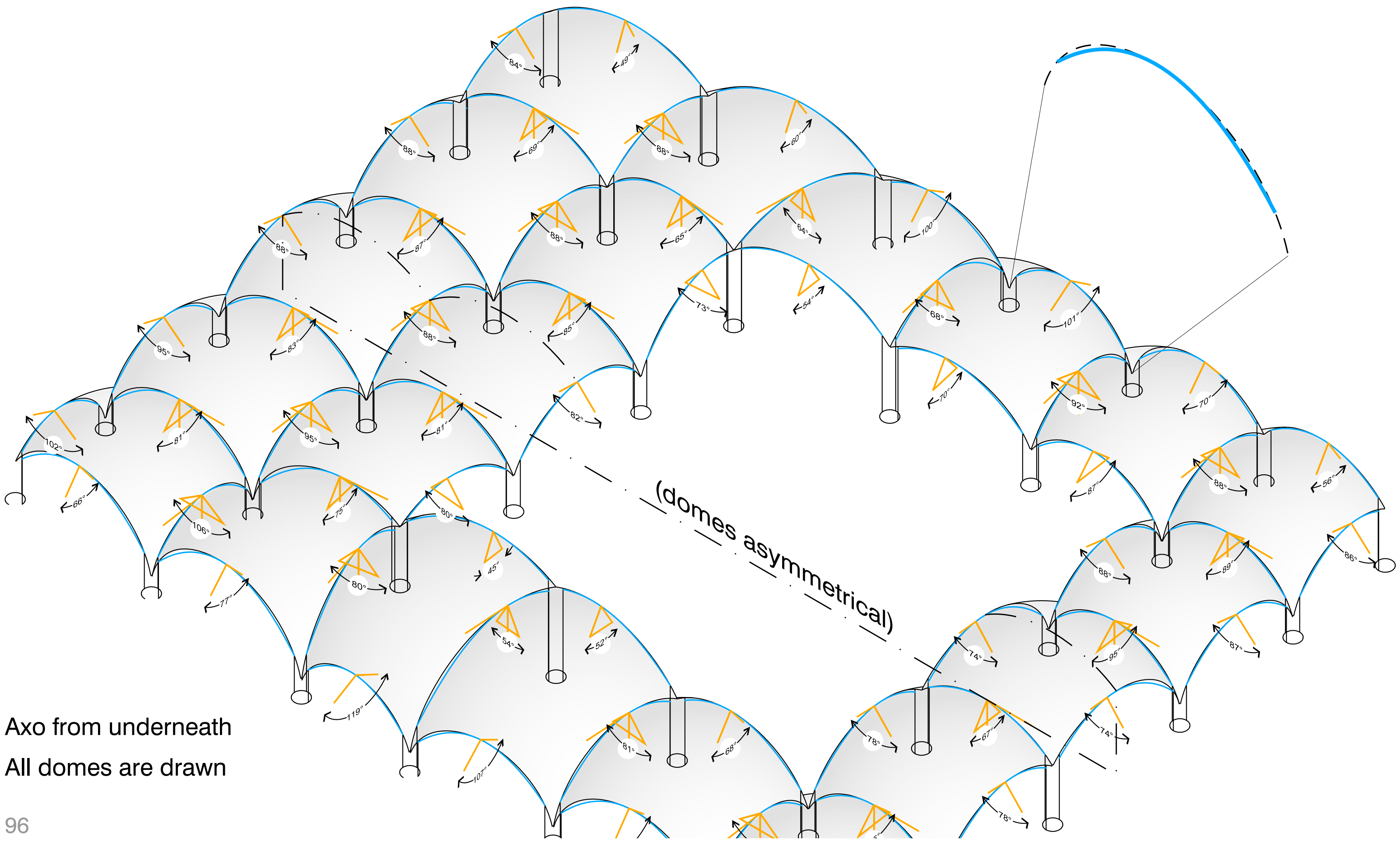
Each parabola is traced to pass through the apex of the arc, and one of its lower points.



Axo from underneath
Half of the domes are drawn

Roof domes

Step 4



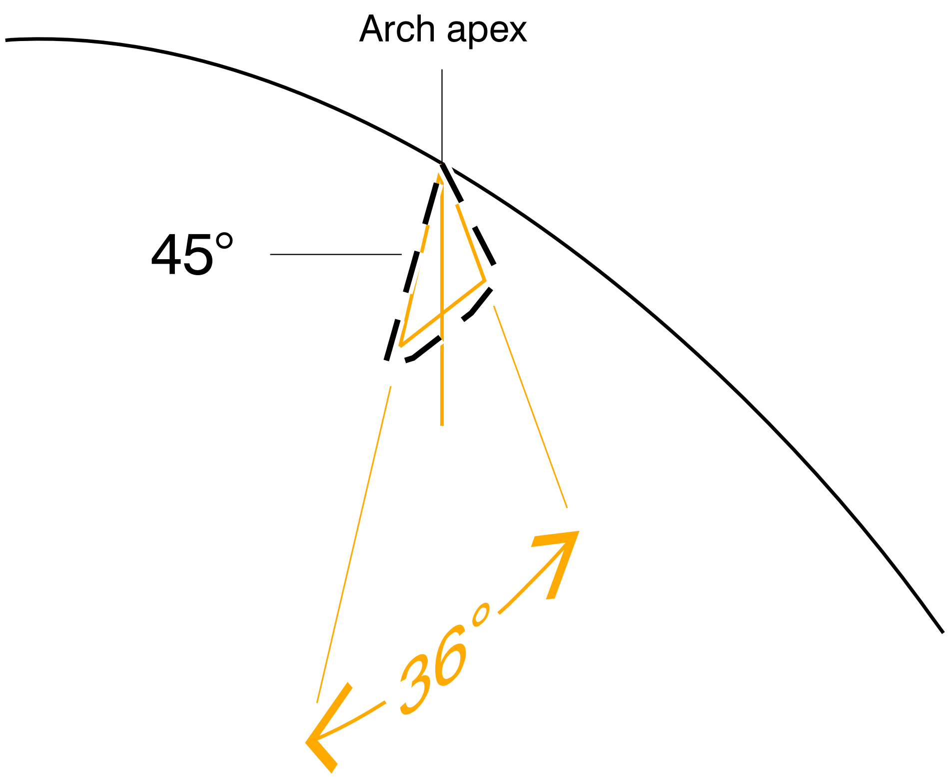
Axo from underneath
All domes are drawn

Ground level domes

Arch V-angle replacement sequence

Step 5

Each arch is made of blocks of type C taken from the catalogue (see p 92). The V-angle must be rounded to the nearest 5° angle, and at least 45°, because the catalogue only covers 5° increments between 45° and 90°.

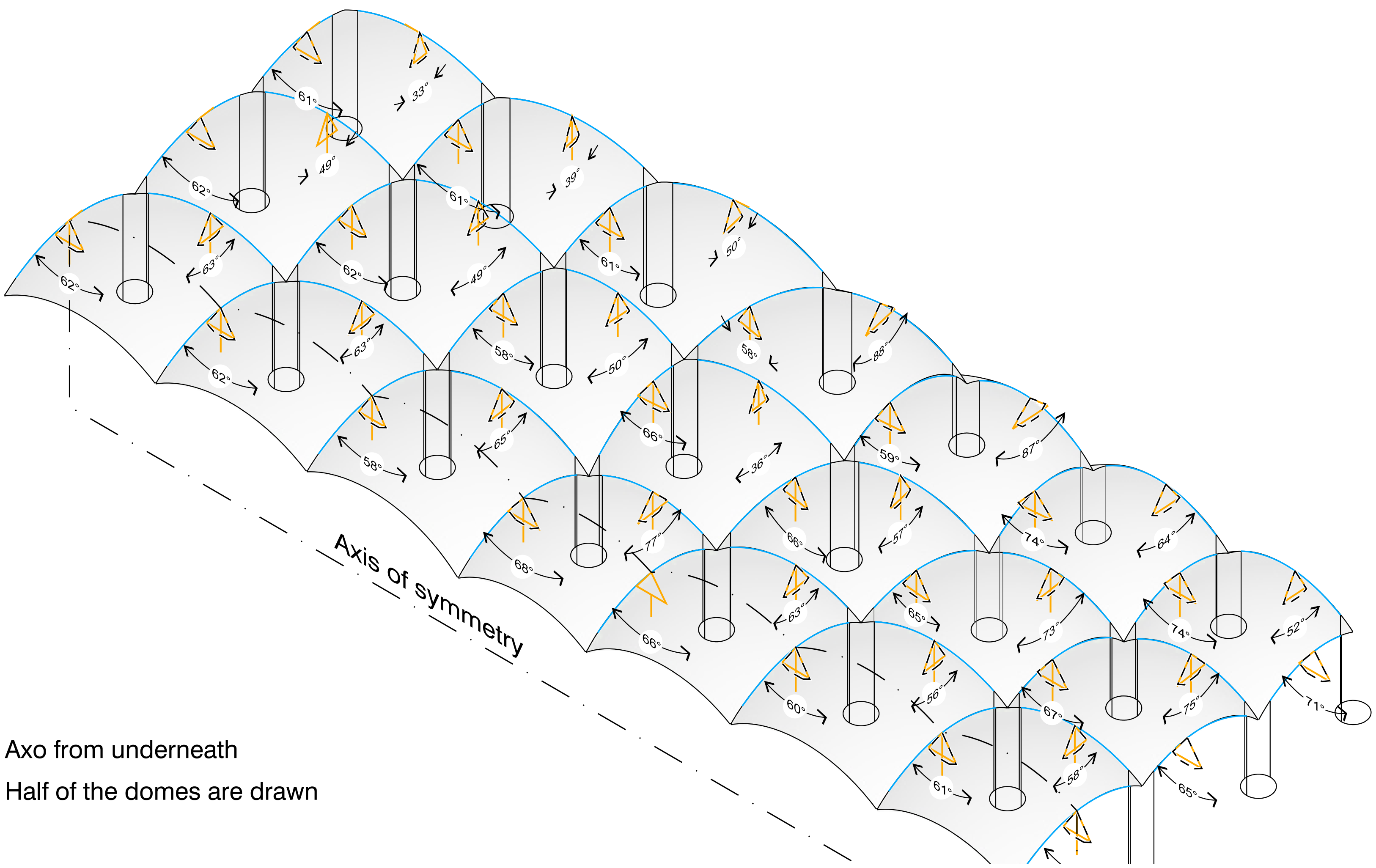


1 Angle read from the intersection of spheres;

2 Angle rounded to nearest available 5° block;

3 Block reoriented in 3d.

Step 4

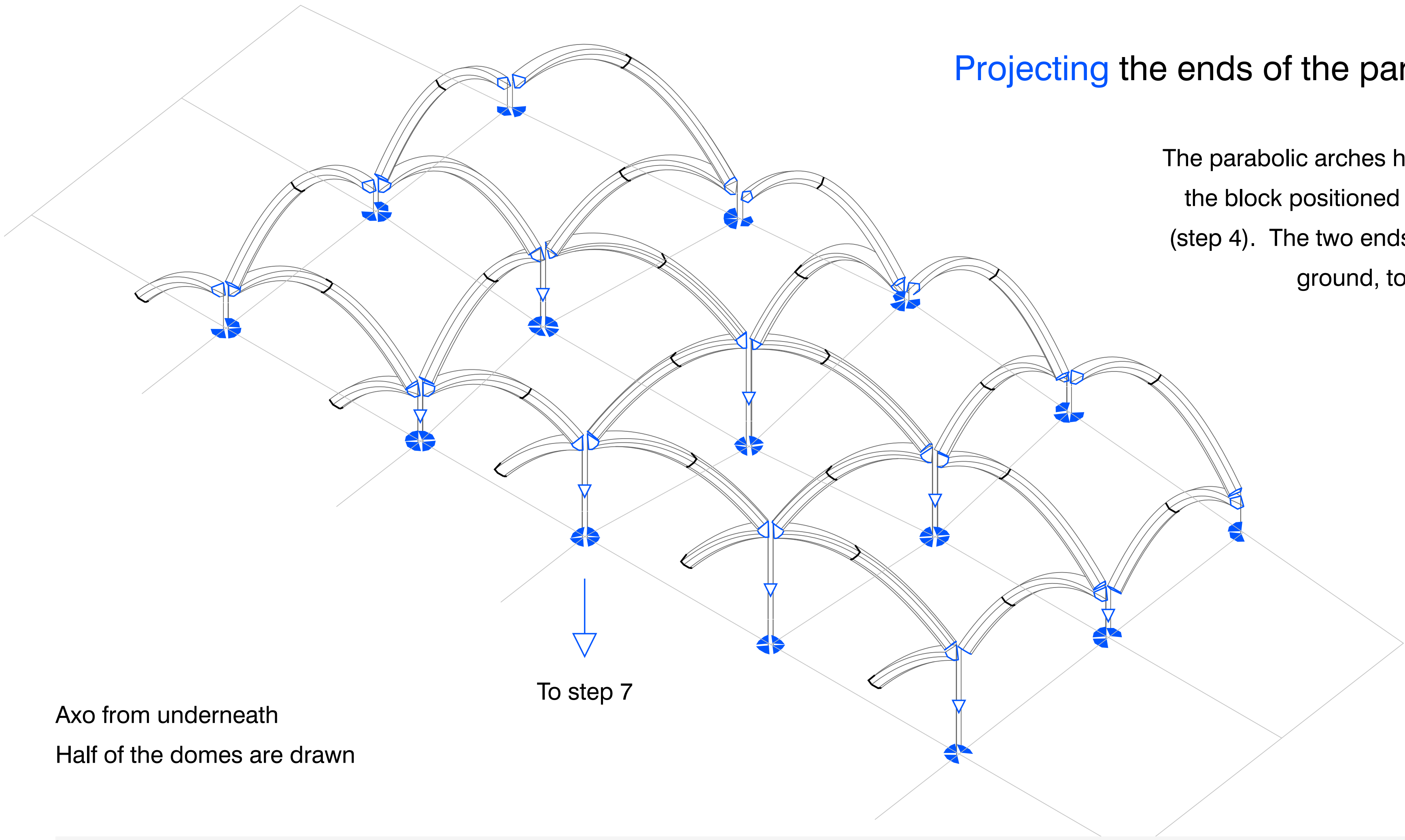


Axo from underneath
Half of the domes are drawn

Crypt level domes

Projecting the ends of the parabolic arches — Step 6

The parabolic arches have been modeled in 3d, by 'sweeping' the block positioned at the apex (step 5) along the parabola (step 4). The two ends of each arch are then projected to the ground, to inform on the required column blocks.



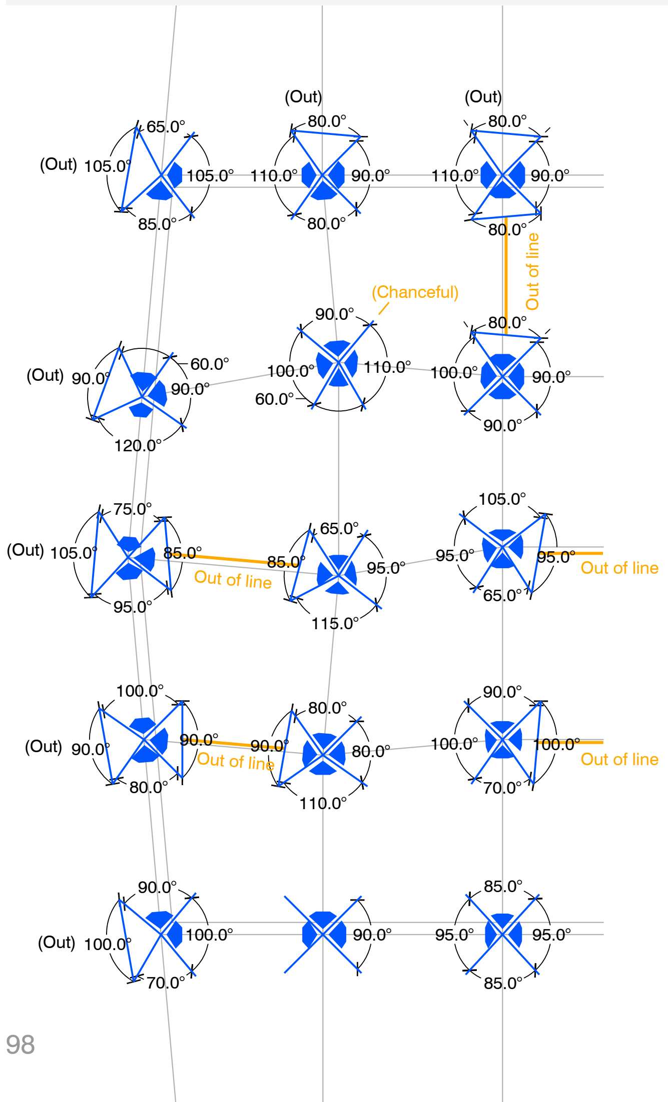
Axo from underneath

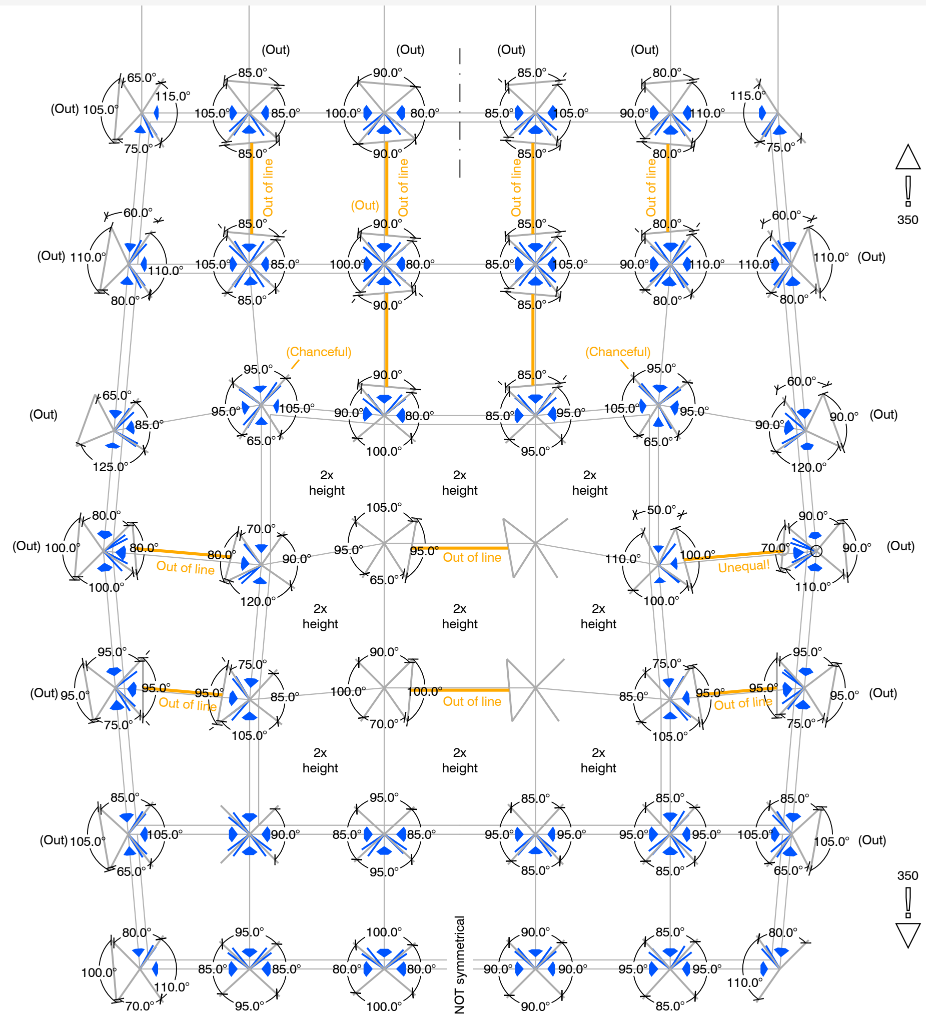
Half of the domes are drawn

Roof domes

Step 7

Measuring the column angles



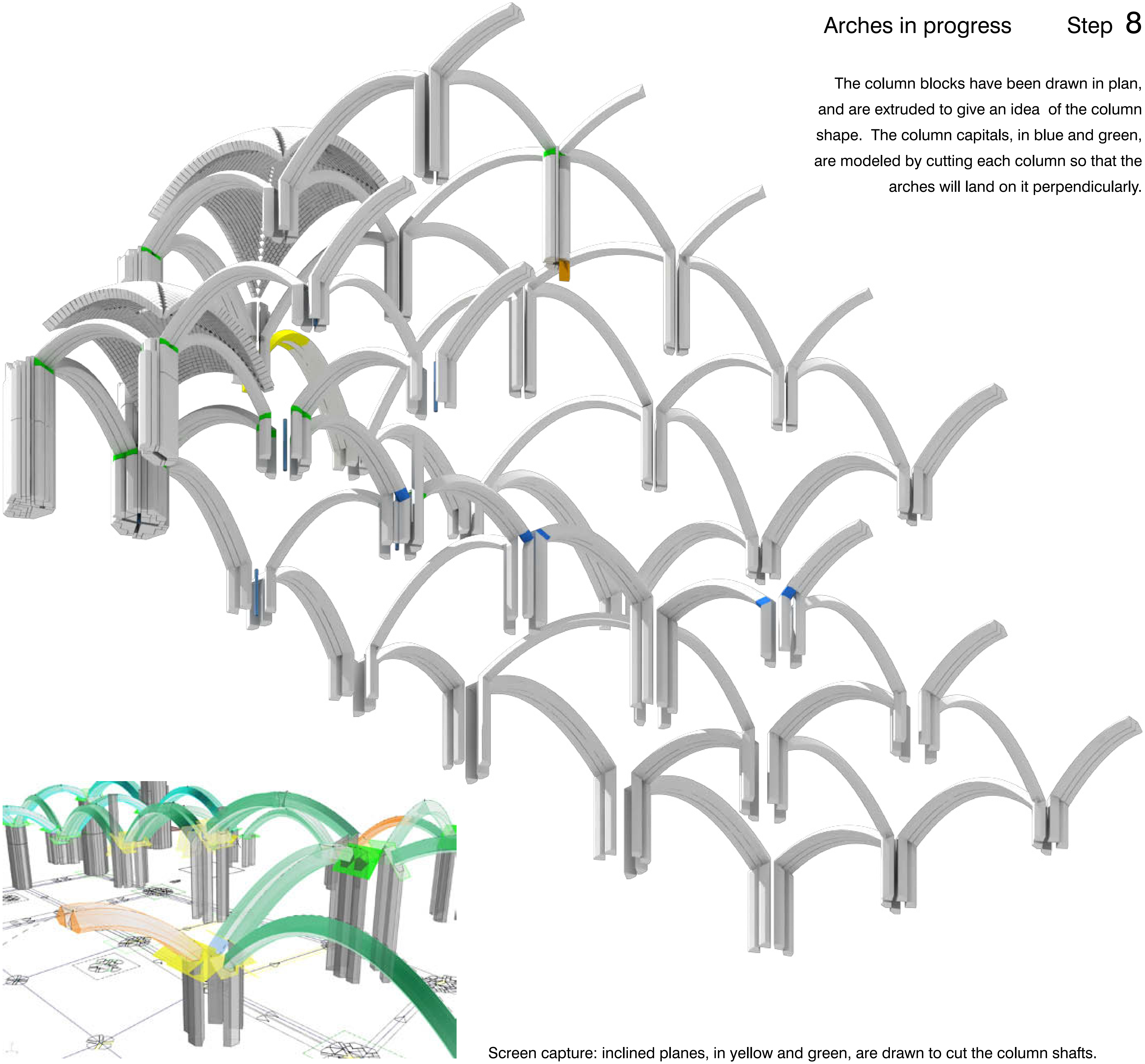


The angles formed by the projected blocks are measured to inform on the required column blocks.

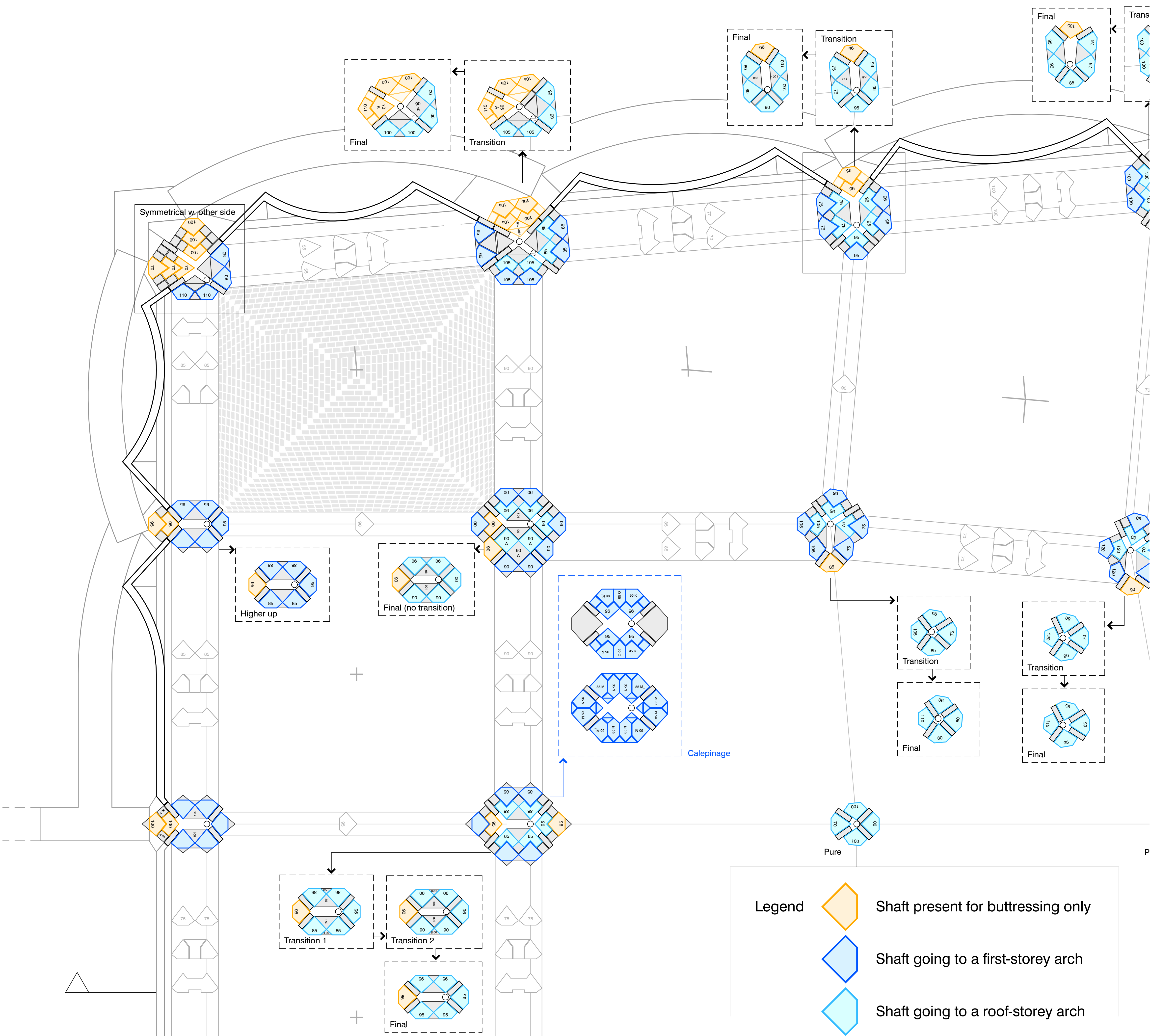
The column are then drawn for each storey (see pages __).

Arches in progress Step 8

The column blocks have been drawn in plan, and are extruded to give an idea of the column shape. The column capitals, in blue and green, are modeled by cutting each column so that the arches will land on it perpendicularly.

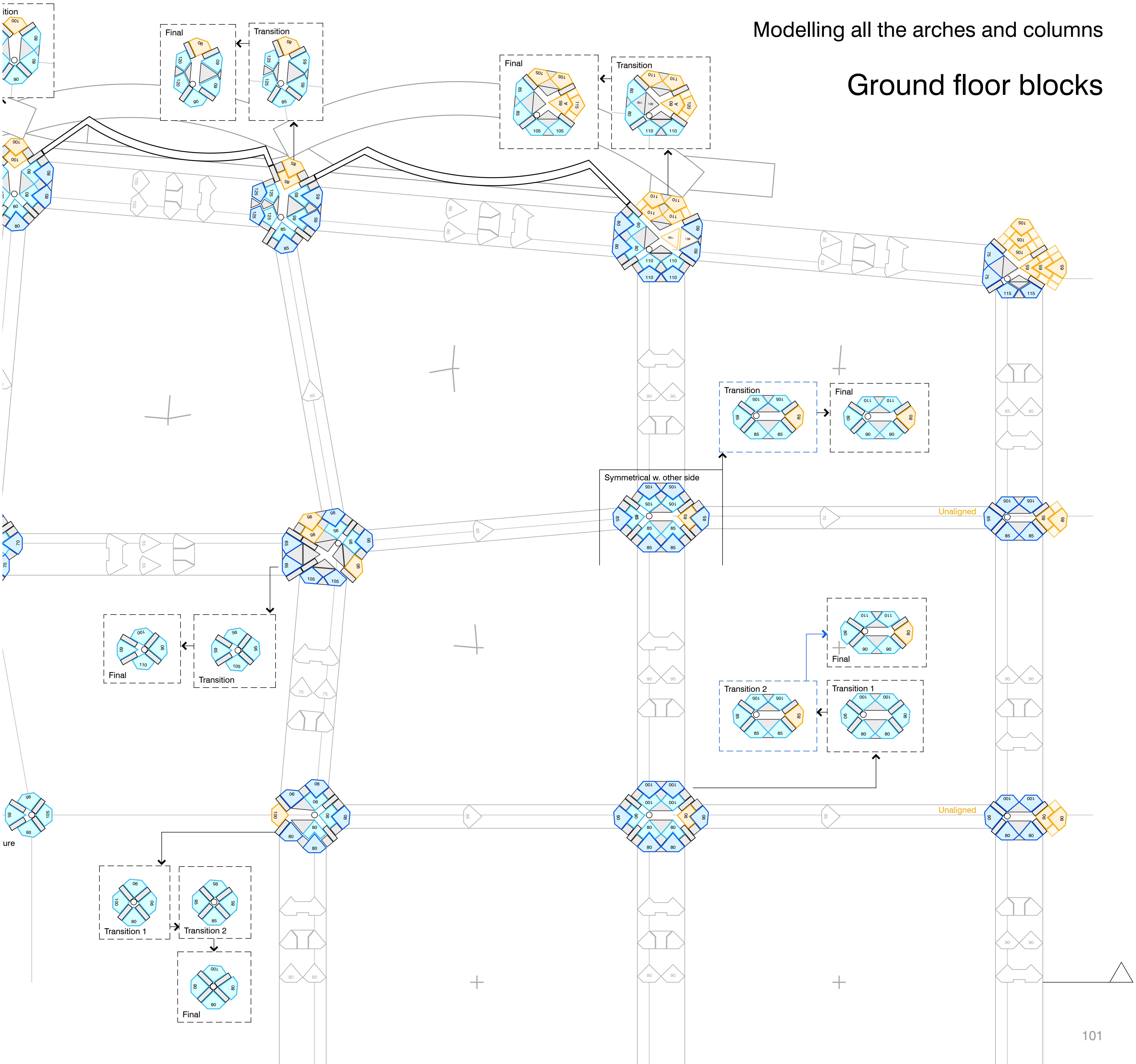


Screen capture: inclined planes, in yellow and green, are drawn to cut the column shafts.

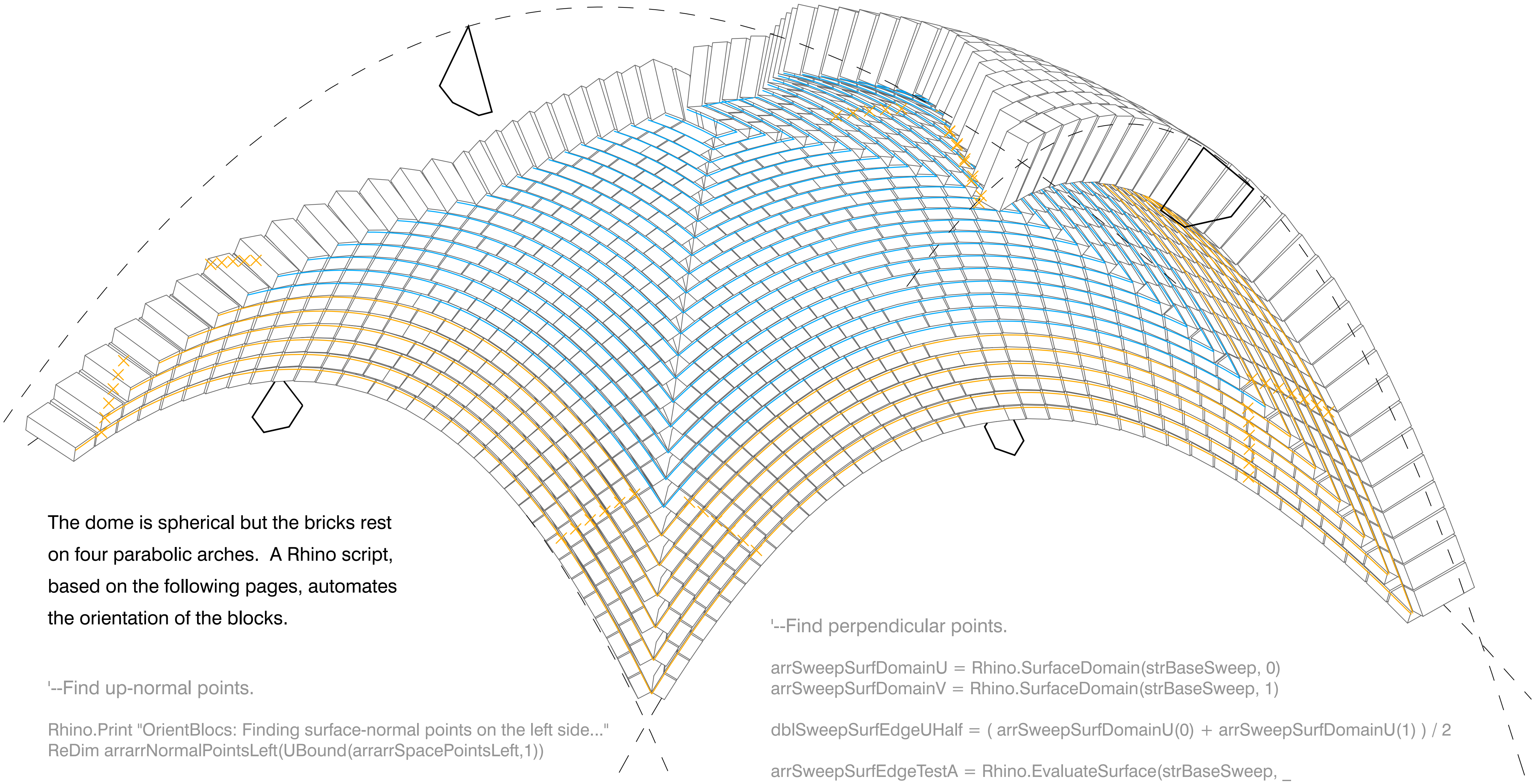

Final
Transition
Final
Transition
Final
Trans
Symmetrical w. other side
Higher up
Final (no transition)
Calepinage
Transition
Final
Transition
Final
Pure
Transition 1
Transition 2
Final
Legend
Shaft present for buttressing only
Shaft going to a first-storey arch
Shaft going to a roof-storey arch

Modelling all the arches and columns

Ground floor blocks



3.11 Modelling all the bricks in a dome



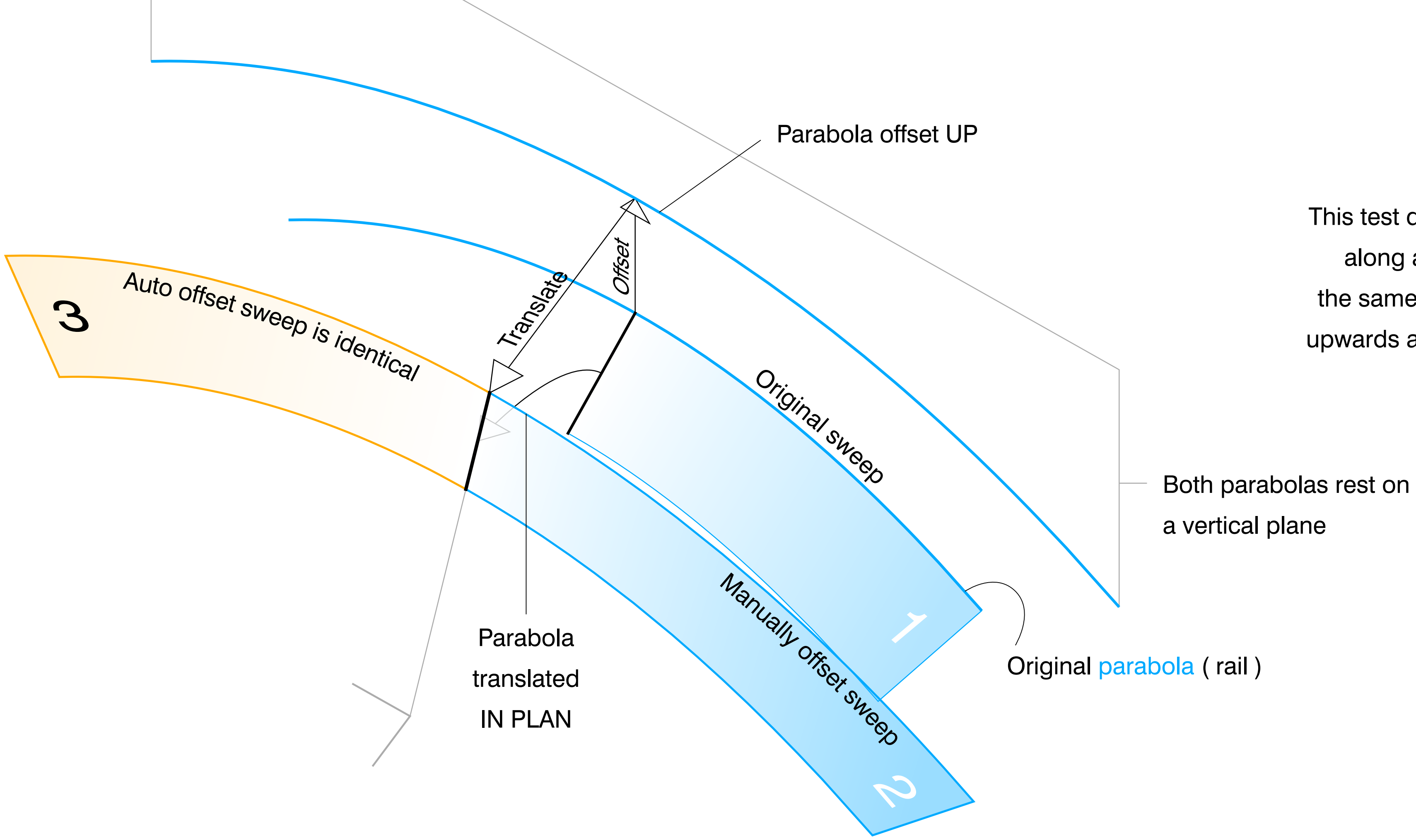
The dome is spherical but the bricks rest on four parabolic arches. A Rhino script, based on the following pages, automates the orientation of the blocks.

```
'--Find up-normal points.

Rhino.Print "OrientBlocs: Finding surface-normal points on the left side..."
ReDim arrarrNormalPointsLeft(UBound(arrarrSpacePointsLeft,1))

i = 0
While i <= UBound(arrarrNormalPointsLeft,1)
    arrarrNormalPointsLeft(i) = fcNormalPoint(strBaseSweep,arrarrSpacePointsLeft(i))
    i = i + 1
Wend

arrdblNormalPointStart = fcNormalPoint(strBaseSweep,arrdblSpacePointStart)

Rhino.Print "OrientBlocs: Left-side surface-normal points found."

Rhino.Print "OrientBlocs: Finding surface-normal points on the right side..."
ReDim arrarrNormalPointsRight(UBound(arrarrSpacePointsRight,1))

i = 0
While i <= UBound(arrarrNormalPointsRight,1)
    arrarrNormalPointsRight(i) = fcNormalPoint(strBaseSweep,arrarrSpacePointsRight(i))
    i = i + 1
Wend

Rhino.Print "OrientBlocs: Right-side surface-normal points found."
```

Etc.

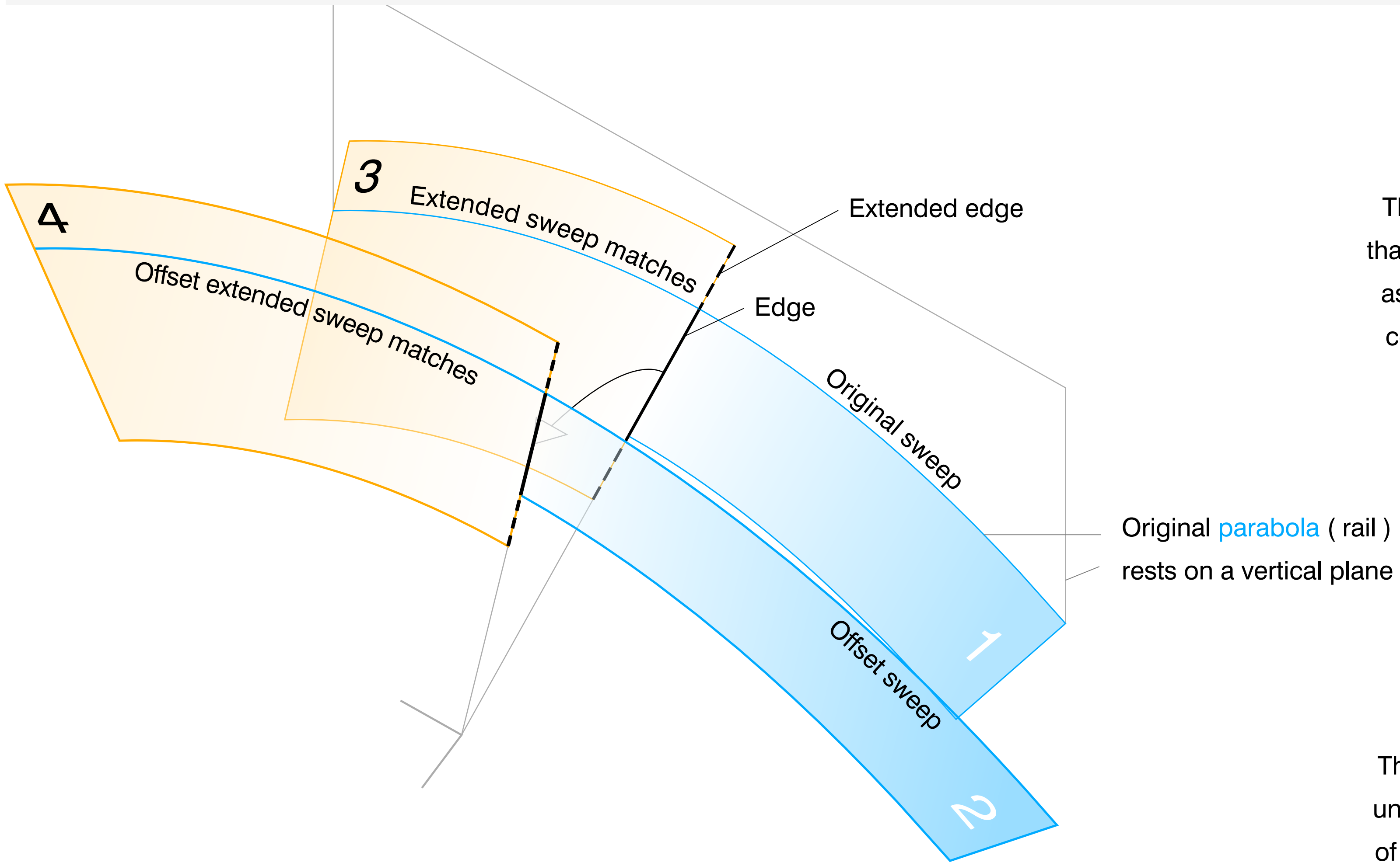
```
'--Find perpendicular points.

arrSweepSurfDomainU = Rhino.SurfaceDomain(strBaseSweep, 0)
arrSweepSurfDomainV = Rhino.SurfaceDomain(strBaseSweep, 1)

dblSweepSurfEdgeUHalf = ( arrSweepSurfDomainU(0) + arrSweepSurfDomainU(1) ) / 2

arrSweepSurfEdgeTestA = Rhino.EvaluateSurface(strBaseSweep, _
            Array(dblSweepSurfEdgeUHalf,arrSweepSurfDomainV(0)) )
arrSweepSurfEdgeTestB = Rhino.EvaluateSurface(strBaseSweep, _
            Array(dblSweepSurfEdgeUHalf,arrSweepSurfDomainV(1)) )

'If the Z coordinate of the test point B is higher than the test point A,
'then this is where we want to extract a U curve.

If arrSweepSurfEdgeTestA(2) <= arrSweepSurfEdgeTestB(2) Then
    i = 1
    strSweepTestPt = Rhino.AddPoint(arrSweepSurfEdgeTestB)
Else
    i = 0
    strSweepTestPt = Rhino.AddPoint(arrSweepSurfEdgeTestA)
End If

arrstrSweepEdge = Rhino.ExtractIsoCurve(strBaseSweep, _
            Array(dblSweepSurfEdgeUHalf,arrSweepSurfDomainV(i)), 0)
arrdblPerpPointStart = fcPerpendicularPoint(arrstrSweepEdge(0),arrdblSpacePointStart)

Rhino.Print "OrientBlocs: Finding perpendicular points on the left side..."
```

Etc.



Rhino sweeps test 1

This test demonstrates that sweeping an edge along a rail that it doesn't touch (3), yields the same surface as if the rail had been offset upwards and translated to touch the path (2).



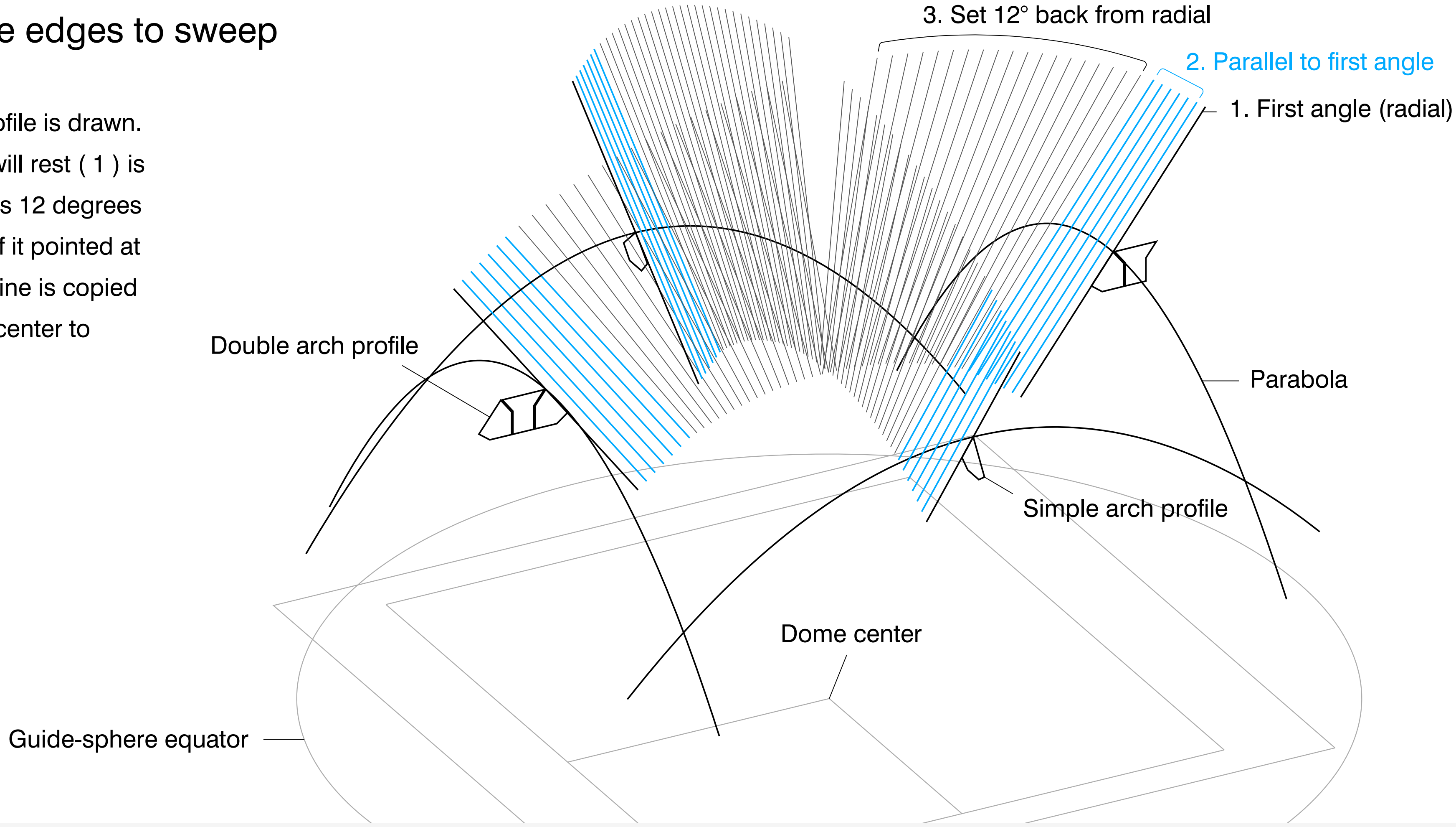
Rhino sweeps test 2

This test demonstrates that sweeping an edge that ends on the parabola gives the same result as sweeping the same edge scaled 2x from its center, and no longer ending on the parabola.

These very technical tests were instrumental in understanding how to automate the generation of the sweep surfaces on which the bricks rest.

Step 1 Tracing the edges to sweep

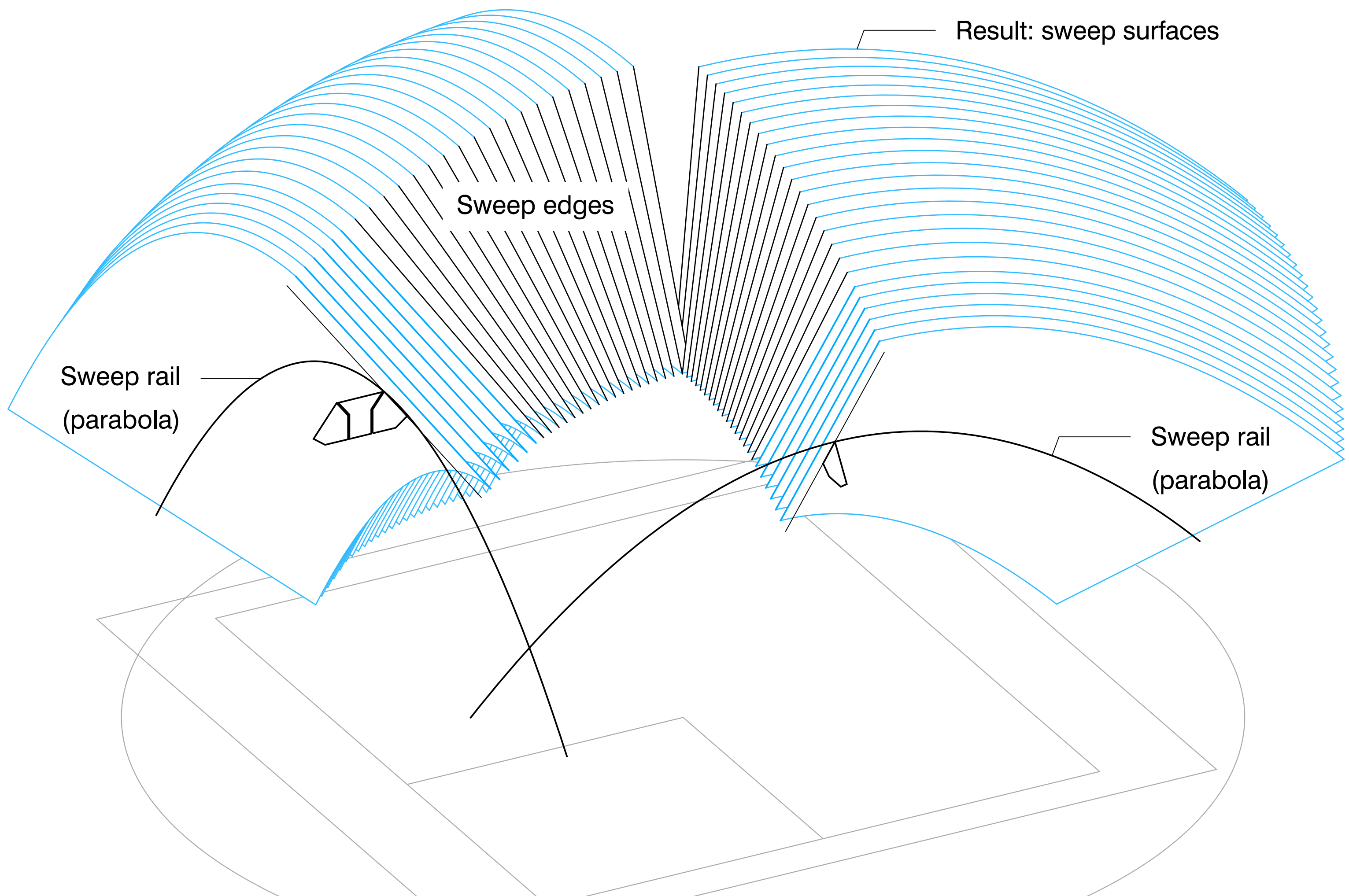
At the apex of each arch, a profile is drawn. The side on which the bricks will rest (1) is offset a few times (2), until it is 12 degrees less inclined than it would be if it pointed at the sphere center. Then, this line is copied and rotated along the sphere center to yield the other lines (3).



Step 2 Sweeping the edges

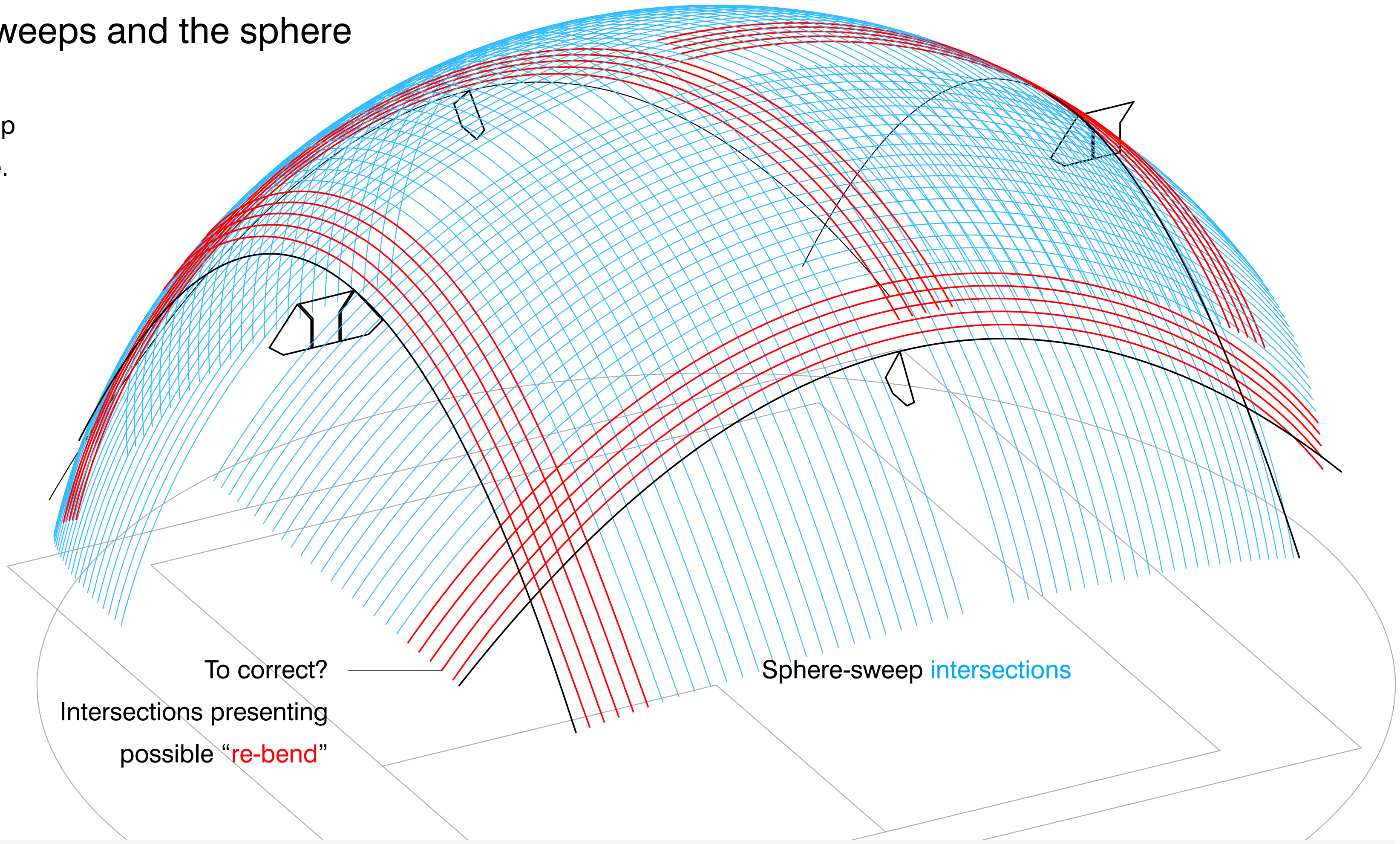
For each edge drawn in step 1, a sweep surface is modeled, using the respective arch parabola as the rail.

The bricks will rest on these sweep surfaces. But to find 'where' they must be on the surfaces, we must intersect the latter with the guide sphere.



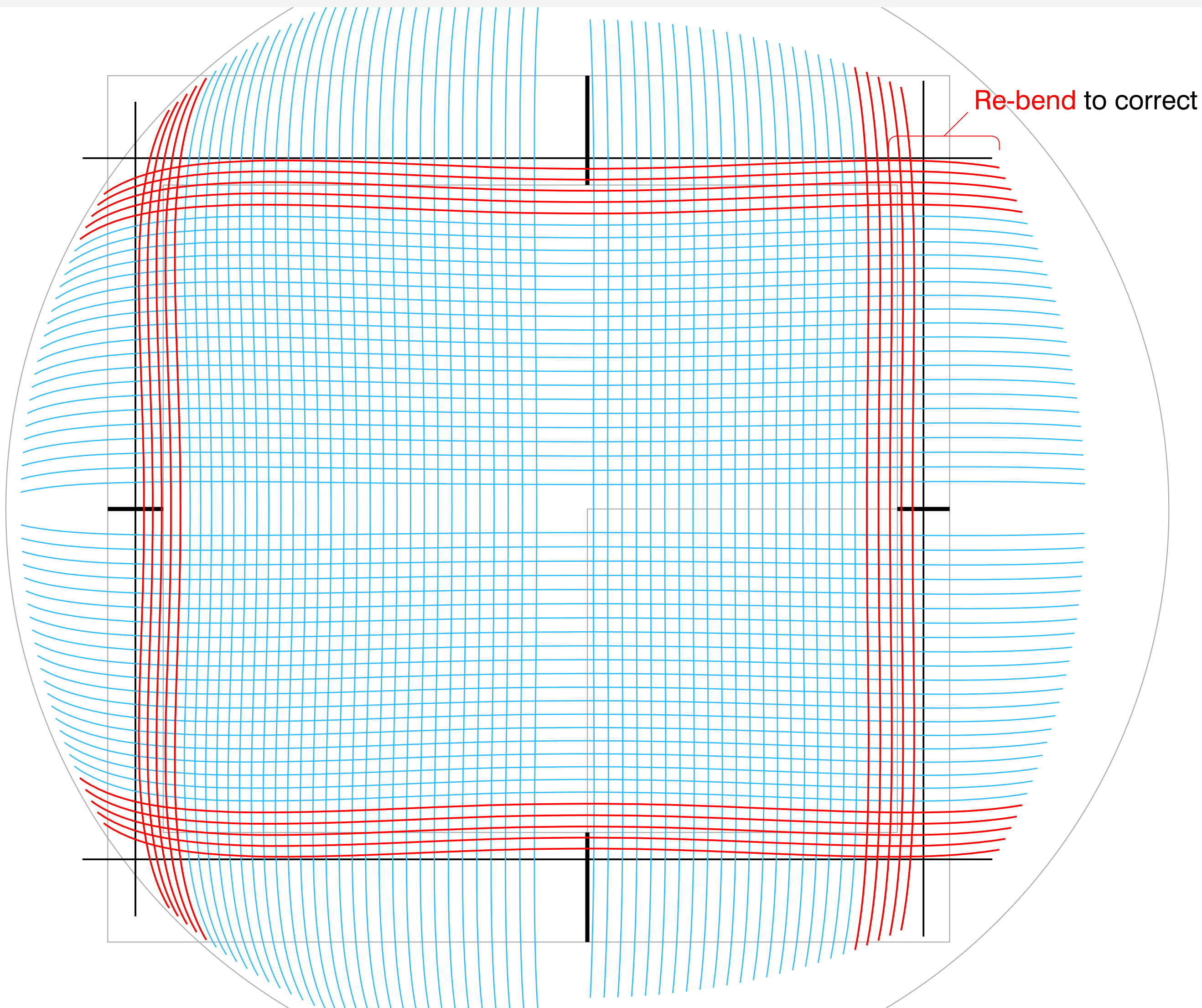
Step 3 Intersecting the sweeps and the sphere

The resulting curves, along with the sweep surfaces, tell us where the bricks must be.



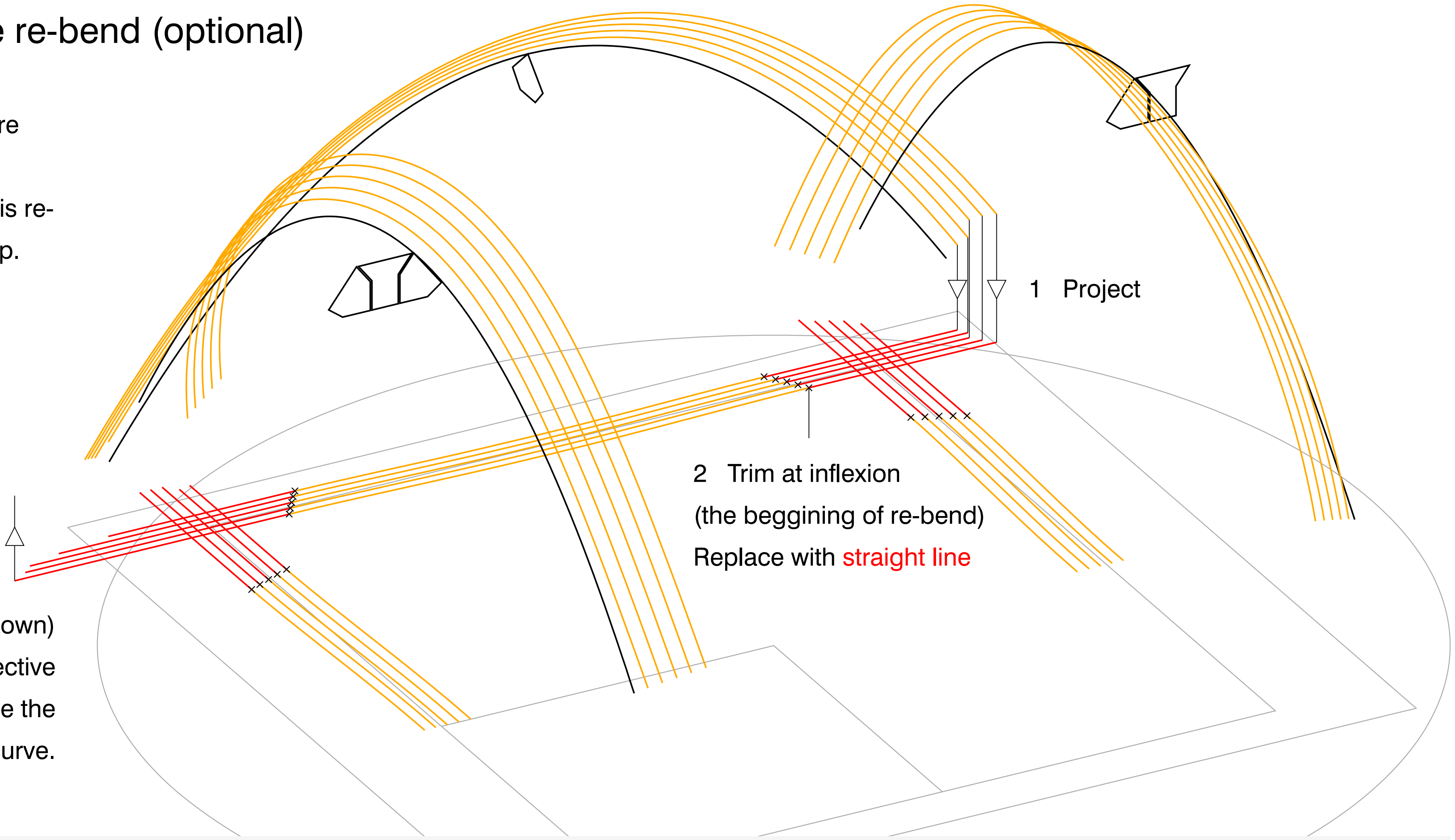
Step 3 (in plan)

Meanwhile, in plan, some of these curves have a slight 're-bend' which we might want to straighten. This is optional.



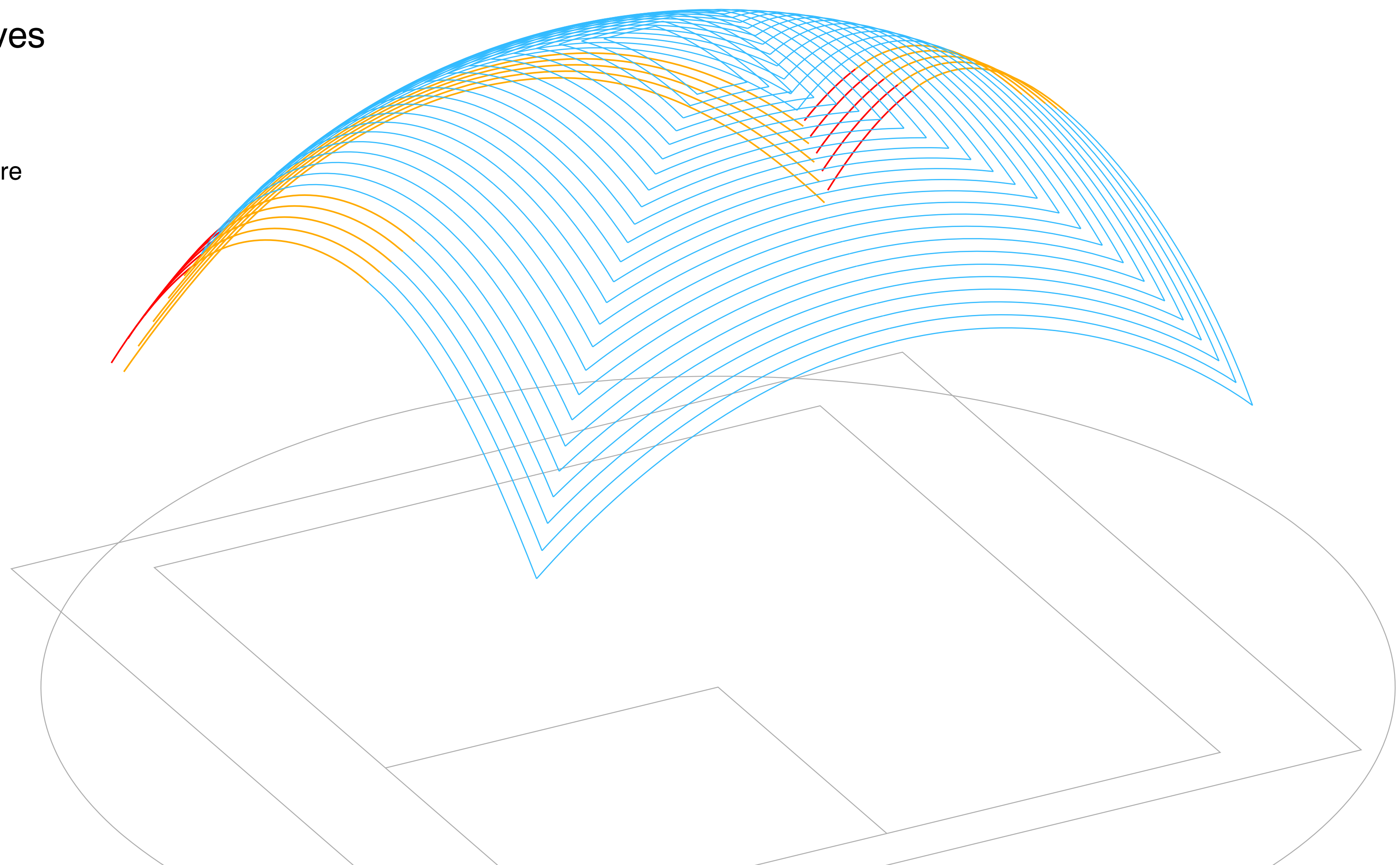
Step 4 Correcting the re-bend (optional)

To correct the re-bend, the curves are flattened, and the re-bending part is replaced with a line. Then, this line is re-projected up to the respective sweep.

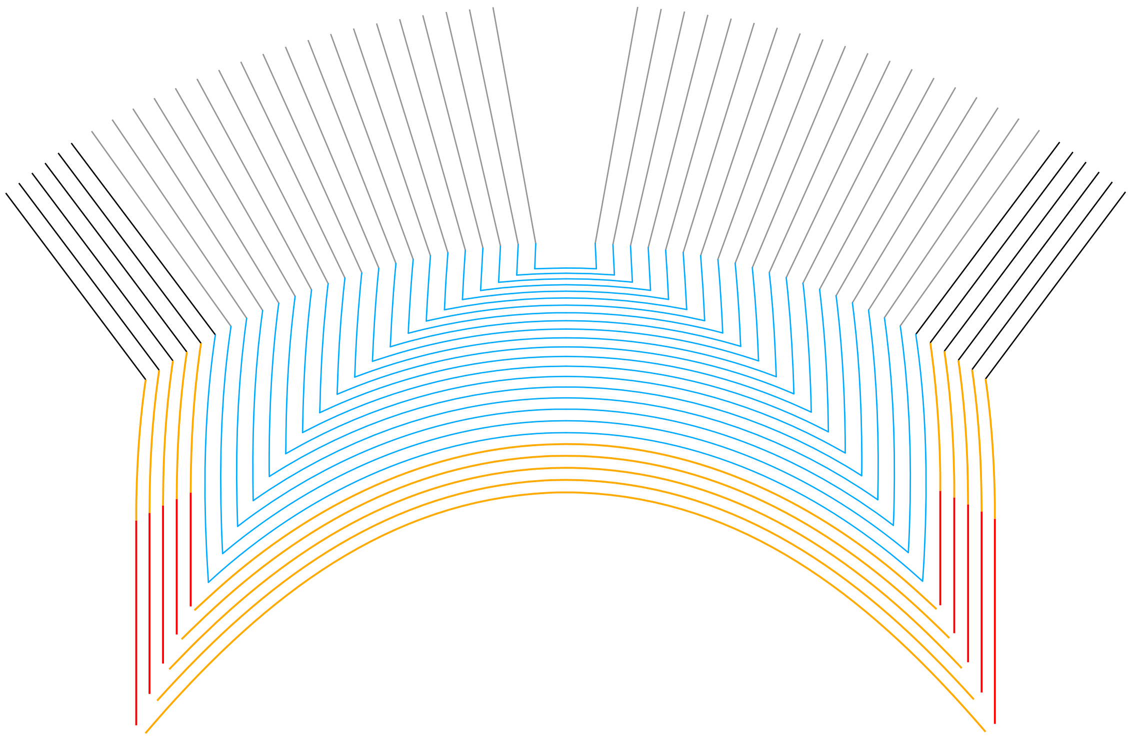


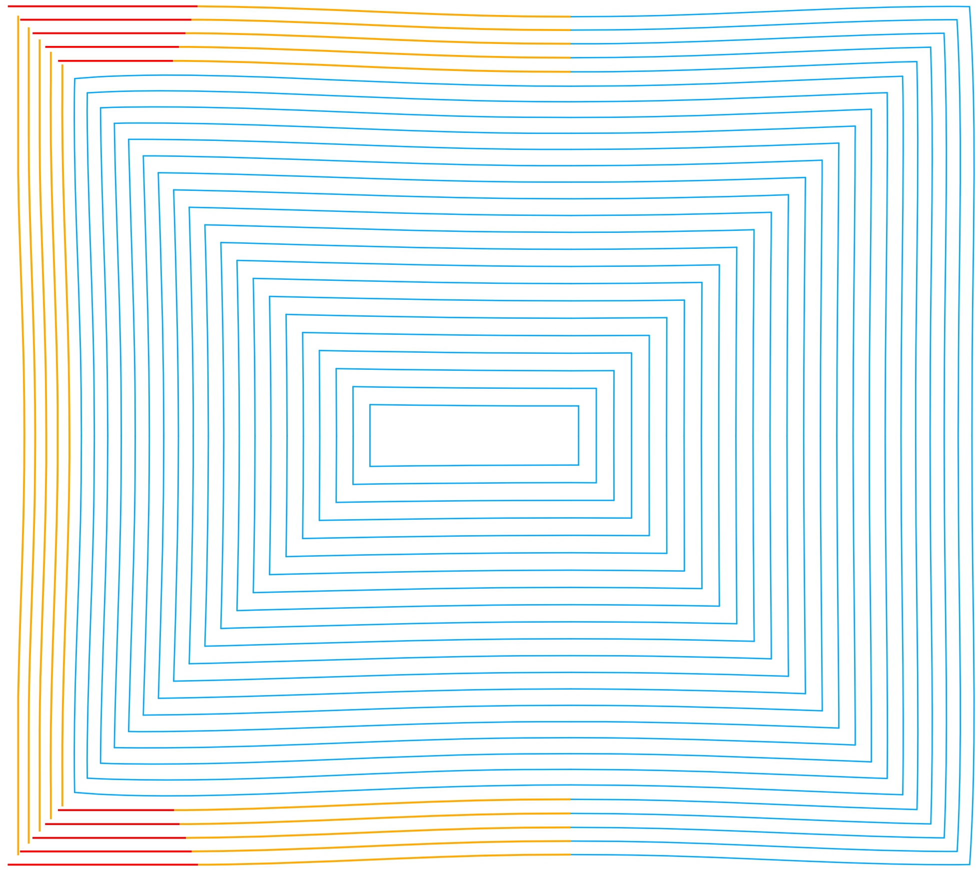
Step 5 Trimming the curves

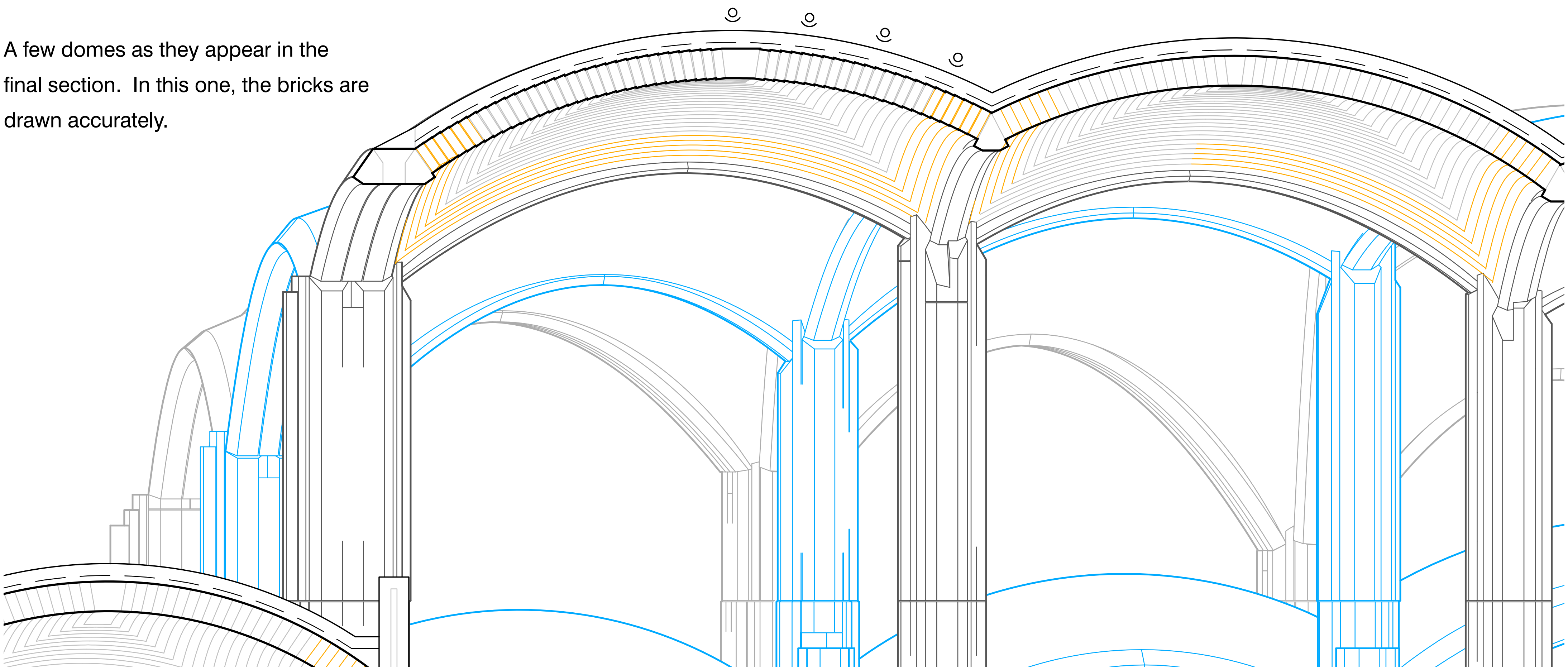
The lines found in step 3 or 4 trim each other naturally. They give an idea of where the courses of bricks will be.



Step 5 (in elevation and in plan)



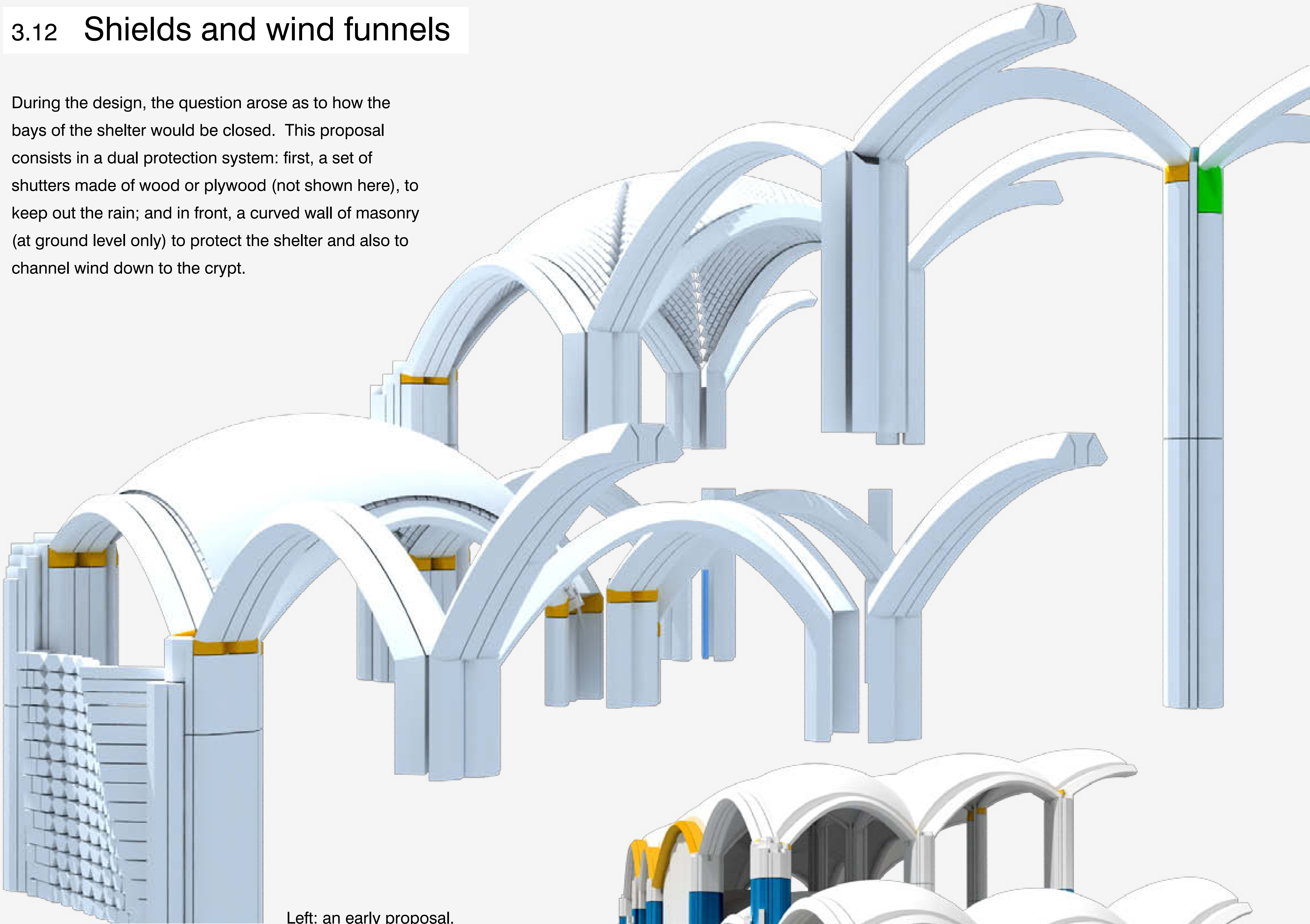




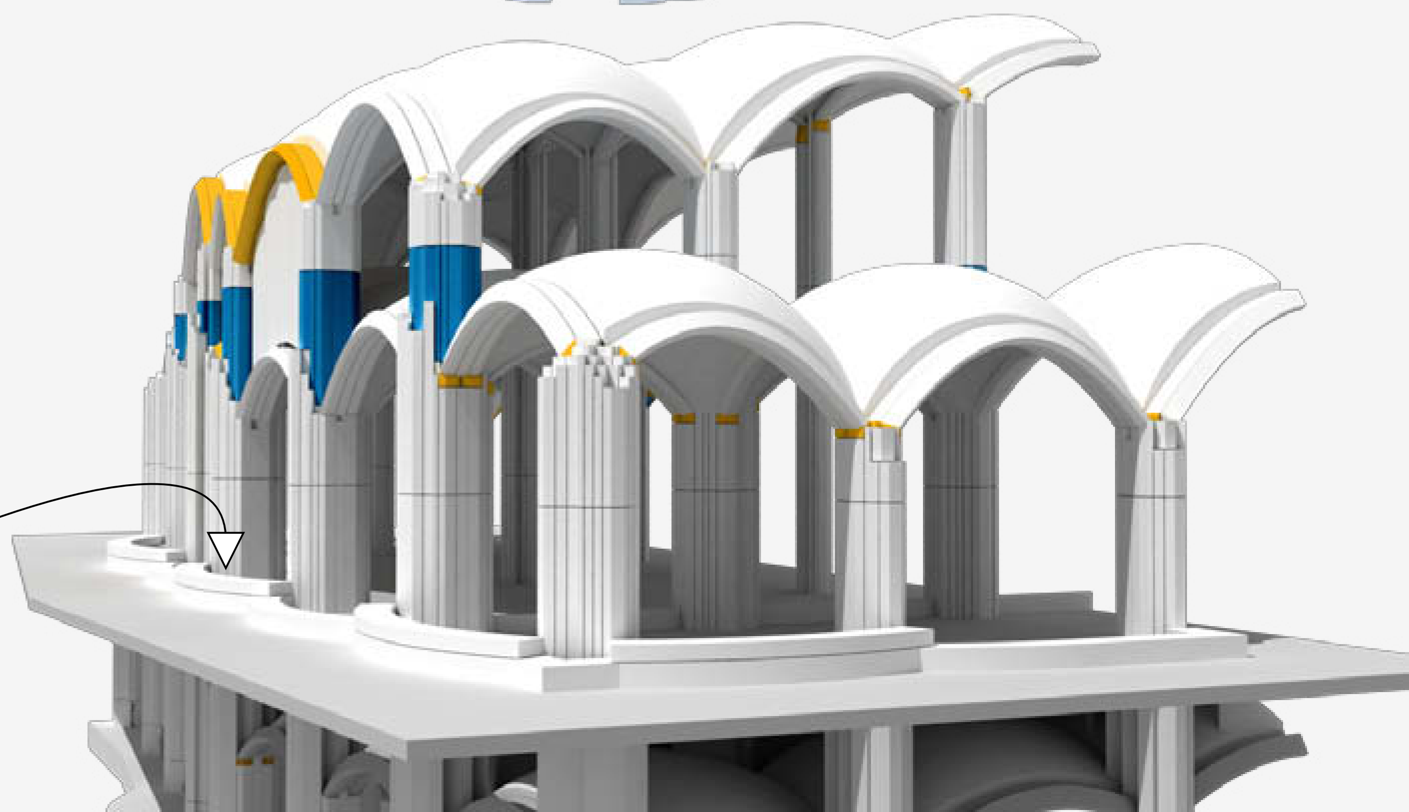
A few domes as they appear in the final section. In this one, the bricks are drawn accurately.

3.12 Shields and wind funnels

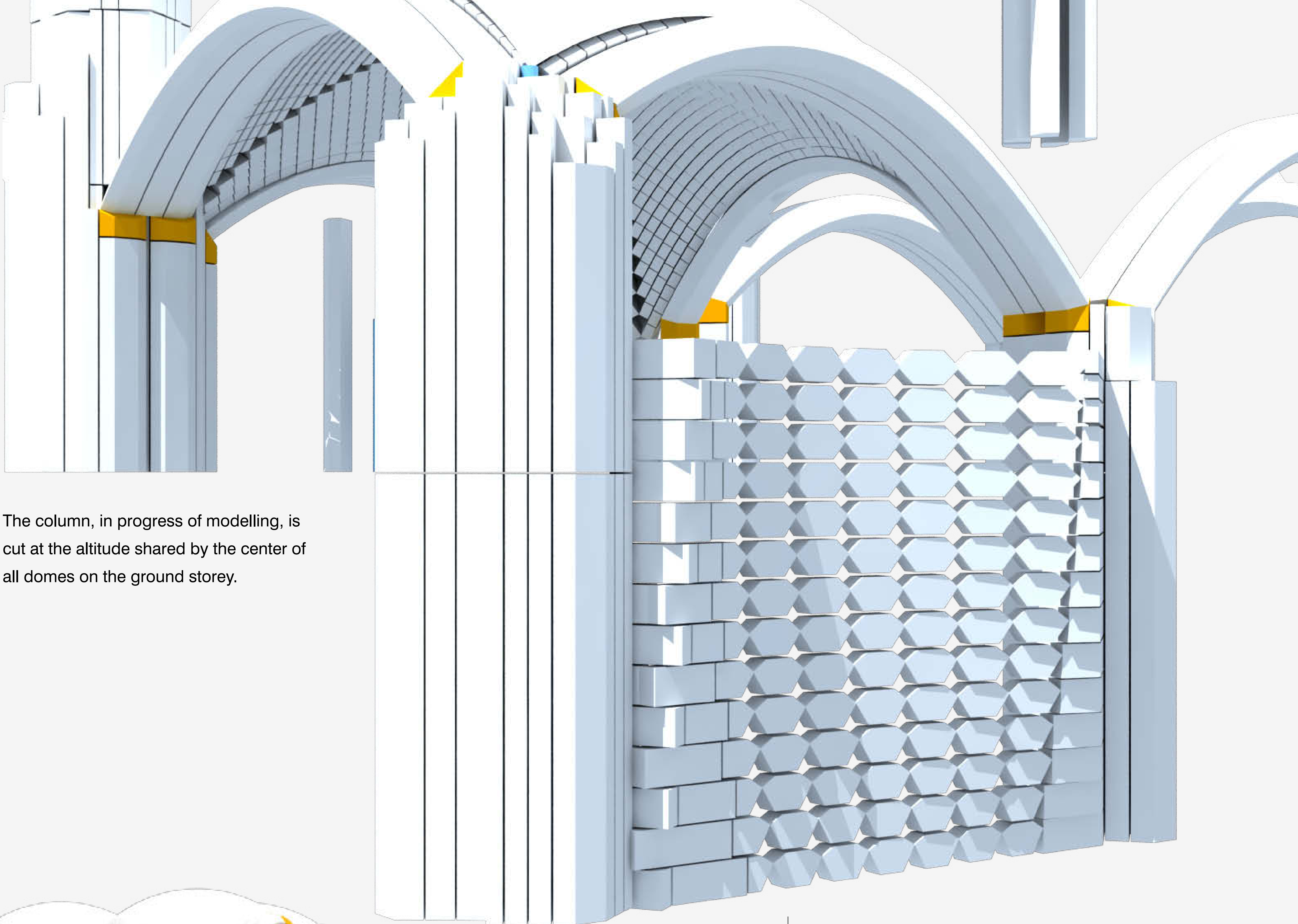
During the design, the question arose as to how the bays of the shelter would be closed. This proposal consists in a dual protection system: first, a set of shutters made of wood or plywood (not shown here), to keep out the rain; and in front, a curved wall of masonry (at ground level only) to protect the shelter and also to channel wind down to the crypt.



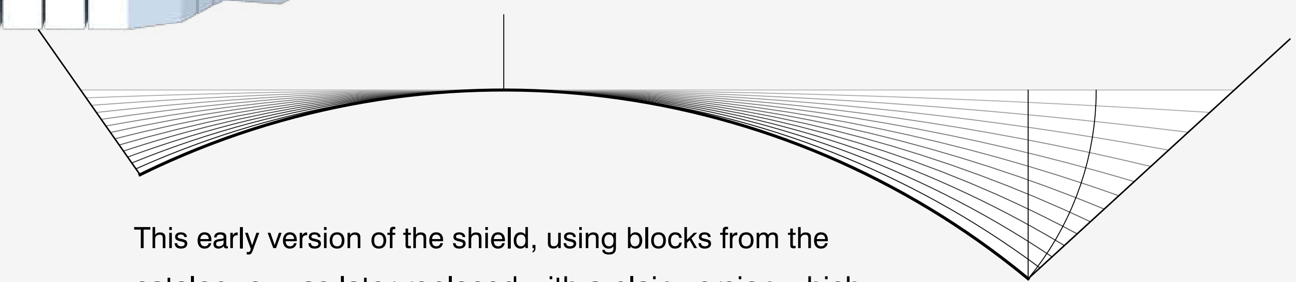
Left: an early proposal.



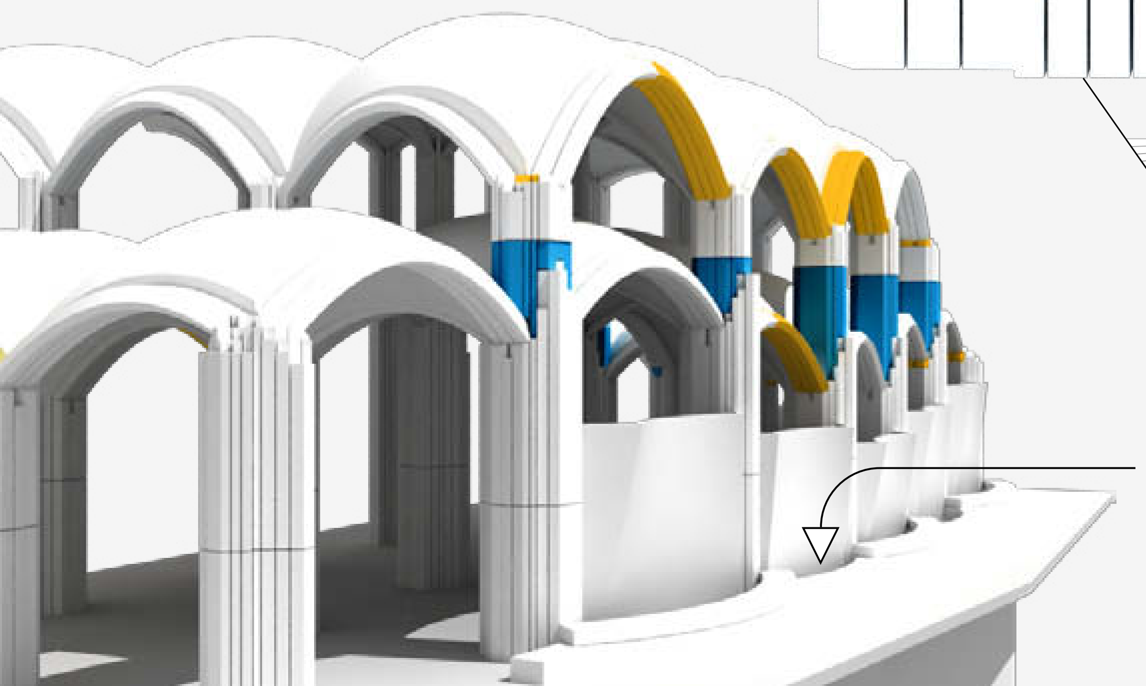
These curves are the caps of the curving foundation walls, hidden here to reveal the crypt. The gaps between the curves and the ground floor let air and light down to the crypt.



The column, in progress of modelling, is cut at the altitude shared by the center of all domes on the ground storey.



This early version of the shield, using blocks from the catalogue, was later replaced with a plain version which could simply be built in brick.



3.13 A mihrab in sheet glass

During the prayer, the imam chants in front of a mihrab, an alcove designed to reflect his voice back at the audience. Here, a GC script was programmed to find the curvature that the reflector must have to create a *radial image of the sound* - as if the imam sang while facing the audience.

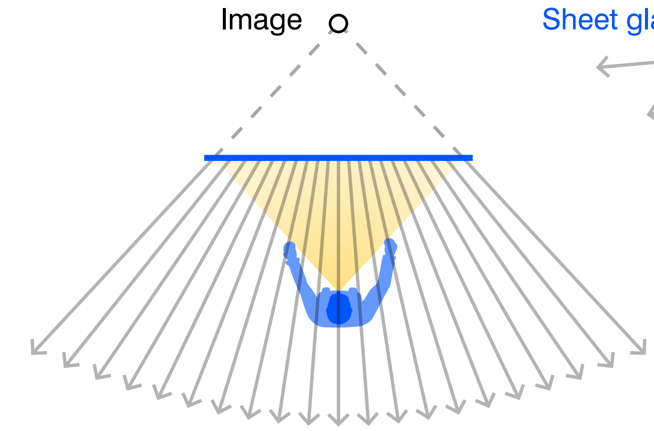


Image behind mihrab Distances 1 and 1

Result: Flat wall

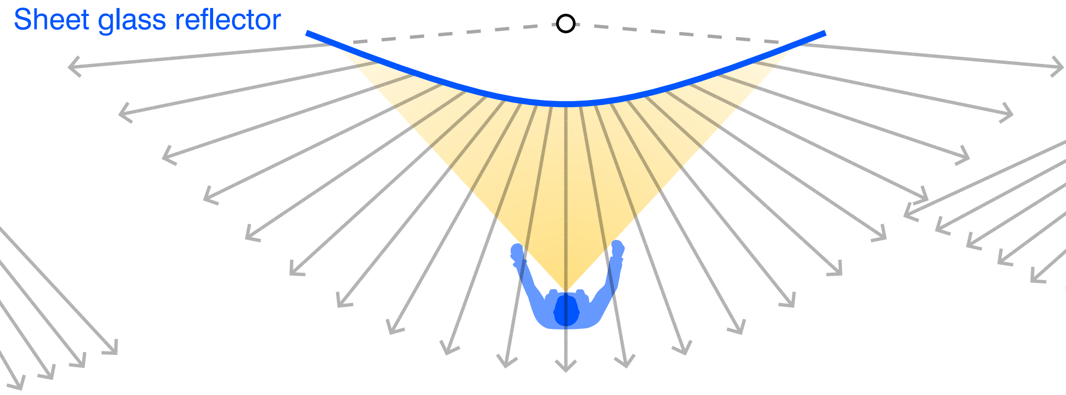


Image behind mihrab Distances 1.4 and 0.6

Result: Convex hyperbola

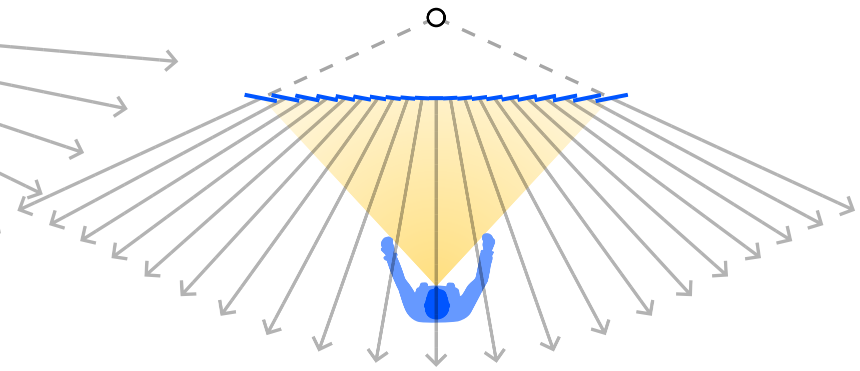


Image behind mihrab Distances 1.4 and 0.6

Alternative result: ‘Fresnel’ hyperbola

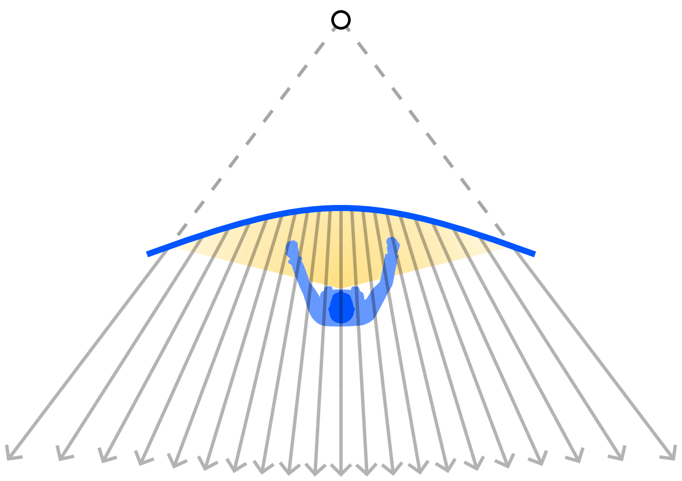


Image behind mihrab Distances 0.6 and 1.4

Result: Concave hyperbola

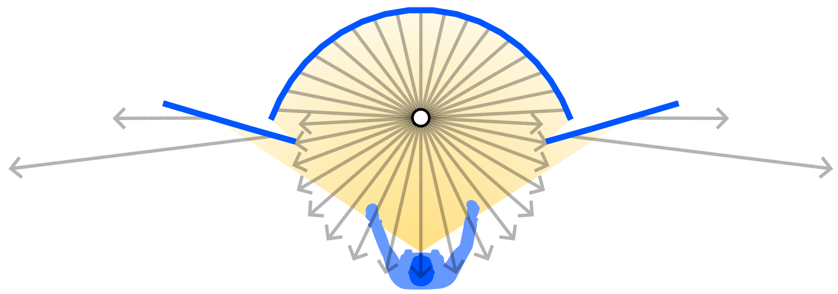


Image between Distances 1 and 0.8

Result: Ellipse

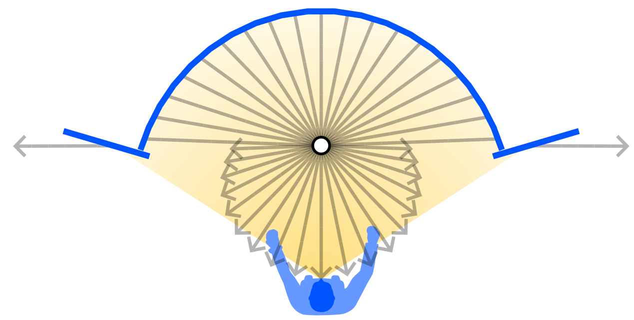


Image between Distances 1 and 1

Result: Ellipse

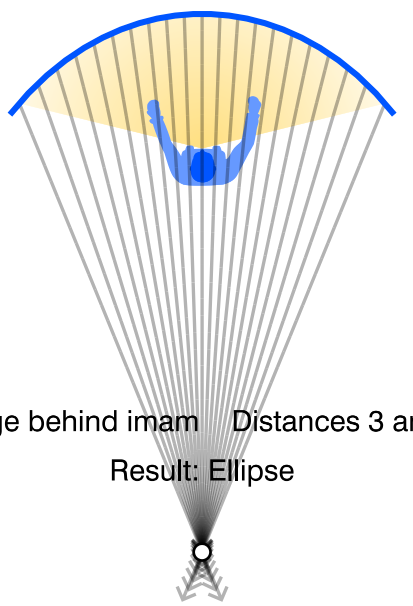


Image behind imam Distances 3 and 1

Result: Ellipse

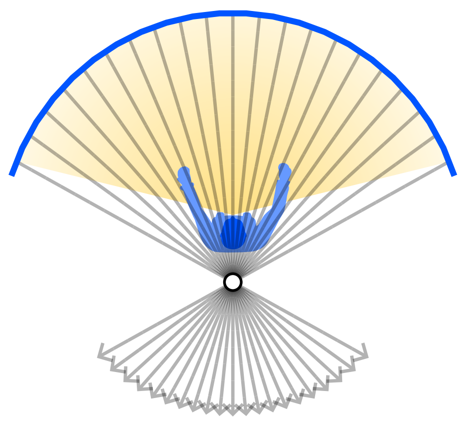


Image behind imam Distances 0.5 and 1.5

Result: Ellipse

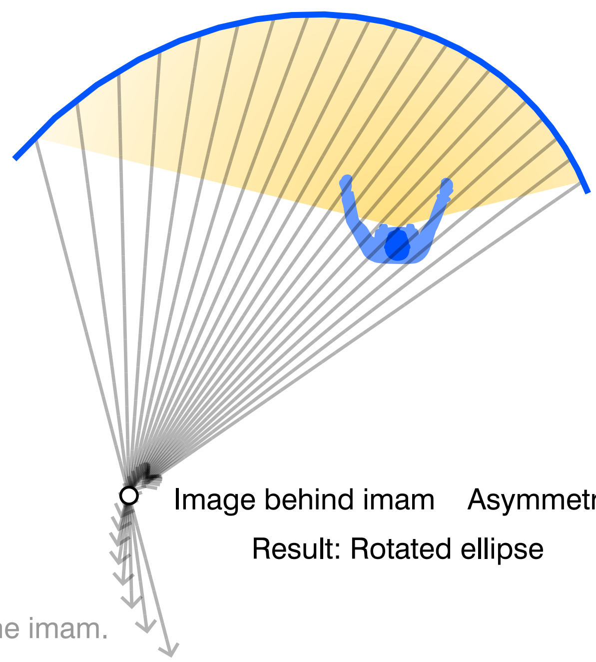


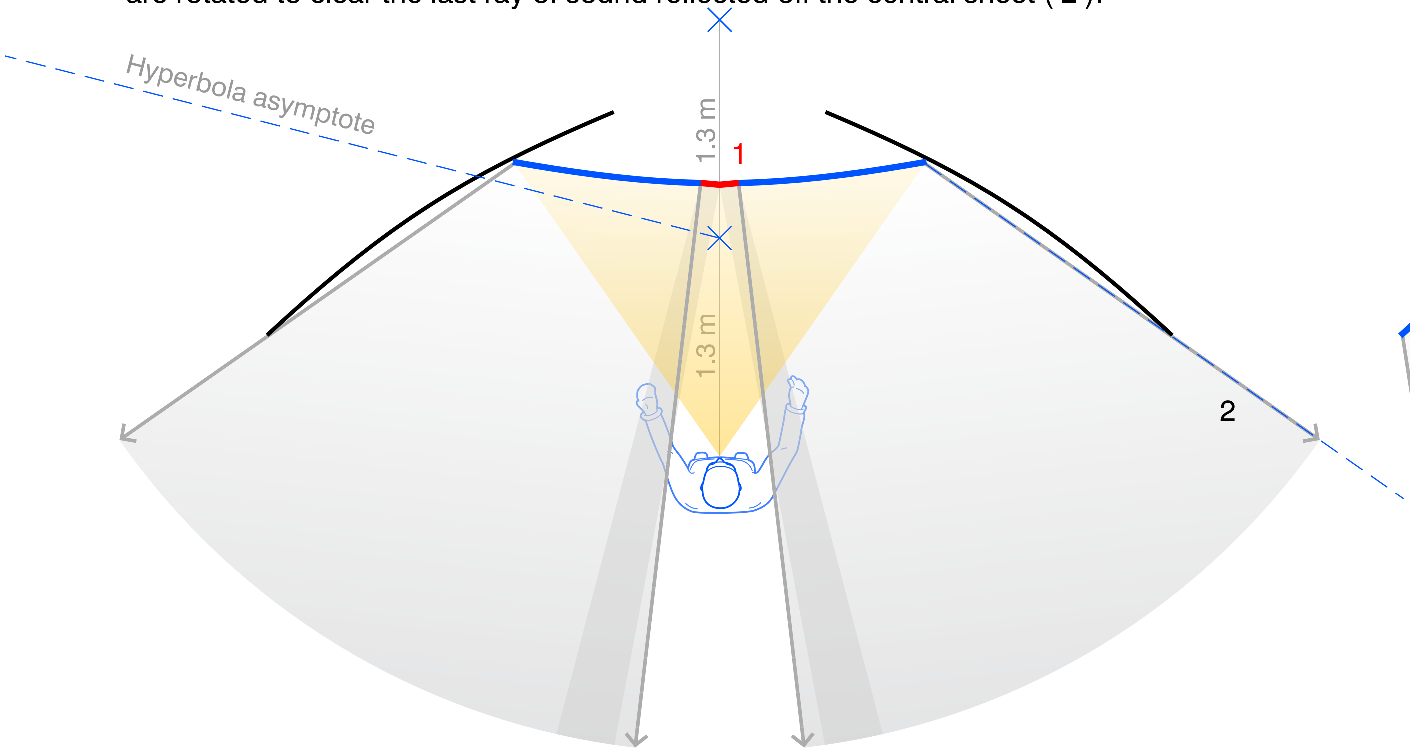
Image behind imam Asymmetric

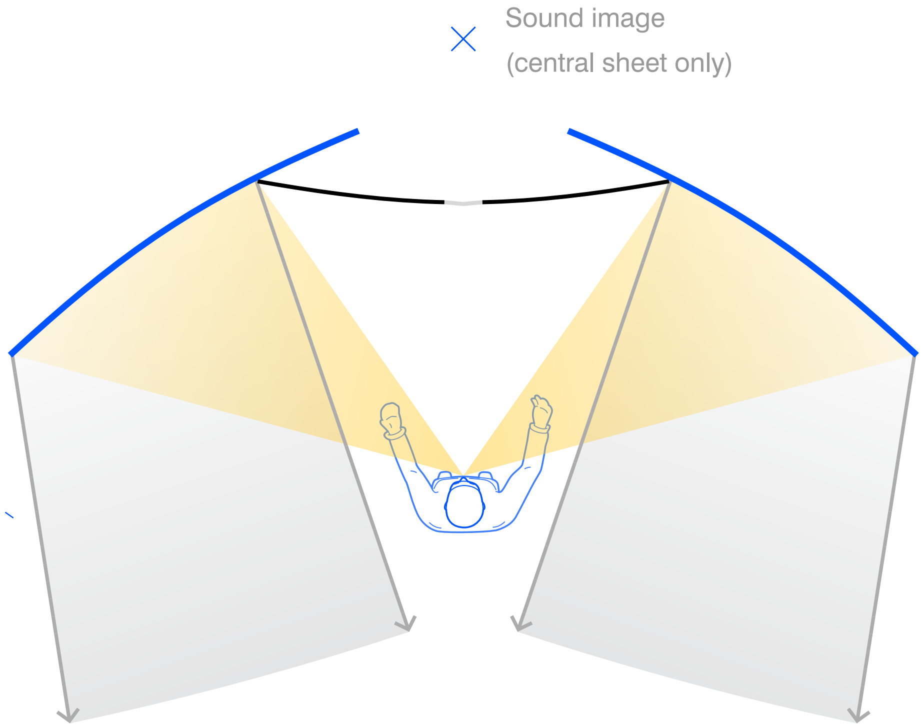
Result: Rotated ellipse

Note: for clarity, the rays are drawn as if they passed through the imam.

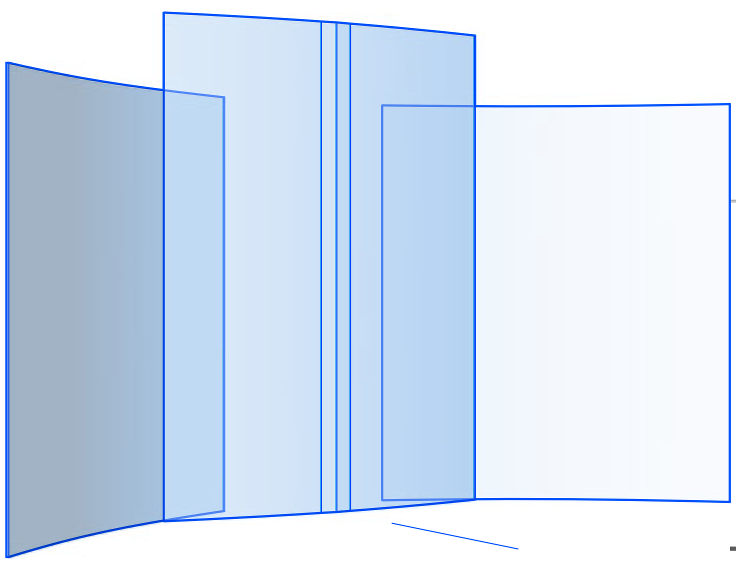
The mihrab is made of three sheets of glass, with hyperbolic single-curvature. They are identical, apart from a sharp fold (1) in the central sheet, located where the sheet would normally reflect sound at the speaker. The lateral sheets are rotated to clear the last ray of sound reflected off the central sheet (2).

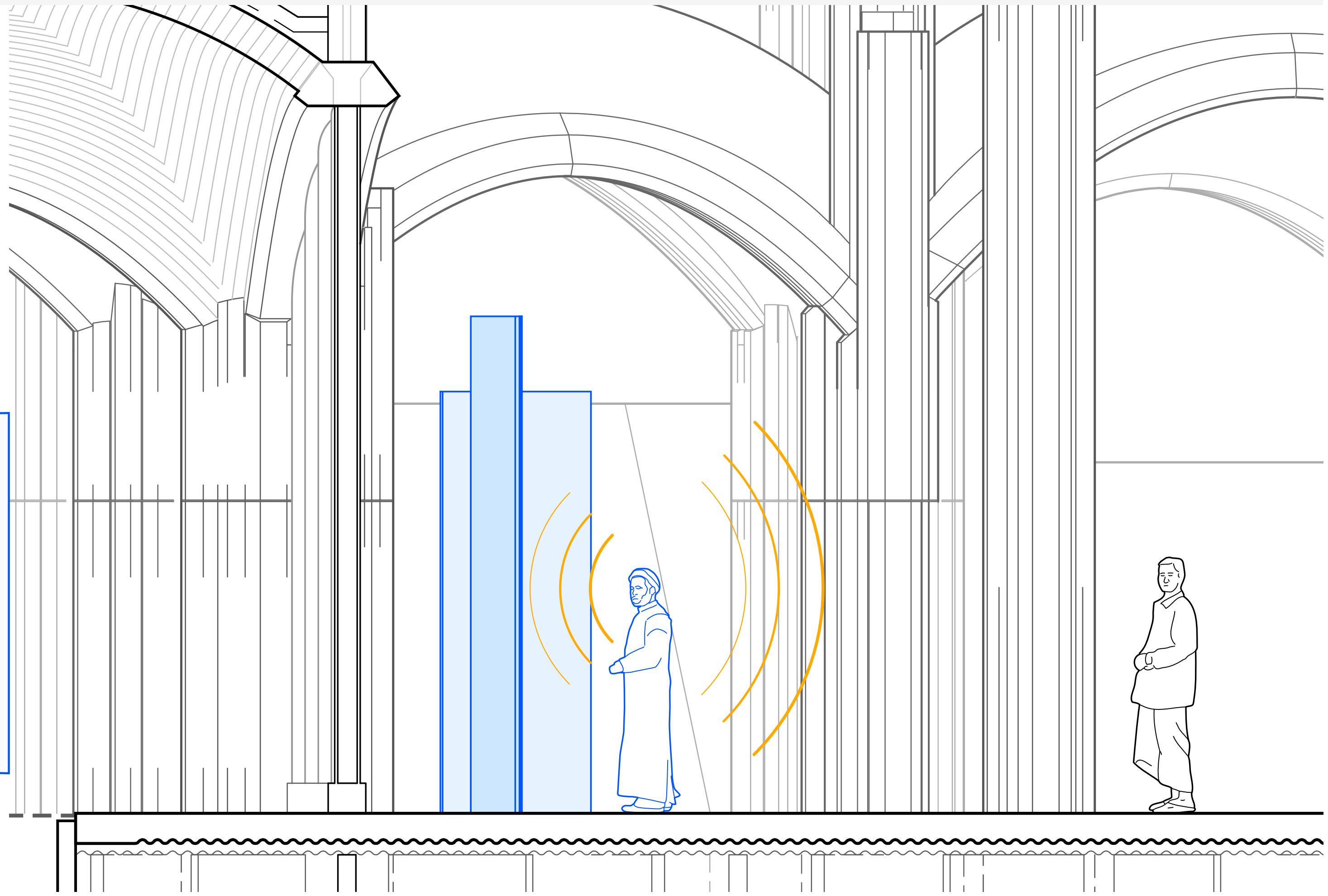
Mihrab in 3 sheets of glass





The mihrab as it appears in the final section, and in perspective at eye level.



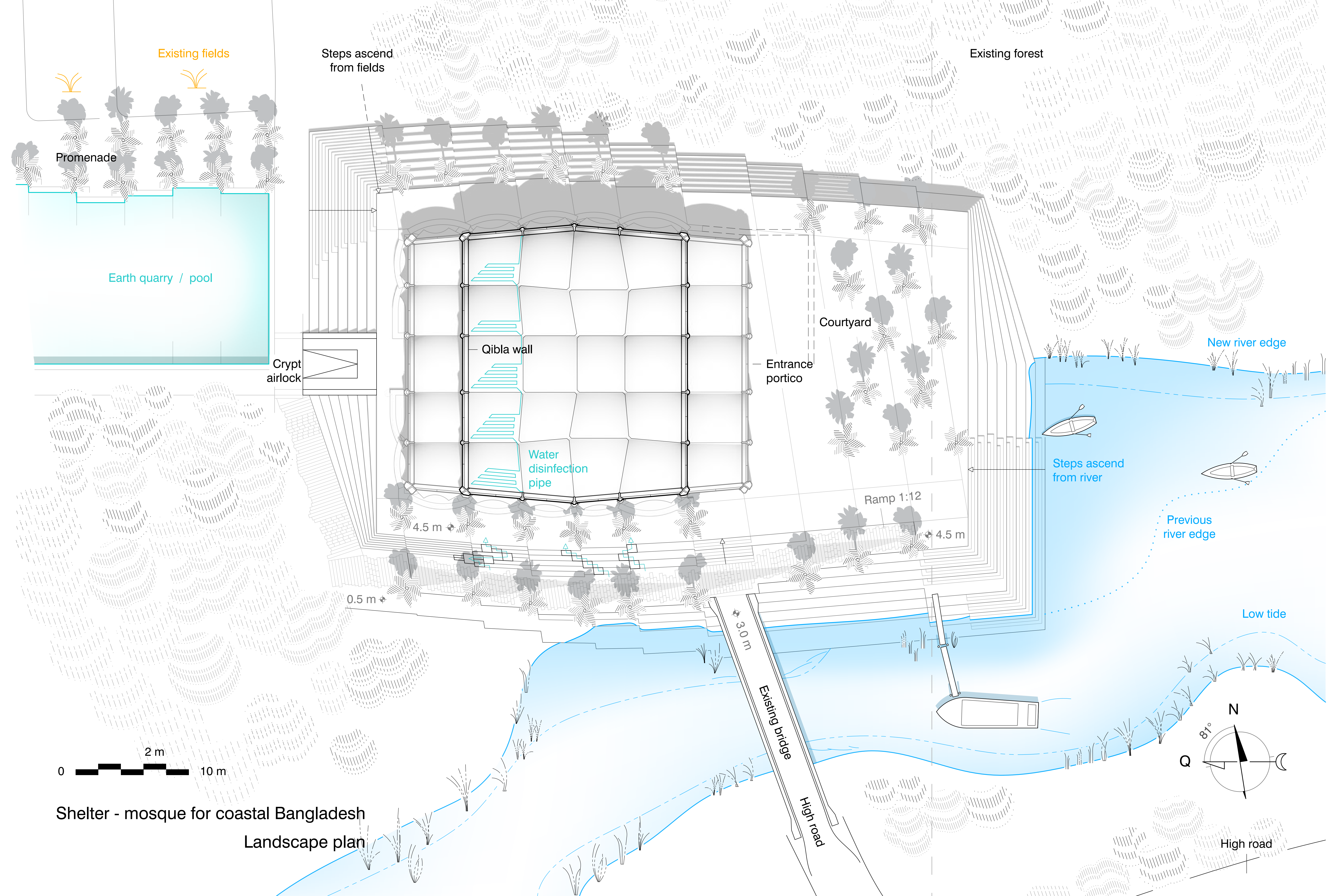


3.14 Final model and drawings

Model of half the shelter - mosque

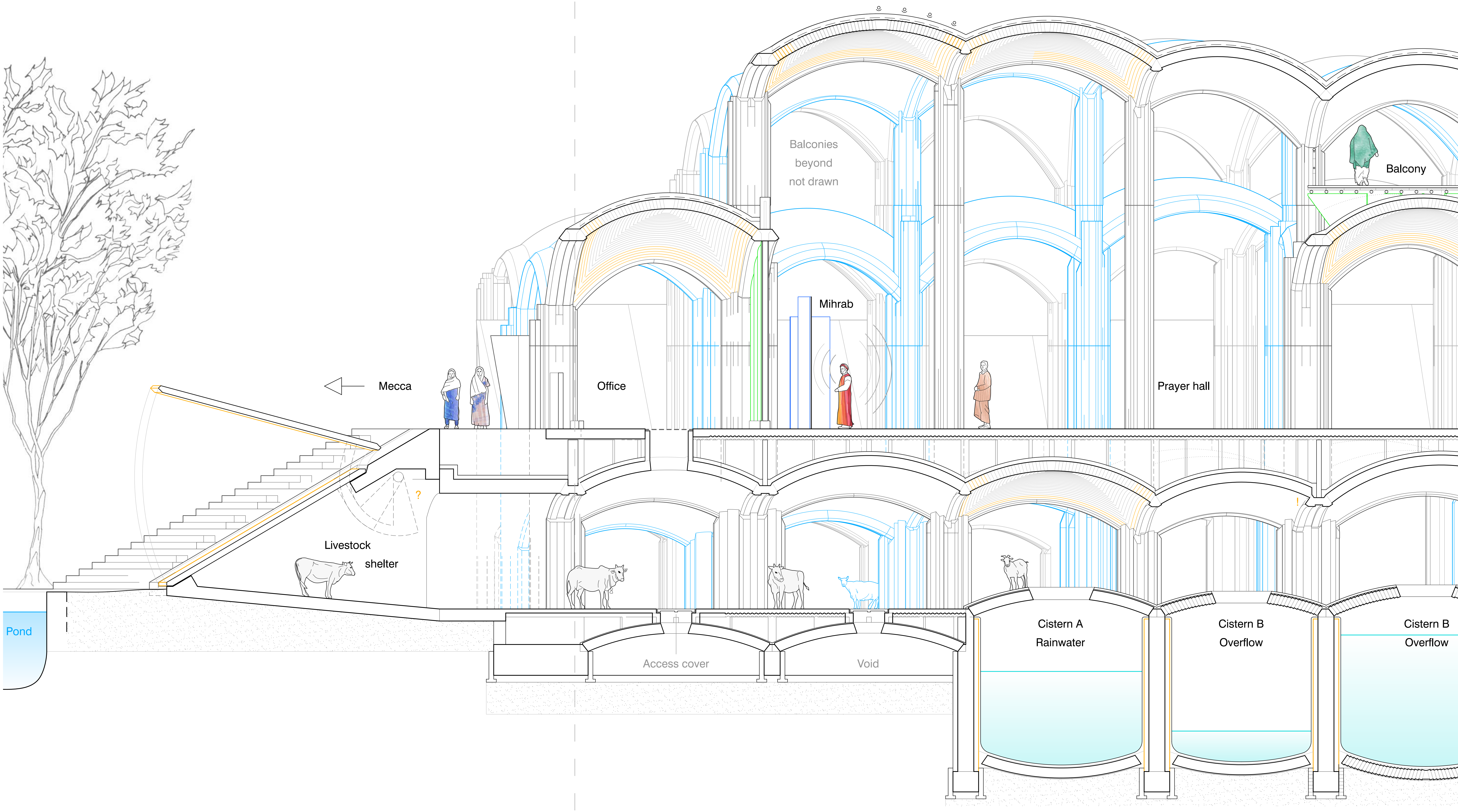
The shelter - mosque was modelled using a low-end 3d printer, which unfortunately did not restitute the sharp, lime-white building very well. Still, it provided an object around which to evaluate the project.

The base was cut manually in walnut, a wood which resembles the rammed earth of which the podium would be made.



Shelter - mosque for coastal Bangladesh

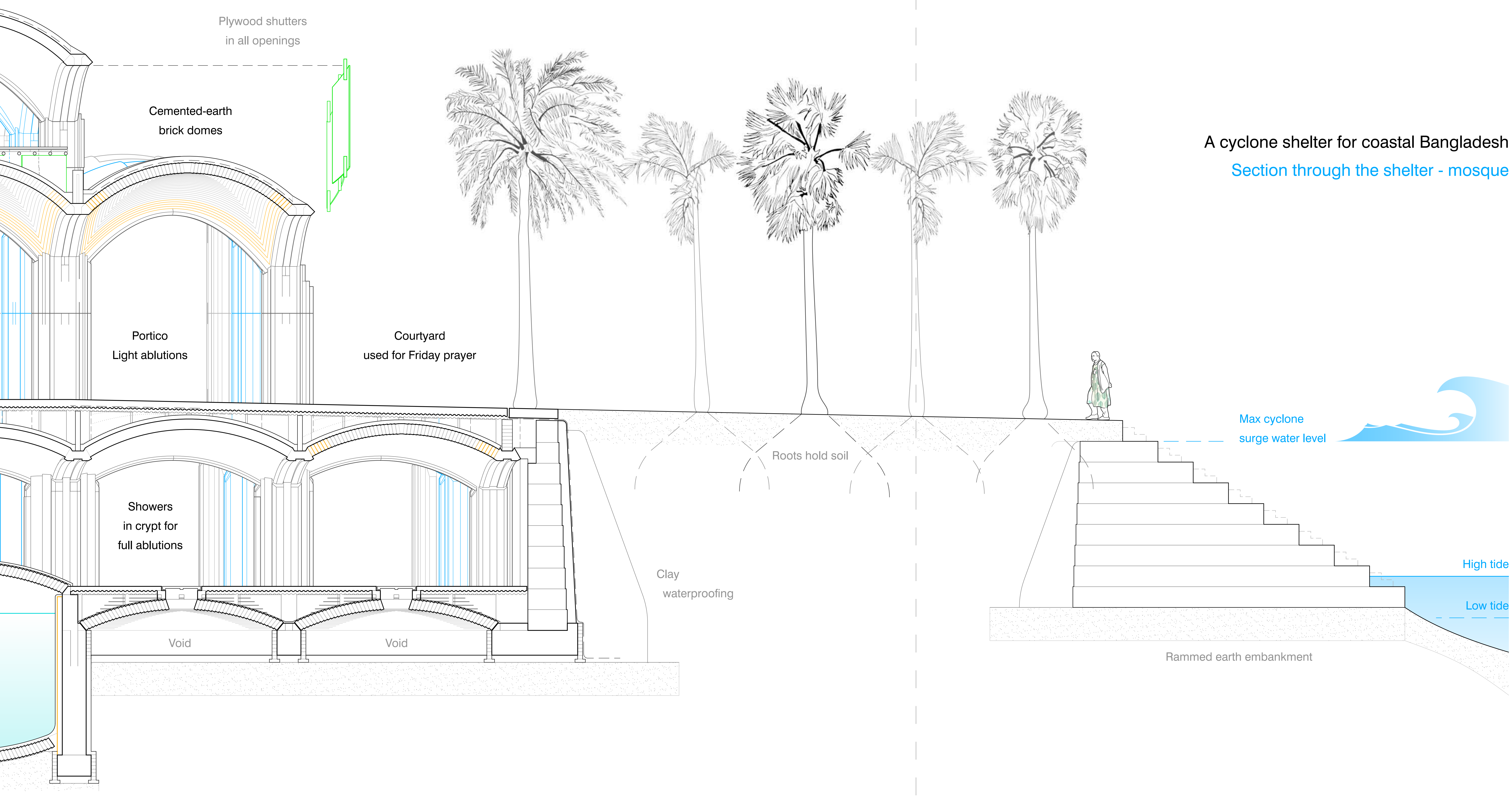
Landscape plan



Balconies
beyond
not drawn
Balcony
Mihrab
Mecca
Office
Prayer hall
Livestock
shelter
Pond
Access cover
Void
Cistern A
Rainwater
Cistern B
Overflow
Cistern B
Overflow

A cyclone shelter for coastal Bangladesh

Section through the shelter - mosque



At the beginning of the year, we were asked to study a precedent and write a thousand words about it. I was assigned the New Gourna project.

New Gourna Village, Egypt, 1946

Hassan Fathy b. 1899 d. 1989

The banks of the Nile were once replenished in nutritious silts by the swelling of the river in the summer season. The floods ended with the completion of the High Aswan Dam, and so did the natural cycle of replenishment of the arable land. This continuous ribbon of agriculture, now fertilized by human means, follows the shore as far as ten kilometers abreast, then disappears abruptly, and gives way to the desert.

Luxor in Upper Egypt rests in this rural scenery, overlooking the crops across the river which gradually rise to the Valley of the Kings, Queens and Nobles. Along the road leading to the resting place of Queen Hatshepsut, one can see two isolated villages: New Gourna set in the fields, and Old Gourna further out, huddled on the first hills of the desert.

Around 1900, a few peasants settled on the ancient burial grounds of the Valley of the Nobles. They became tomb plunderers and lived off the trade of antiques, until the tombs grew scarce in valuable artifacts. The project of New Gourna arose in 1944 from an unprecedented scandal: in their increasing struggle for revenue, the Gourniis had extracted and stolen a large bas-relief from a classified tomb.

"It was as if someone had stolen a window from Chartres".

Architecture for the Poor, p16

Consecutively, the Ministry of Antiquity projected to relocate seven thousand Gournis in the fields along the Nile, where they would hopefully engage in agriculture and the trade of crafts. When facing the necessity to design the new village, the Ministry turned to Hassan Fathy. This classically trained architect, then 46, had recently completed a model house, complete with vaulted roofs, for 165 E£. In the scarceness subsequent to the World War, the equivalent in concrete had cost 1100 E£. Fathy's economy relied on the use of adobes – traditional sun dried bricks – and on masons from lower Nubia, who had the skill to erect vaults without centering. Fathy wrote of this technique:

New Gourna, entrance to the Mosque
The Aga Khan Collection

"Besides being cheap, it is also beautiful. It cannot help being beautiful, for the structure dictates the shapes and the material imposes the scale ... The structural elements themselves provide unending interest for the eye."

Architecture for the Poor, p11

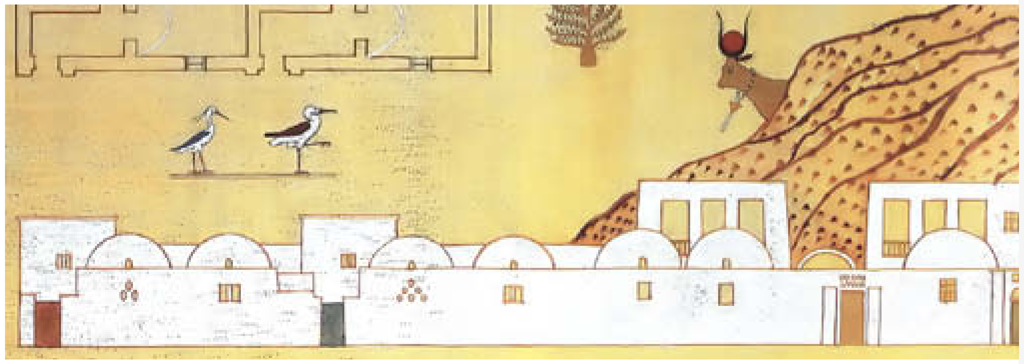
Fathy's esteem of traditional methods placed him at odds with the narrow-minded modernists who refused to value anything but concrete fabrication. Yet his understanding of the ingenuity of traditional architecture placed him in the current of true modernity, many years before the current of critical regionalism was appreciated. His lucidity of the principles, rather than the forms of vernacular design, kept him from the risk of referring to traditional architecture in a superficial manner, which would plague many of his successors.

In New Gourna, the peasants were entitled to a plot equal to the ground area of their house in Old Gourna: the parcels would thus vary in size. An orthogonal urban layout would have accommodated varying parcels while allowing the plan of a small house to be as similar as possible to the plan of a large house. Yet Fathy realized that no two houses were quite alike in villages built by peasants : each was at least subtly shaped by its inhabitant. He thus restrained from a monotonous orthogonal layout, *"considered by some to be all that the poor deserve".* He preferred to draw oblique alleys and polygonal residential areas, *"not simply to make them quaint or because of some love for the Middle Ages" (p71)*, but to embed in the urban fabric the necessity to adapt each house to its parcel, as well as the opportunity to change it according to the needs of the dwellers. This desire to adapt each house has often been recycled by architects, alas, as a kind of prowess in which each house is different, but none designed in collaboration with the dwellers.

Concrete houses for the poor
Architecture for the Poor, fig 26

Dwelling courtyard, New Gourna
The Aga Khan Collection

Fathy's drawings astonish by their simplicity. Surely it must have been courageous for a pupil of the Beaux-Arts school to arrive at such designs confidently. Nevertheless, the dwellings of New Gourna were perfectly adapted for traditional rural life in Egypt. The hydrophilic adobes naturally regulated the ambient humidity of the house; vaulted spaces allowed warm air to rise above a standing person, and thus made for temperate interiors. Courtyards provided shade and cross-ventilation; staircases held on arches afforded niches where to leave jars of fresh water; multiple roof terraces were used as storage areas, as well as surfaces where a family could dine at sunset and sleep during the warm nights. Fathy reinstated the typology of the *qa'a*, the formal greeting room of a merchant, and even replaced the ovens and charcoal braziers, which gave off smoke and carbon monoxide, with his own design based on his research of the Austrian *kachelofen*, an efficient stove made of clay.



Gouache of New Gourna by Hassan Fathy. Hathor, the fertility goddess represented by the cow, blesses the project. *J. Steele, p60.*

Like many great endeavours, New Gourna is remembered as much for its excellence as for the irony of its failure. The Gournis were not keen to let go of tomb plundering; many despised the new village and sabotaged the works. The Ministry of Antiquities was boiling with angry bureaucrats who resented working to rehabilitate tomb plunderers. Endless delays in the delivery of equipment and mischievous plots to increase the costs finally exceeded Fathy's patience. He turned to the peasantry department and the housing department: both refused to help. His book "Architecture for the Poor" is a poignant account of the power of corruption to put an end to the best of human enterprises.

New Gourna stands as a warning of the difficulty of building for the poor. The feasible and sensible project of an Egyptian intellectual, hired by the Egyptian government to resettle Egyptian peasants, has failed. What should architects expect when they are called to design in foreign developing countries, of which they barely understand the culture?

Jean-François C. Lemay

Family living in New Gourna. A fourth of the village masterplan was built before the project was cancelled in 1948. Today all the houses are inhabited, most of them not by descendants of Old Gourna. *The Aga Khan Collection*

Map of the countryside of Luxor
Drawn by the author

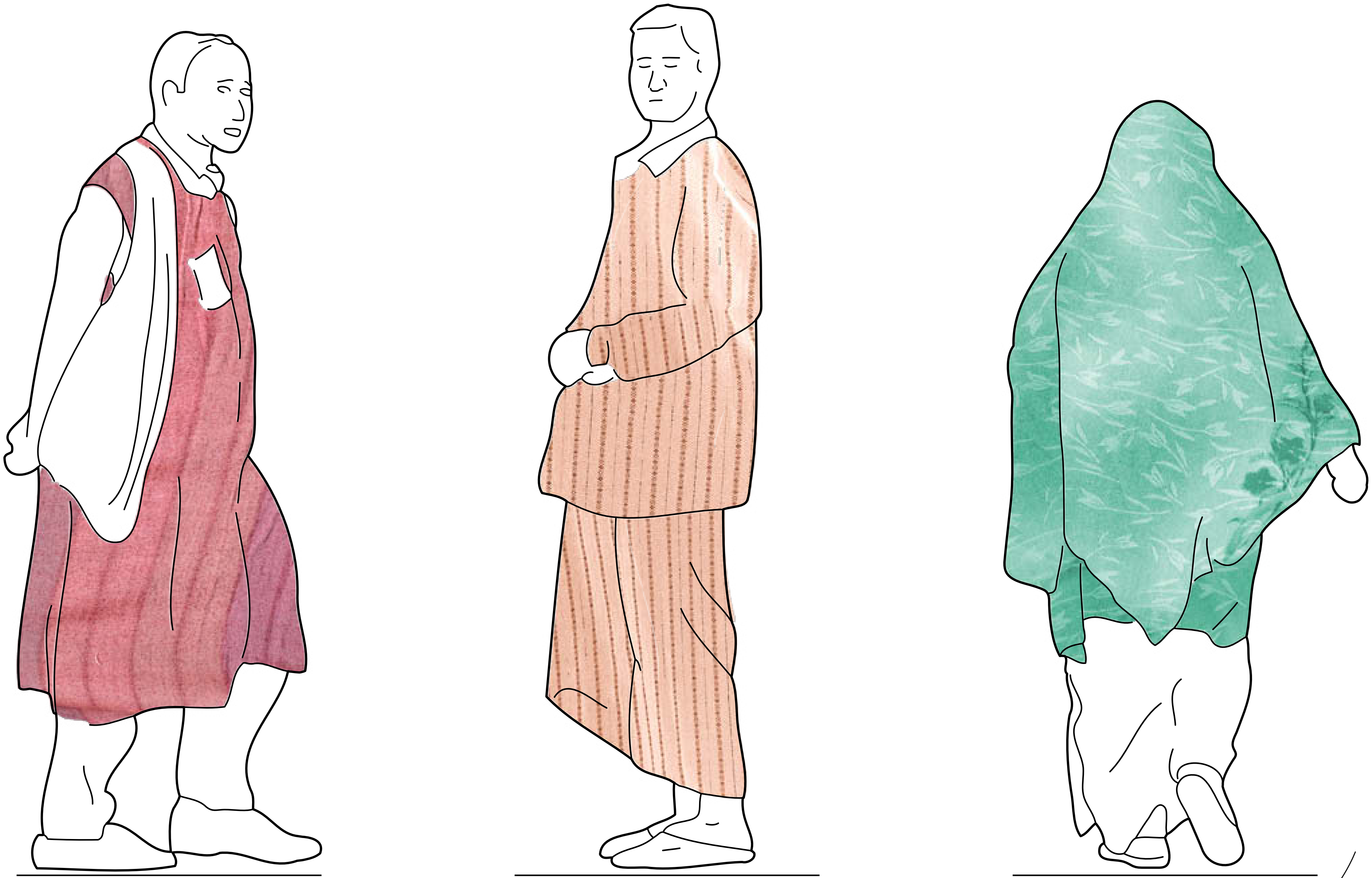
Key references:

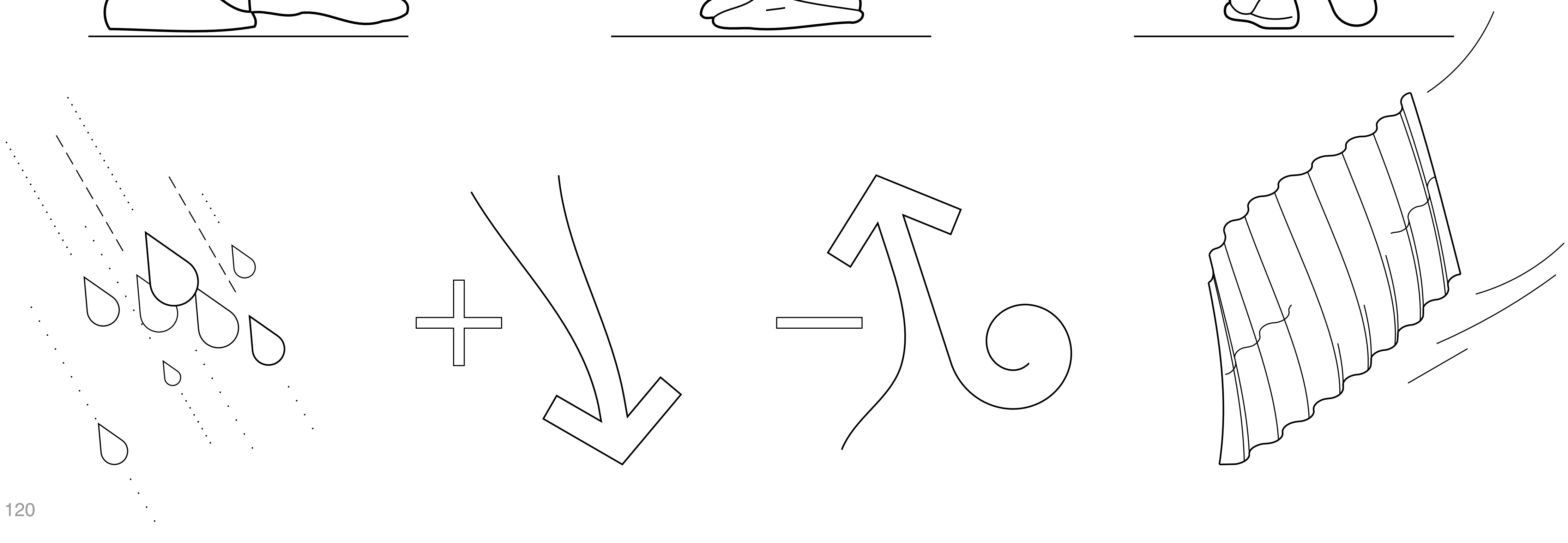
William J.R. Curtis. "Modern architecture since 1900". Phaidon Press, New York1996, 3rd ed, 736p.

Hassan Fathy. "Architecture for the Poor". University of Chicago Press, Chicago 1973, 233p + ill.

James Steele. "An Architecture for the People, the complete works of Hassan Fathy". Thames and Hudson, London 1997.

Appendix

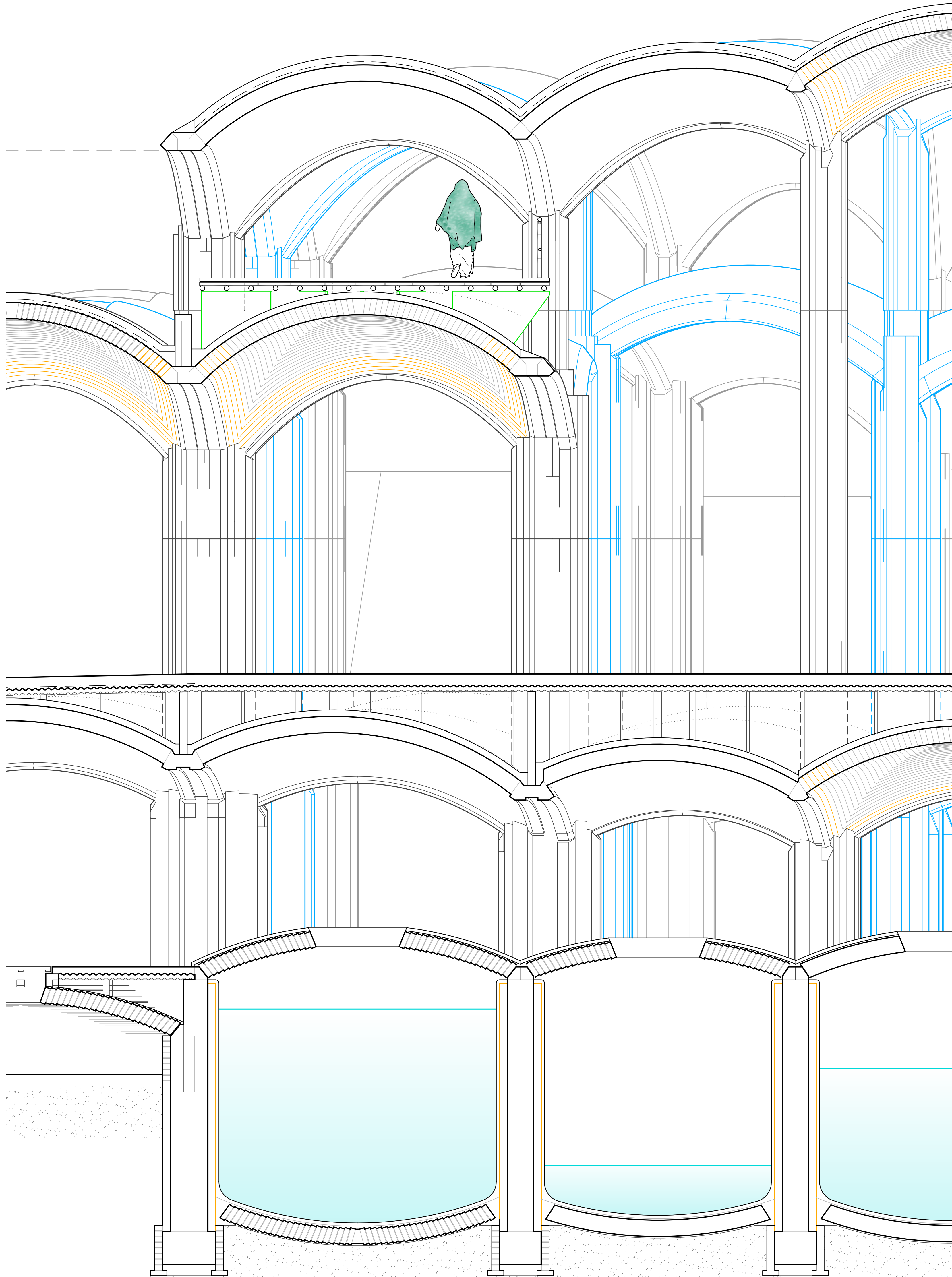




A Cyclone Shelter For Coastal Bangladesh

Jean-François C. Lemay

A 4th year student's work at the Architectural Association, this book presents an idea for a light-weight deployable shelter, then invites the reader to witness the devastation caused by cyclone Sidr in a coastal village of Bangladesh. In order to alleviate the effects of future cyclones, a strategy is proposed which comprises of a model cyclone-proof bamboo house, as well as a community mosque, where spaces for congregation and shelter would form one architecture.



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J F C Lemay