

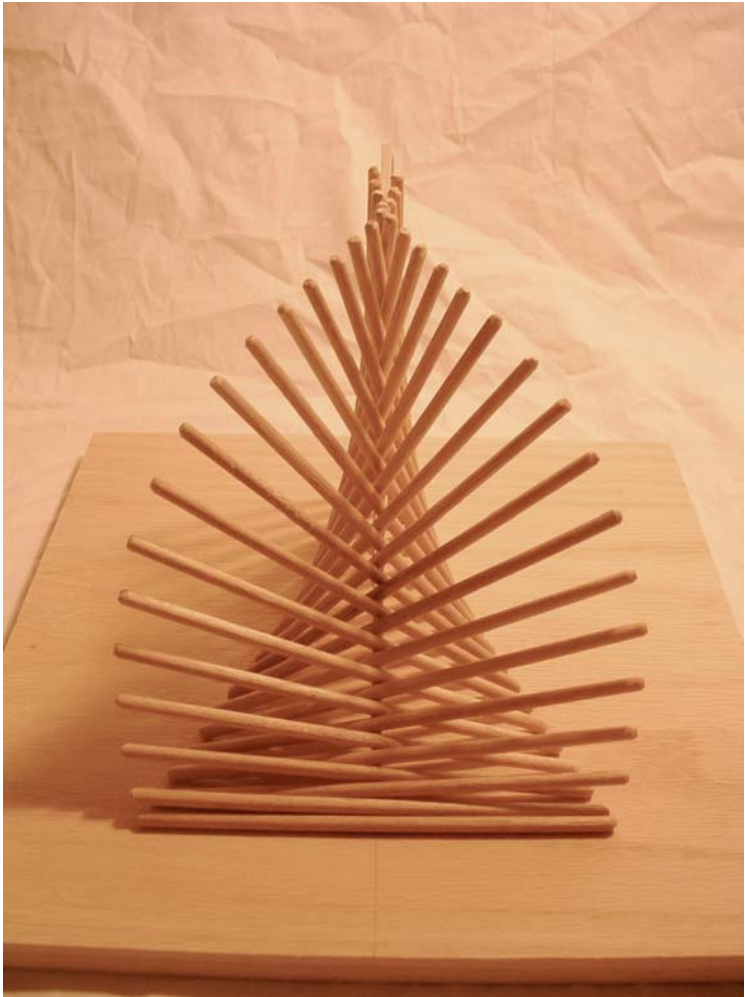
Introduction: Between Gehry and Mies

Conceptually, it is fairly simple to model an arbitrary blob and then demand that every piece of it be custom made. In fact, some modeling programs like Rhinoceros can generate beautiful shapes with just a dozen clicks of the mouse.

The execution of this form, however, can be extremely complex. Thousands of unique parts must be fabricated, organized and assembled in a precise sequence, involving a massive investment of technology, labor and capital. This, to many, is the price of architecture.

Is it possible, however, to make a building between the customized blob and the standardized box - a building which combines the visual richness of the former with the economic elegance of the latter? In such a building, a handful of custom pieces act as a generator for the form, which is comprised mostly of standardized parts. My thesis is an exploration of this idea.

Because the investigation is primarily the development of a personal language of construction, the final project has no site and no program. (In addition, the initial studies have no scale.) Ideally, my conclusions can be adapted to a range of programs, sites and scales. My goal with this thesis was closer to experimental research than the design of a specific project.



Initial Studies



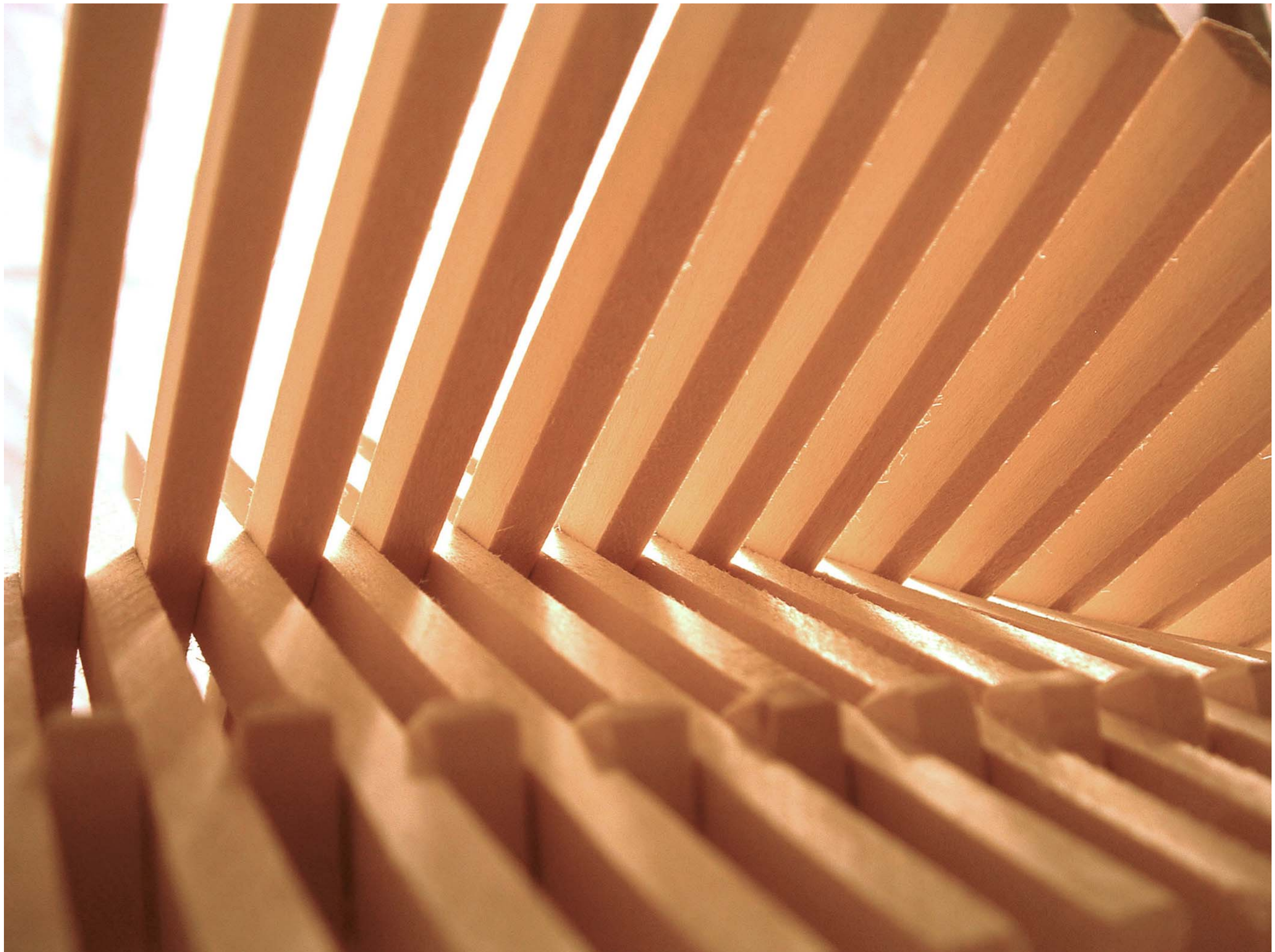
Model 1.0

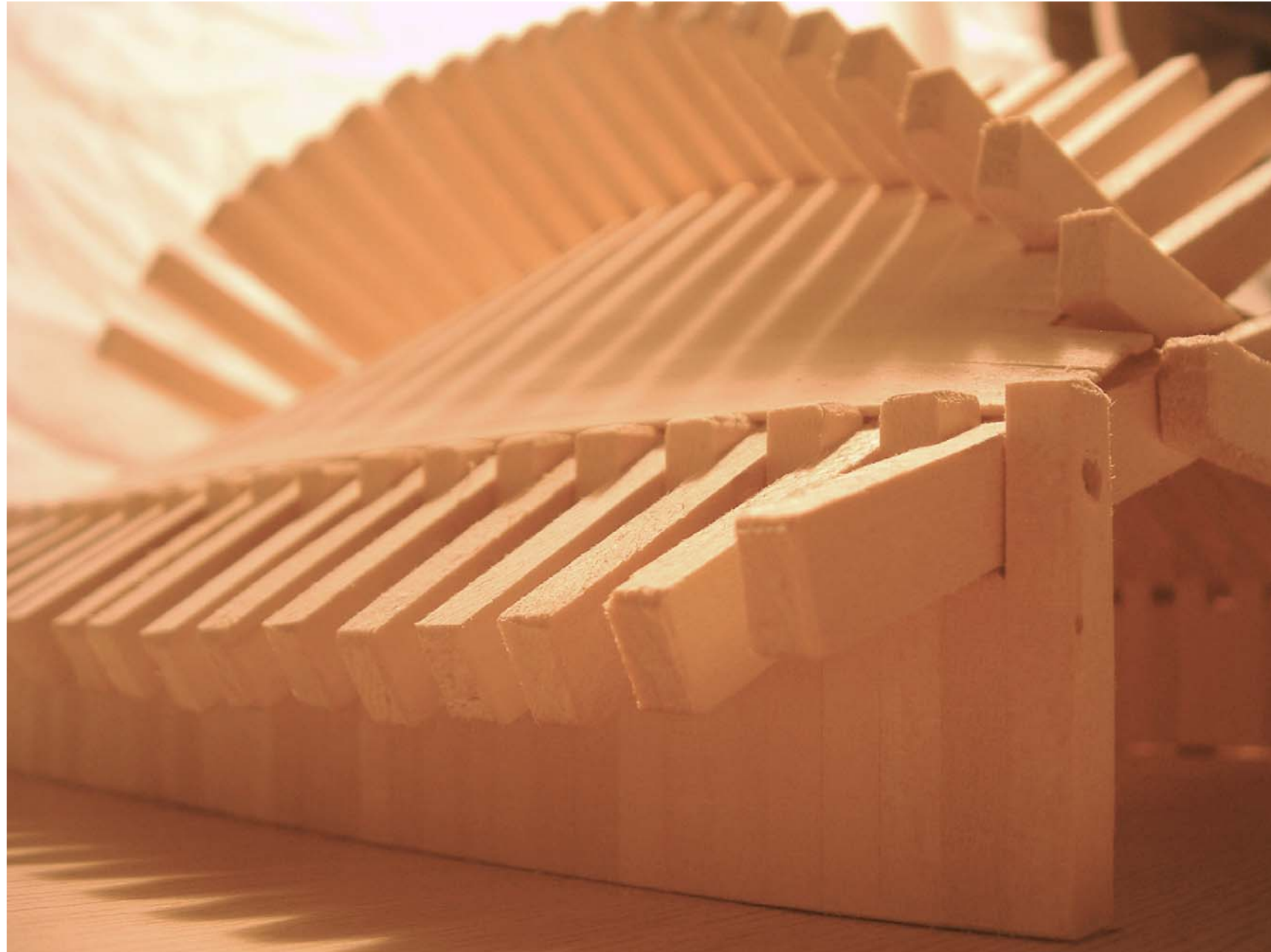
128 pieces, 3 types

(generator removed)

The initial model was built as a flexible prototype, with each roof member connected to the supporting walls by means of a pin connection. This gave each beam the freedom to move independently; once in place, the model held its shape by friction.

One problem with this model was the limited range of forms, due to the limited movement of the members. The picture above illustrates the full range of motion of the members.

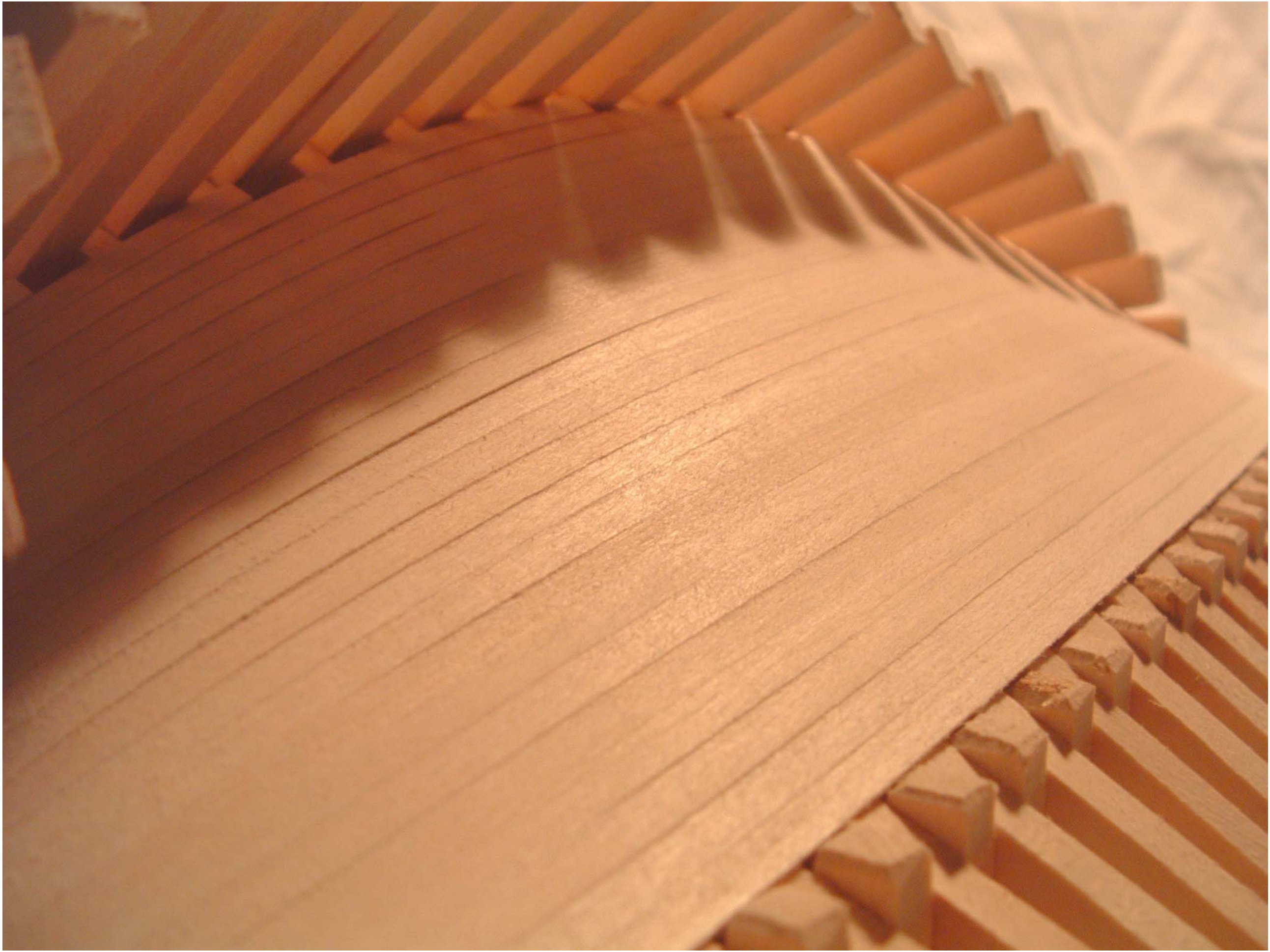


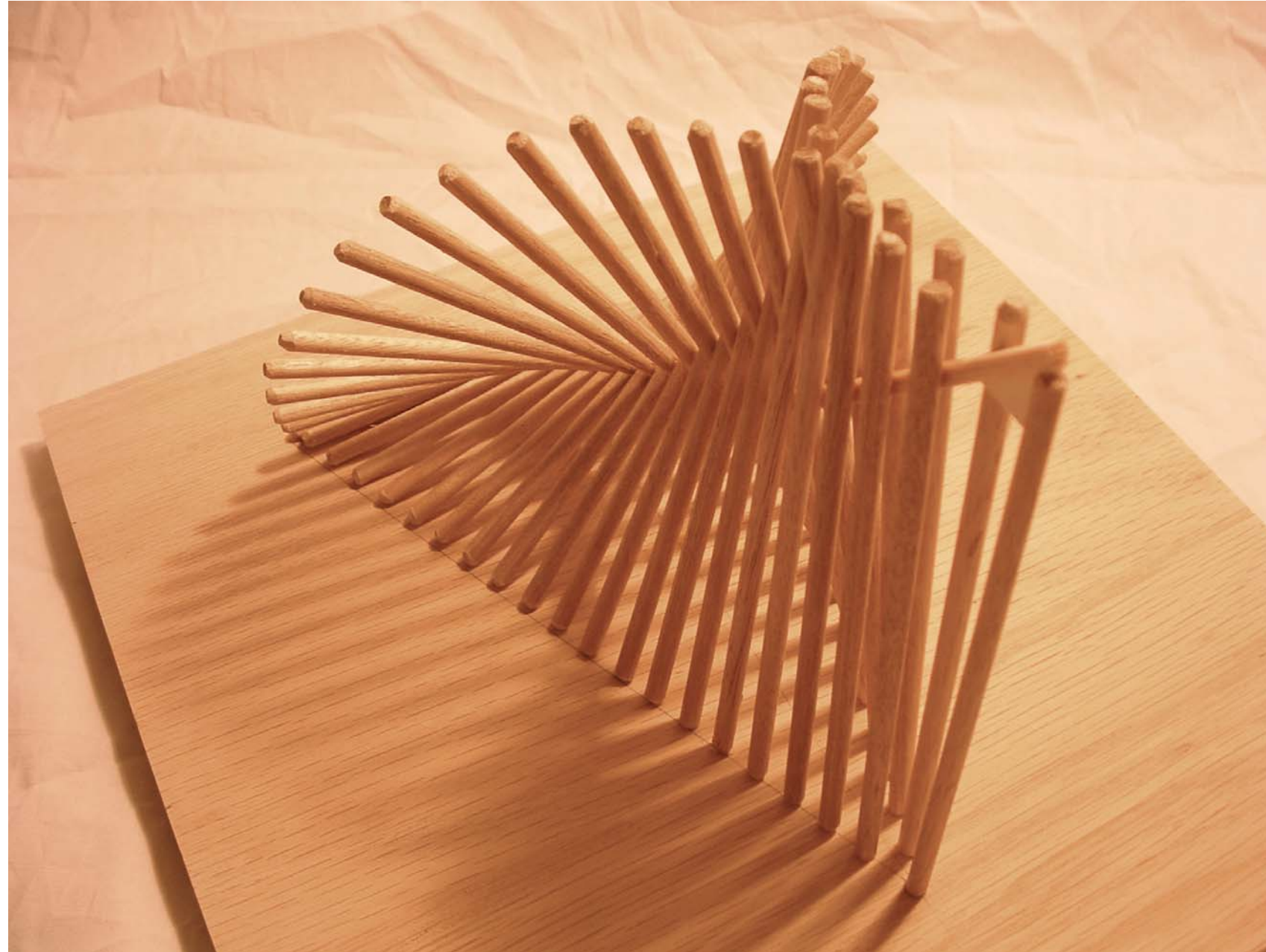


Model 1.1

49 cladding strips added

For this adaptation, the supporting walls were moved further apart and the shape was fixed with a circular arch placed diagonally in plan. Then, flexible basswood strips were glued to the exterior to investigate the cladding of this curvilinear surface. Overall, the experiment was successful; the radius of curvature was sufficiently large to accommodate the bending stiffness of the cladding strips.



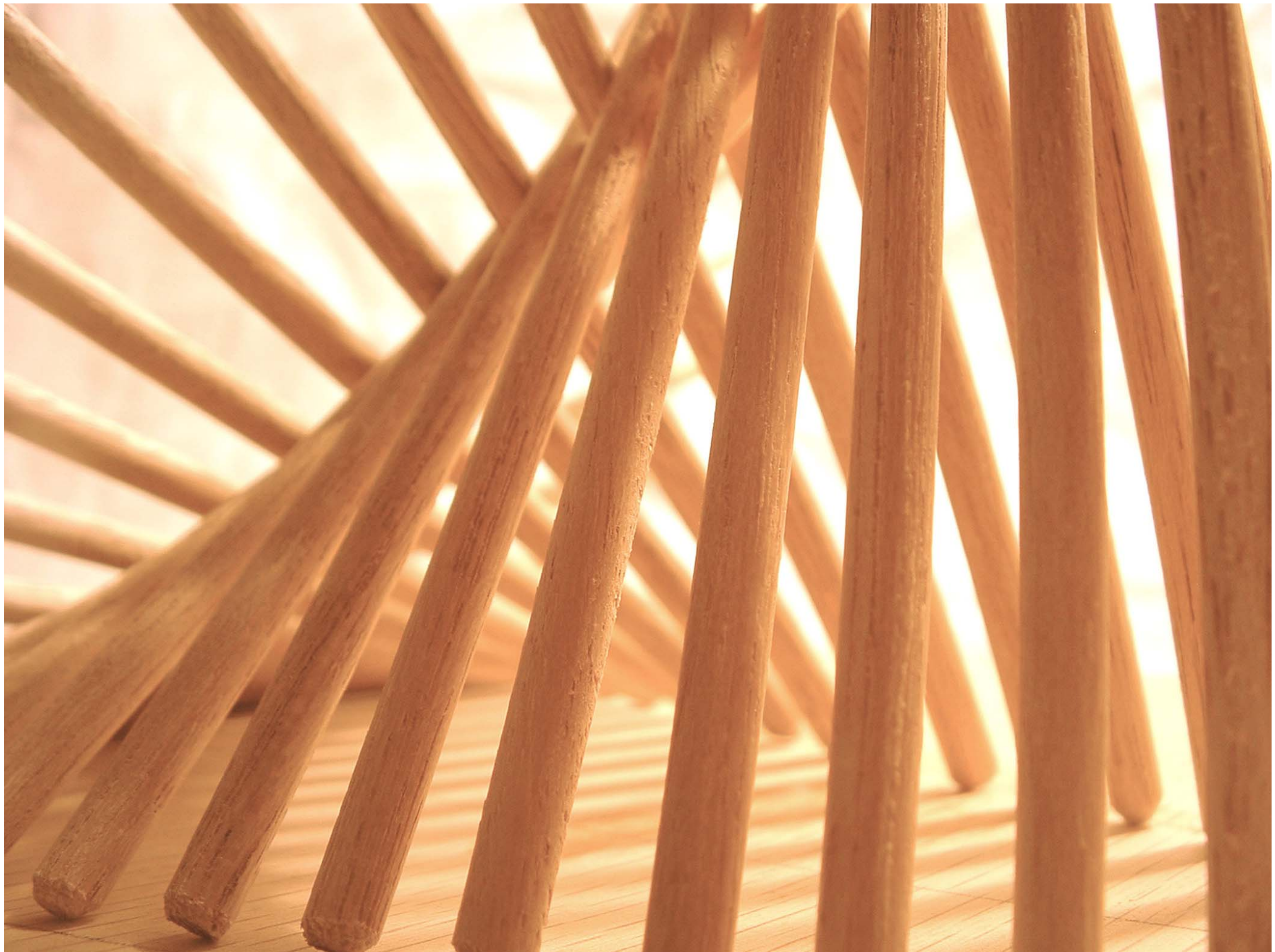


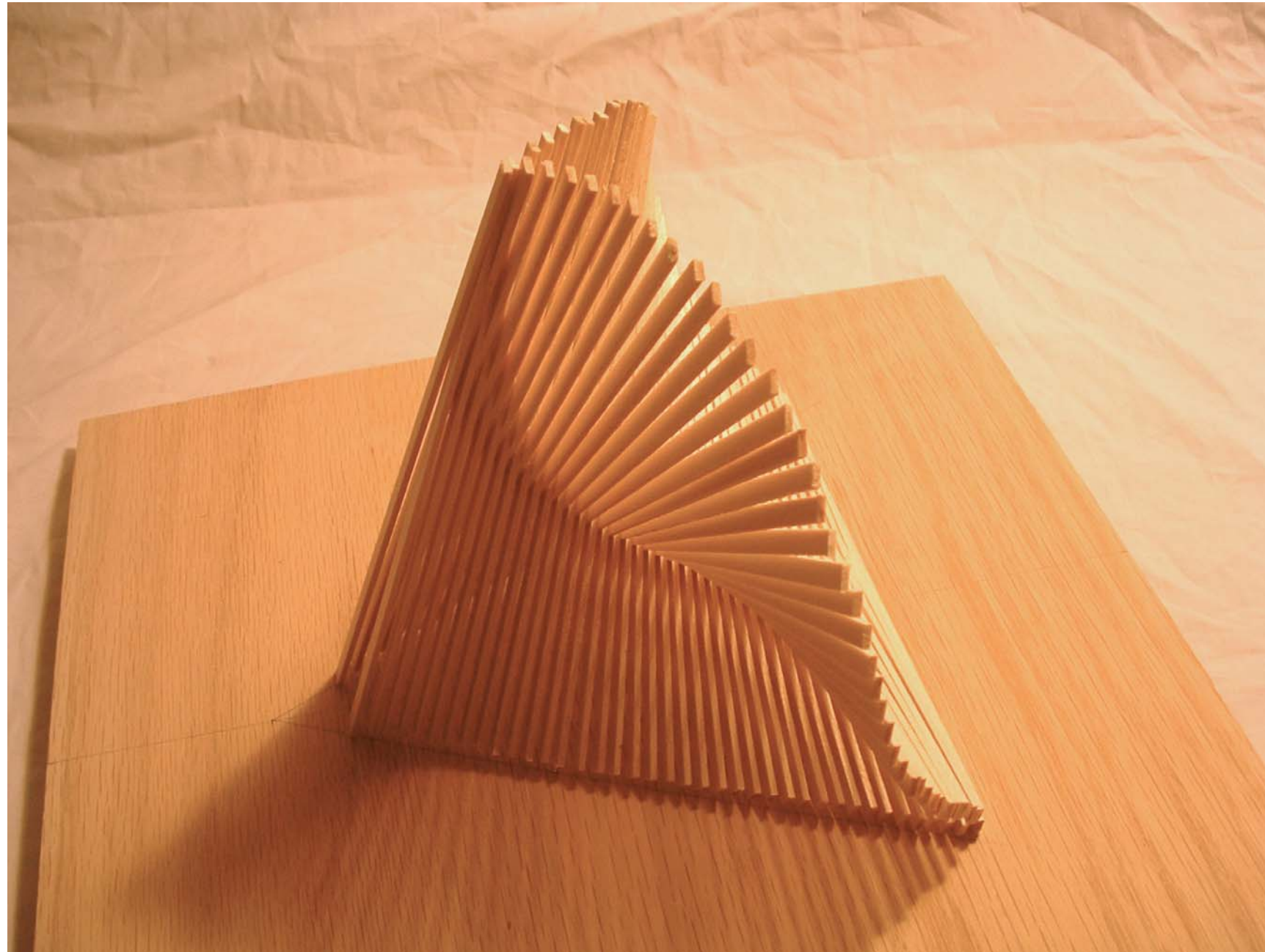
Model 2.0

40 pieces (1 type) + generator

This is a model of ascending space. Occupants enter at the horizontal base of the structure, and inside they see the individual beam-columns marching toward vertical. The bases of these members would bear on a concrete retaining wall at grade level; their horizontal outward thrust would counter the overturning moment due to the soil pressure outside the building.

Because the elements are circular in cross-section, they only come into contact at their points of tangency. This idea could be realized with bamboo; the connections between members would likely be made with cords.





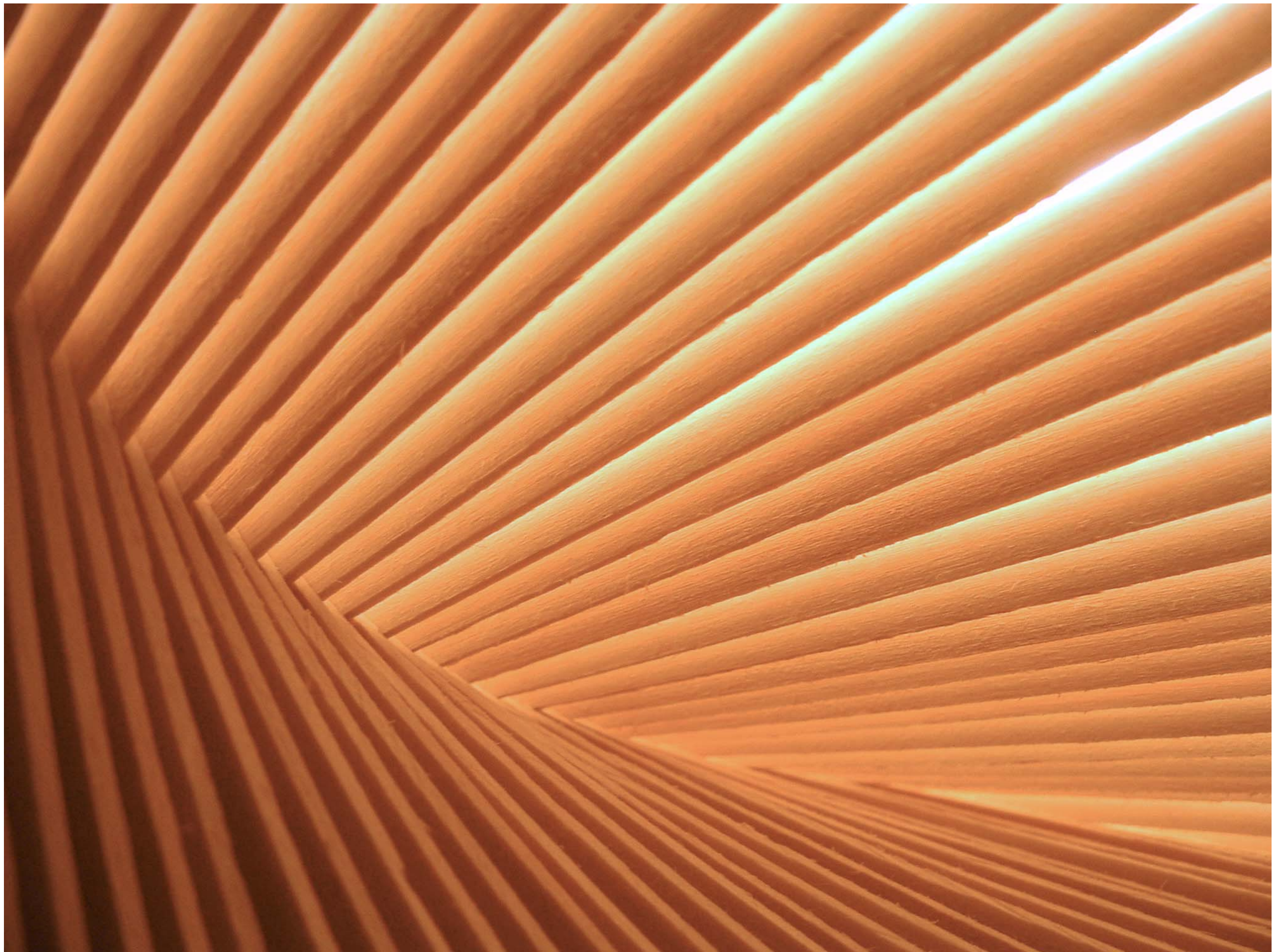
Model 3.0: Architecture as a Flexible Spine

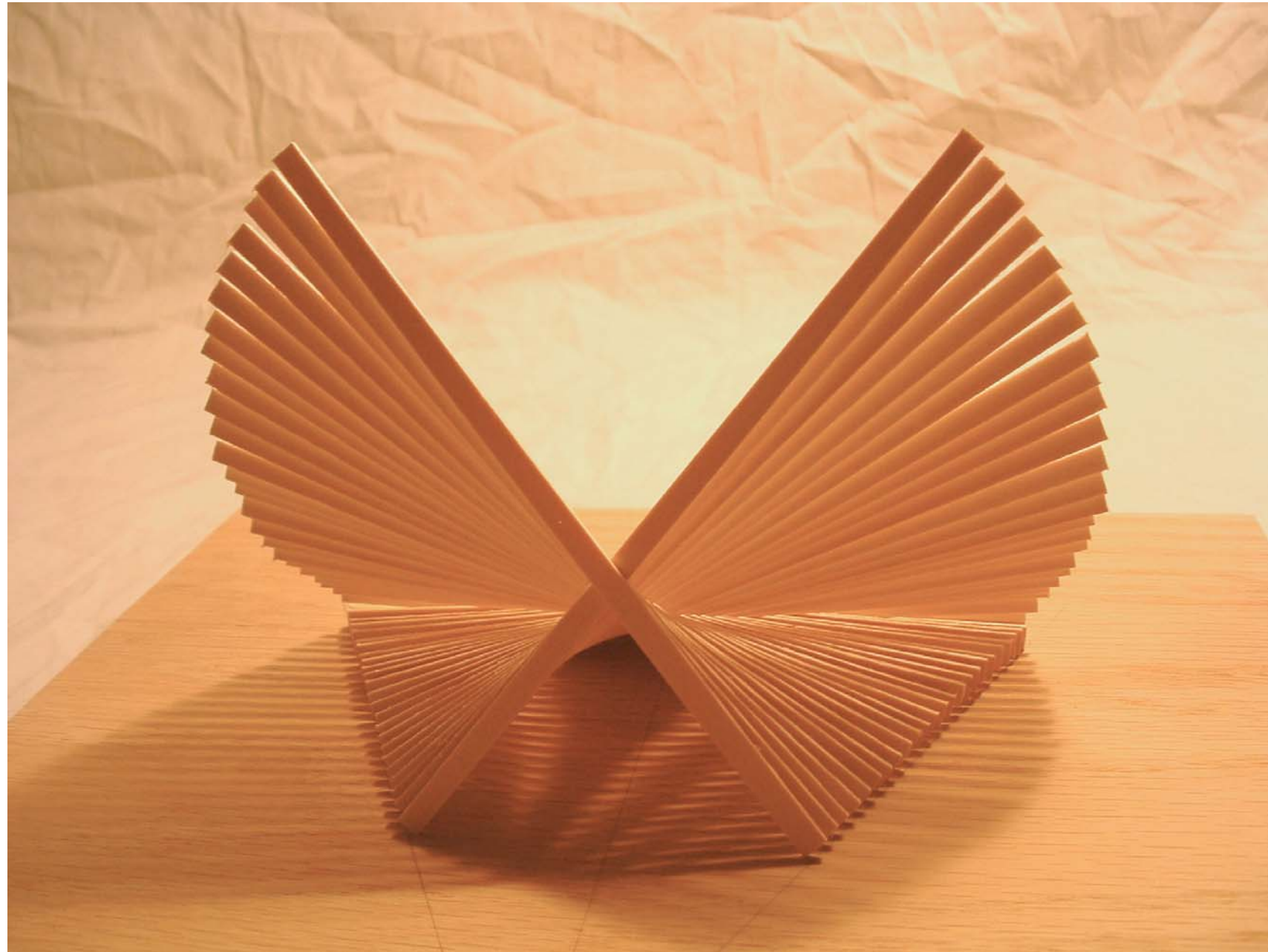
78 pieces (1 type)

(generator removed)

In this model, each piece is only connected to the member before it; only the horizontal member is glued to the base. The result is a relatively pliable structure.

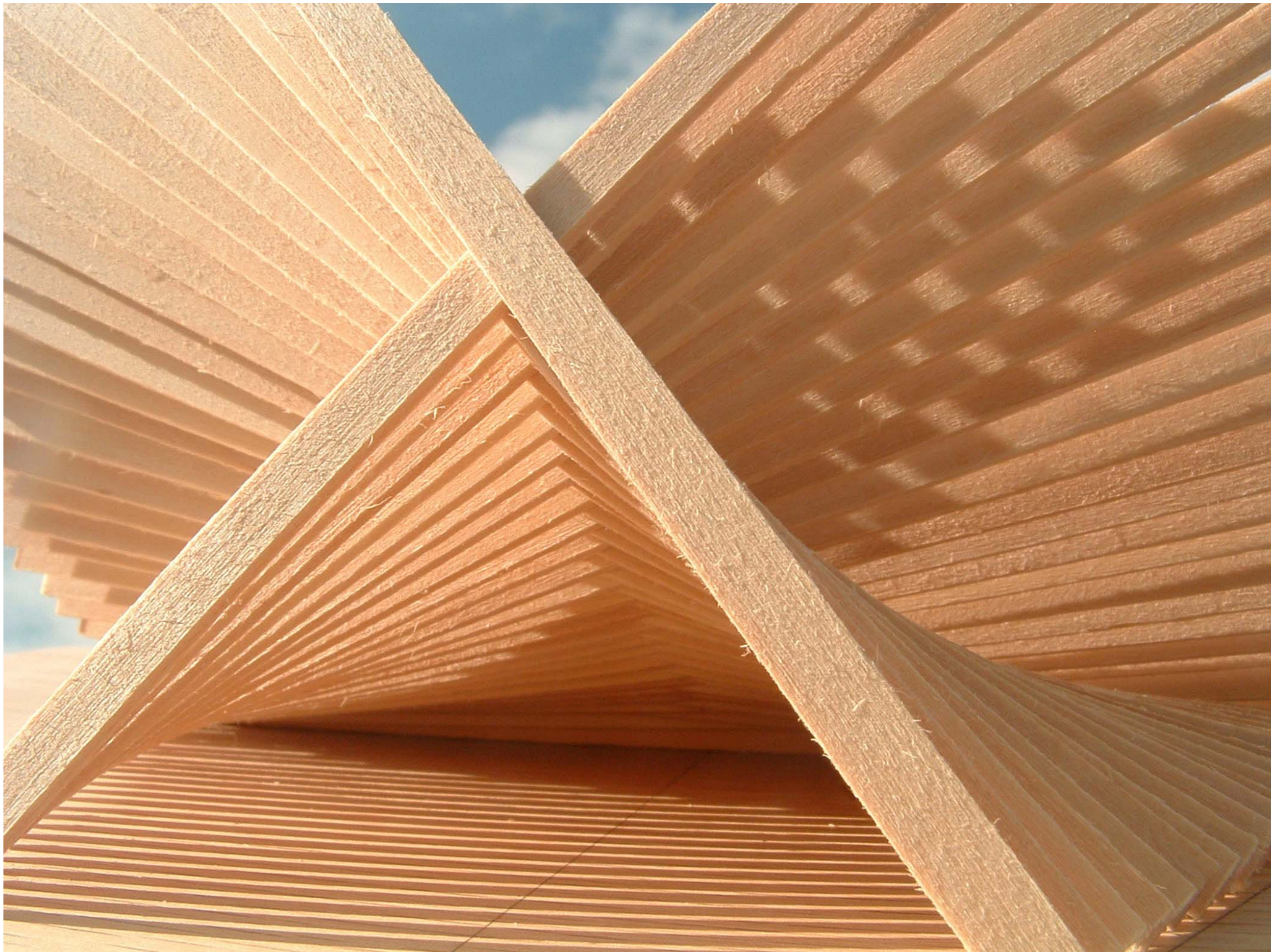
The progressive tilt of the members is a consequence of the construction method. Because each rectangular piece rests on a curved ridge beam, it tends to bend slightly downward. Over time, this minor inaccuracy adds up to a significant distortion.

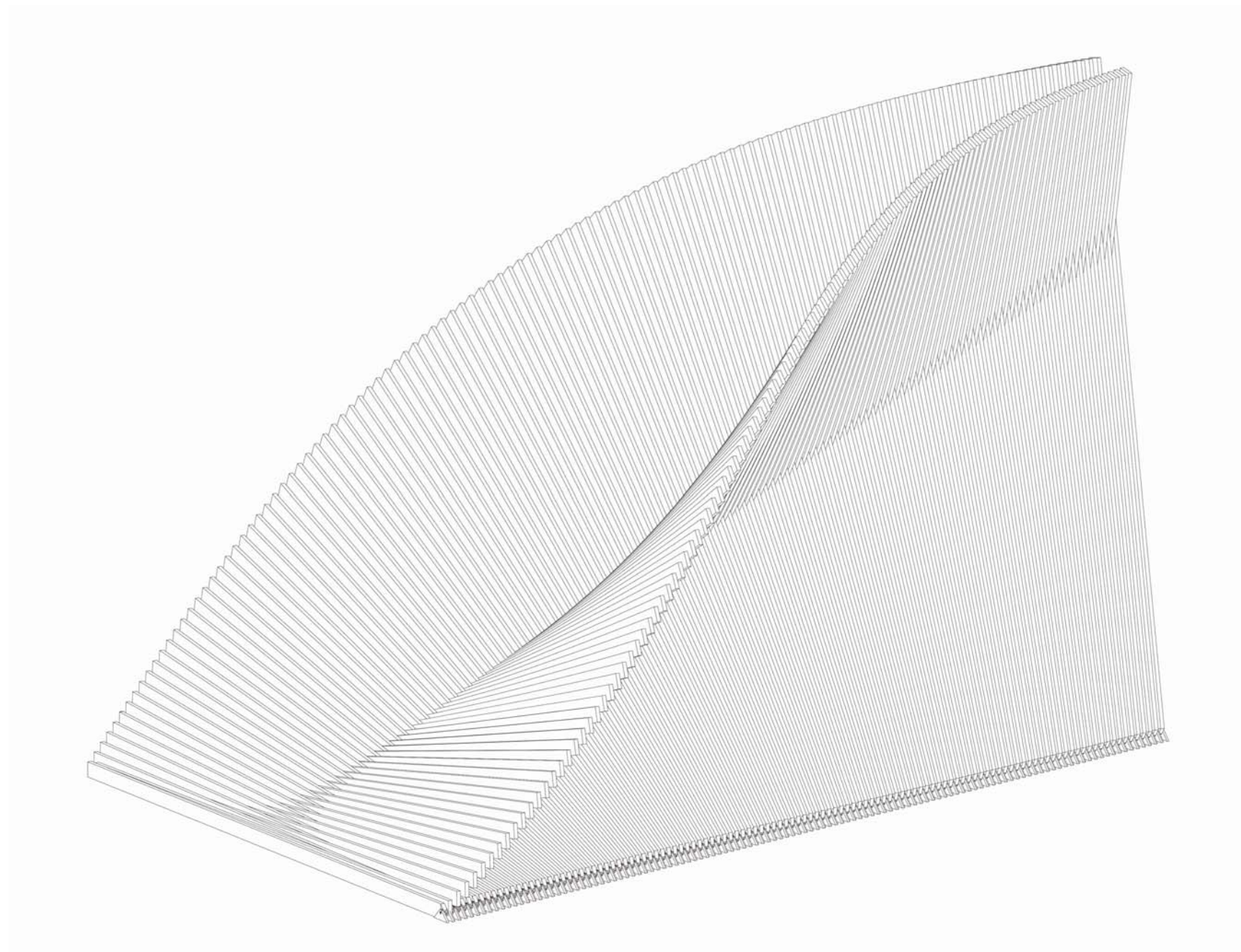




Model 3.1: Broken
29 pieces removed

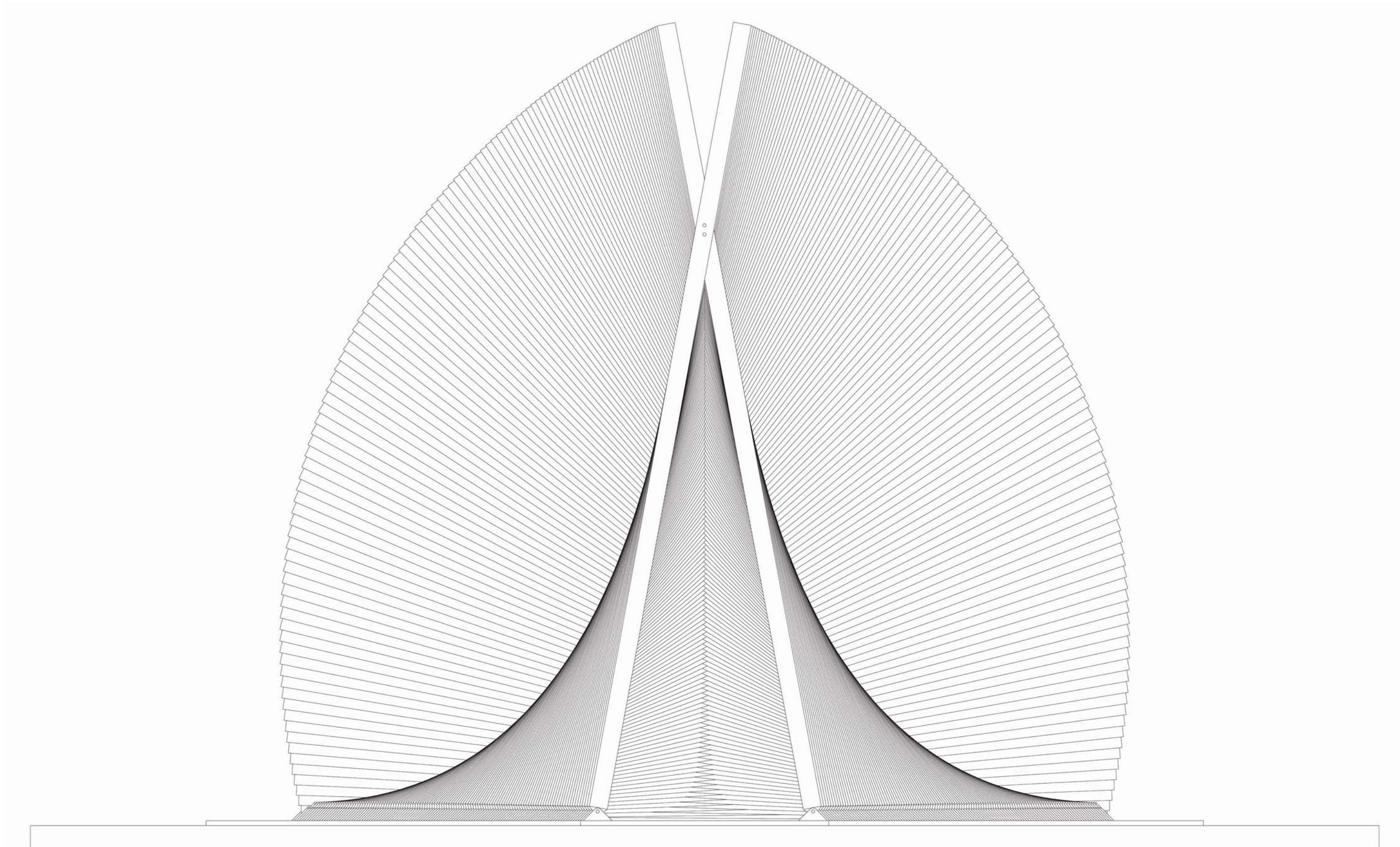
While testing the flexibility of model 3.0, a weak joint near the center of the model broke, leaving the shape shown above. Happily, this design appears to be superior to the original.





Model 4.0
472 pieces (2 types)
(generator removed)

Digital models are a fundamentally different means of exploration than physical models. In my opinion, even radiosity modeling cannot completely predict the light effects that happen with a physical model. However, digital models allow for rapid prototyping of new ideas, and complete control over member proportions. This is a further development of the idea behind model 2.0 and 3.0, built with greater numerical accuracy but less *visual* accuracy.

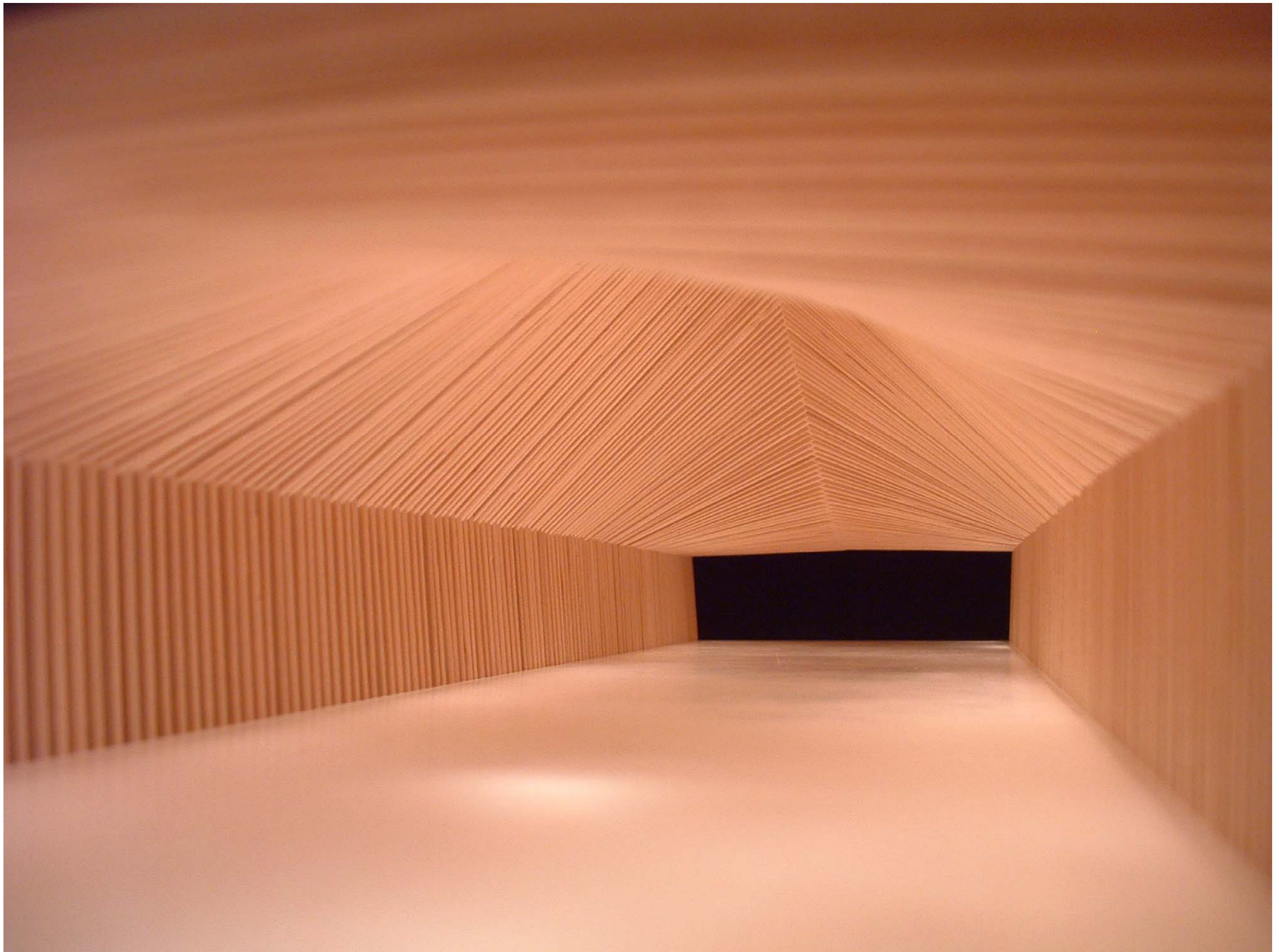


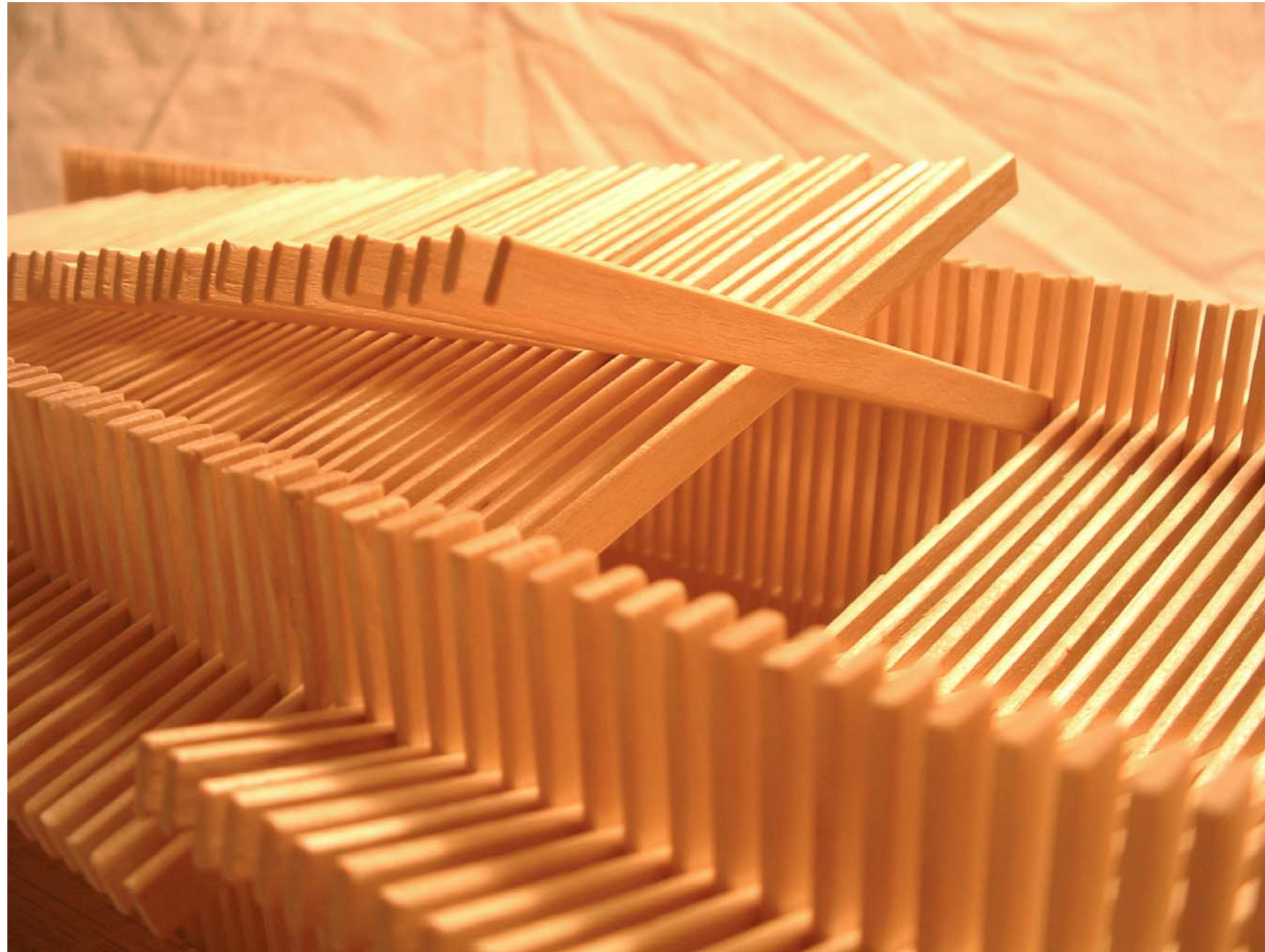
Generator Variations



Model 5.0
786 pieces (2 types)
(generator removed)

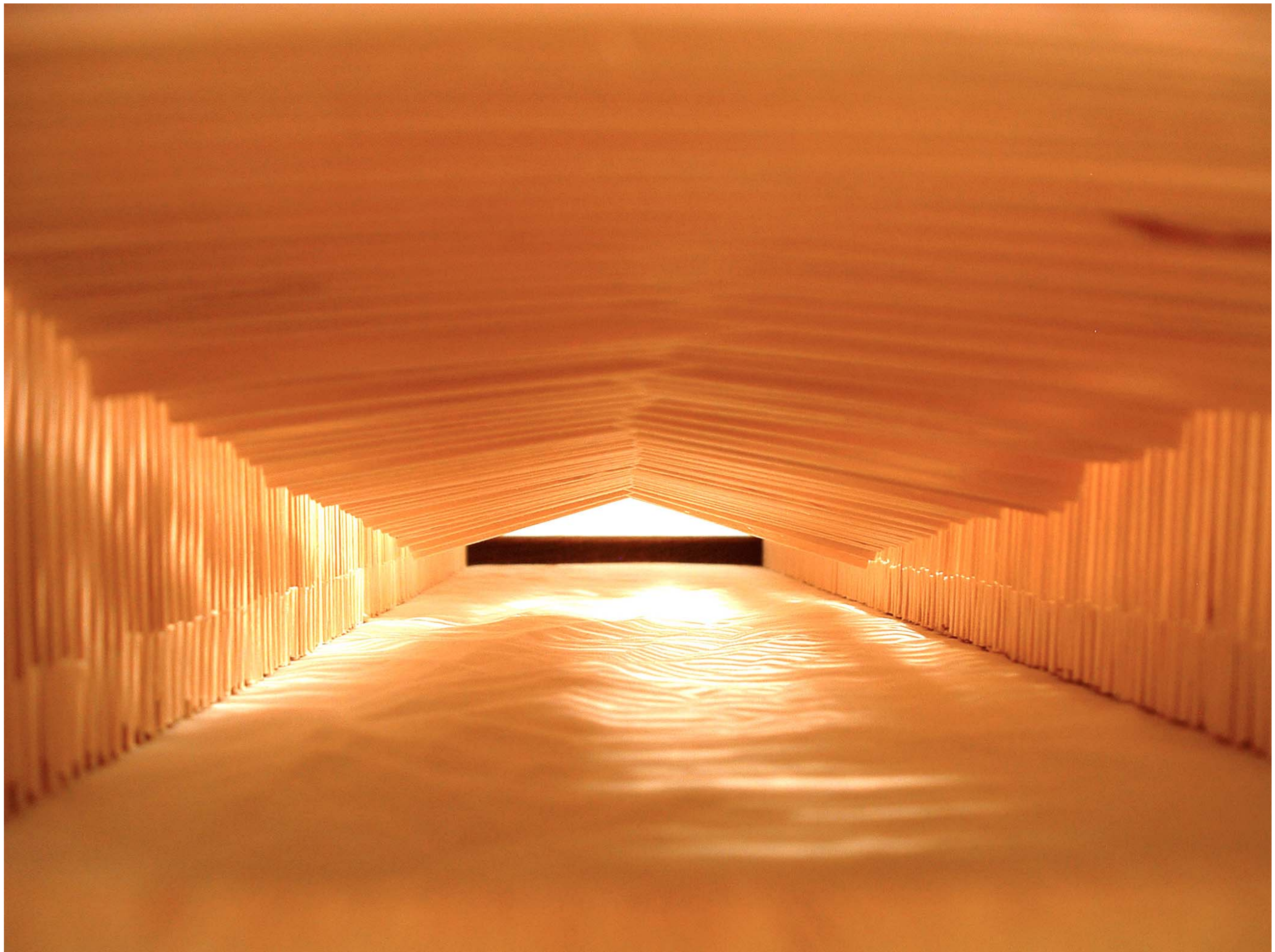
This model represents a further refinement of model 1.0. Each beam has complete range of movement, limited only by the supporting surface. Also, the number of members has been increased significantly, which means that the members blend into each other with distance.





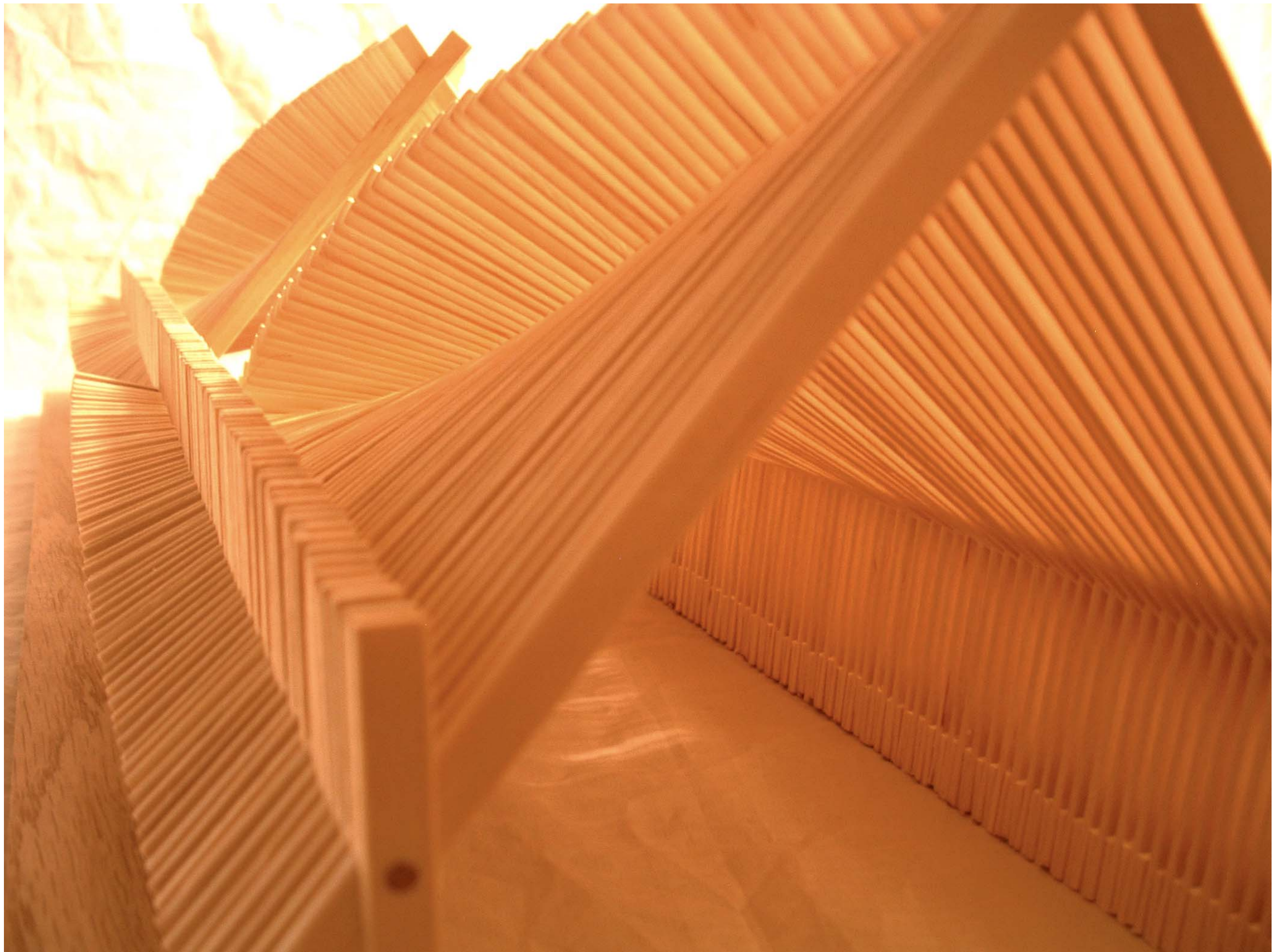
Model 5.1
786 pieces (2 types)
(generator removed)

This is simply a rearrangement of model 5.0; the pieces have been rotated according to a different generator. The same is true of models 5.2 and 5.3.



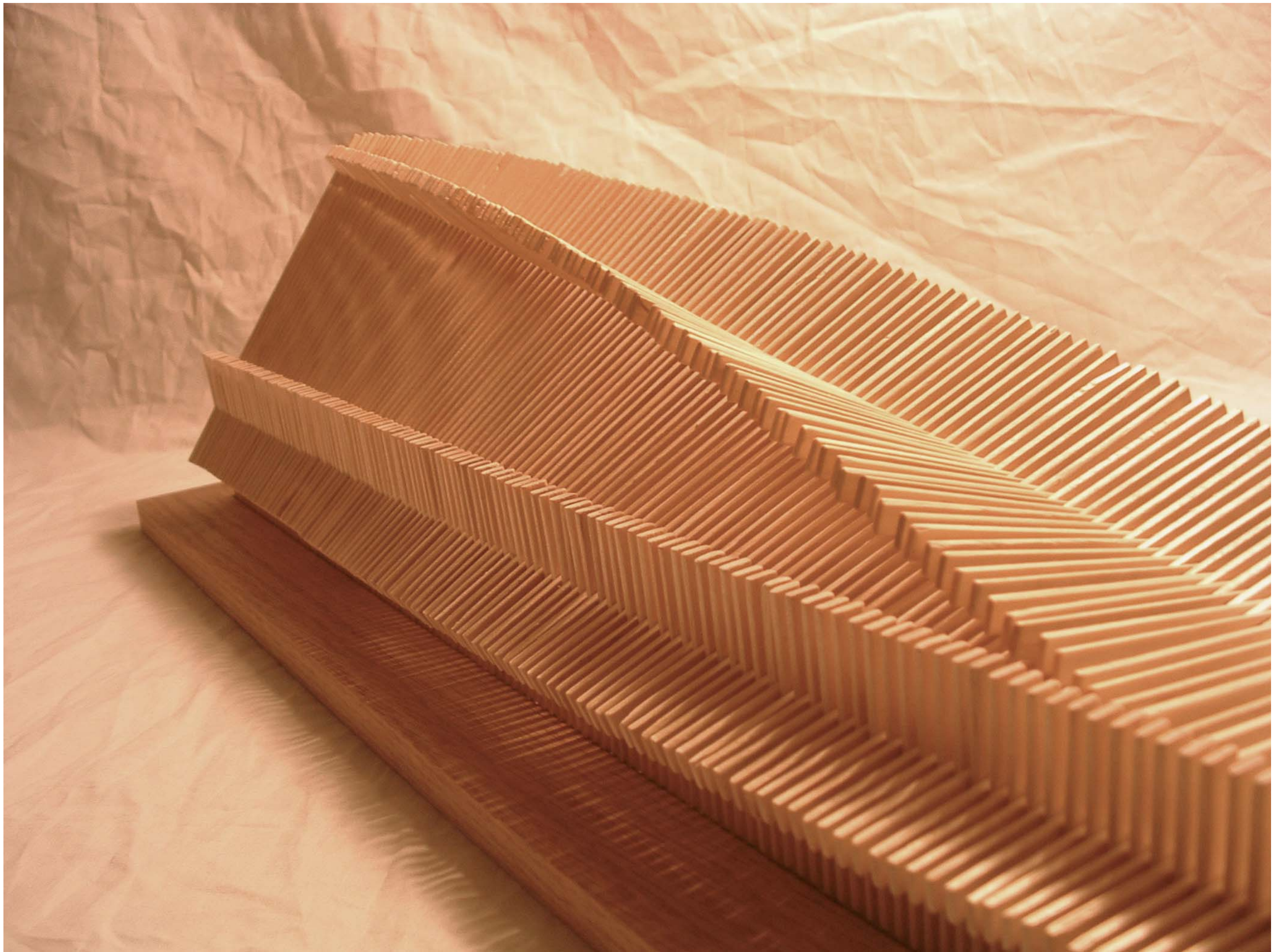


Model 5.2
786 pieces (2 types)
(generator removed)





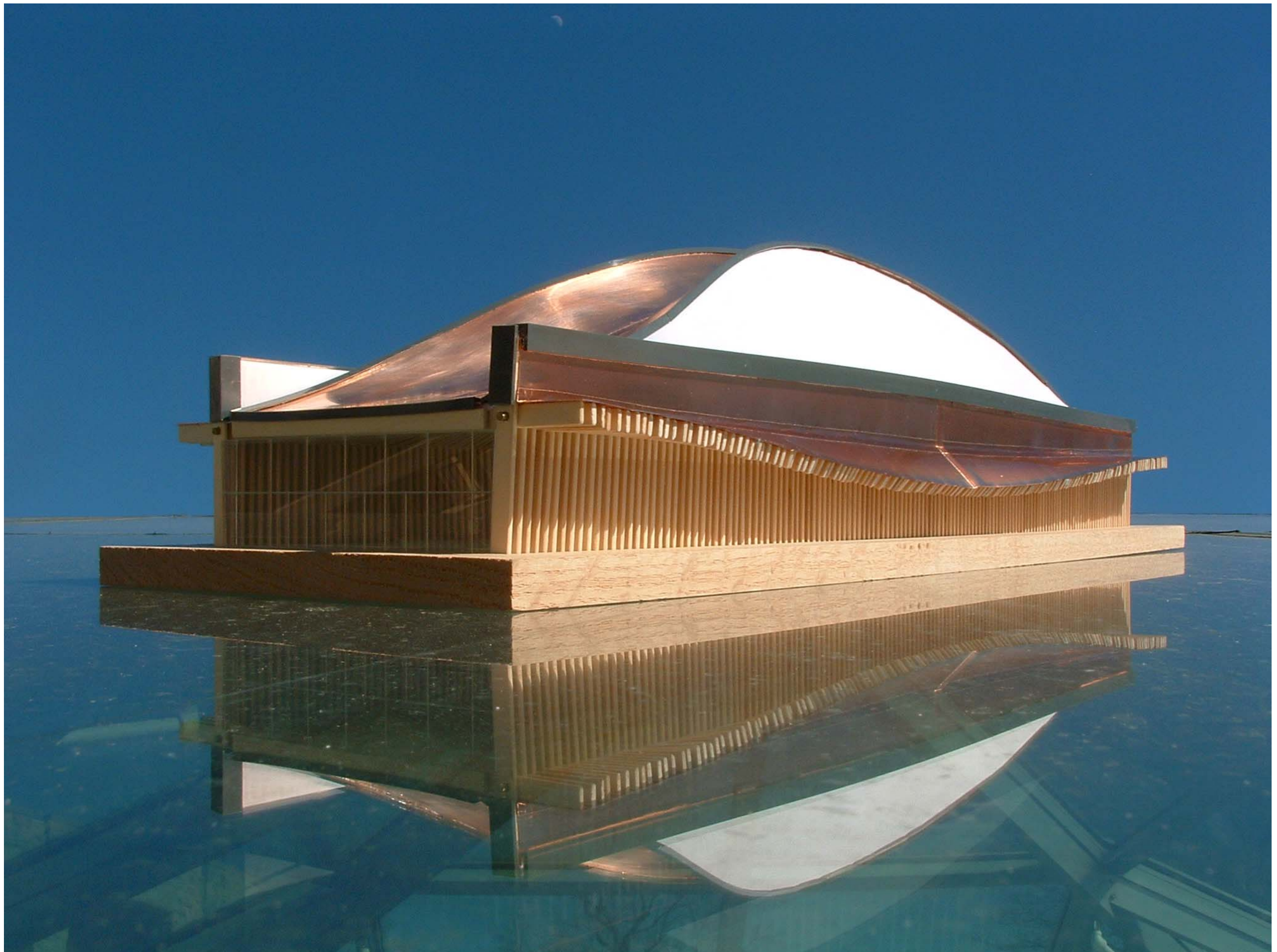
Model 5.3
786 pieces (2 types)
(generator removed)

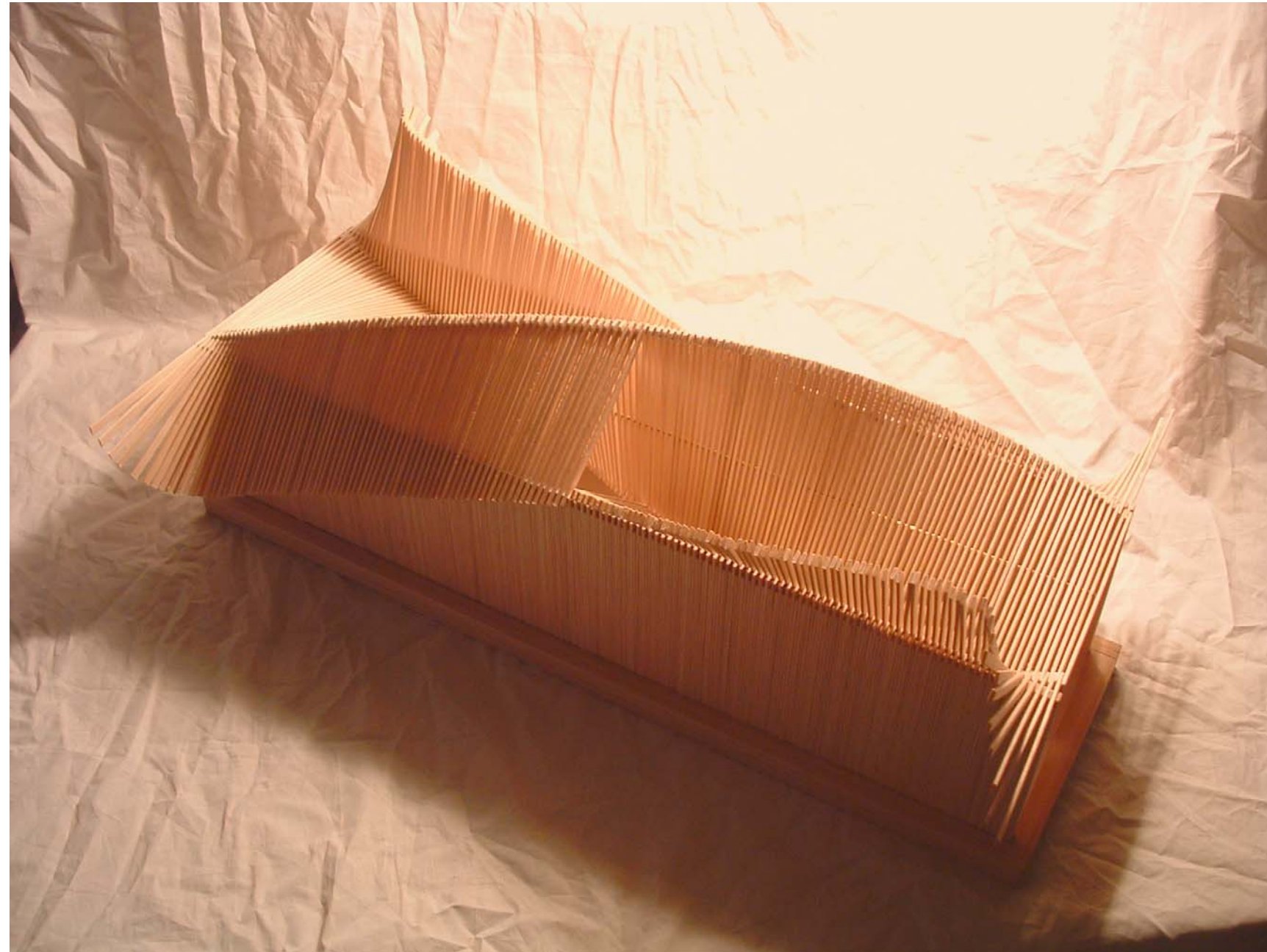




Model 5.0.1
7 pieces added

After evaluating the different forms, model 5.0 was chosen for further development. The pieces were fixed in place, and an exterior shell of stretched fabric and copper was used to clad them. This represents one possible approach to weatherproofing; simply construct an exterior building envelope which conceals the logic of the construction. Ultimately, it was found to be unsatisfactory. Partly, this is because the members form a *ruled* surface, they do not form a *developable* surface. A ruled surface consists entirely of straight lines; cones and cylinders are ruled, but spheres are not. A developable surface is one that can be clad using flat materials; only cones and cylinders meet this criteria. I was able to achieve the cladding shown only because of the large radius of curvature of the surfaces.

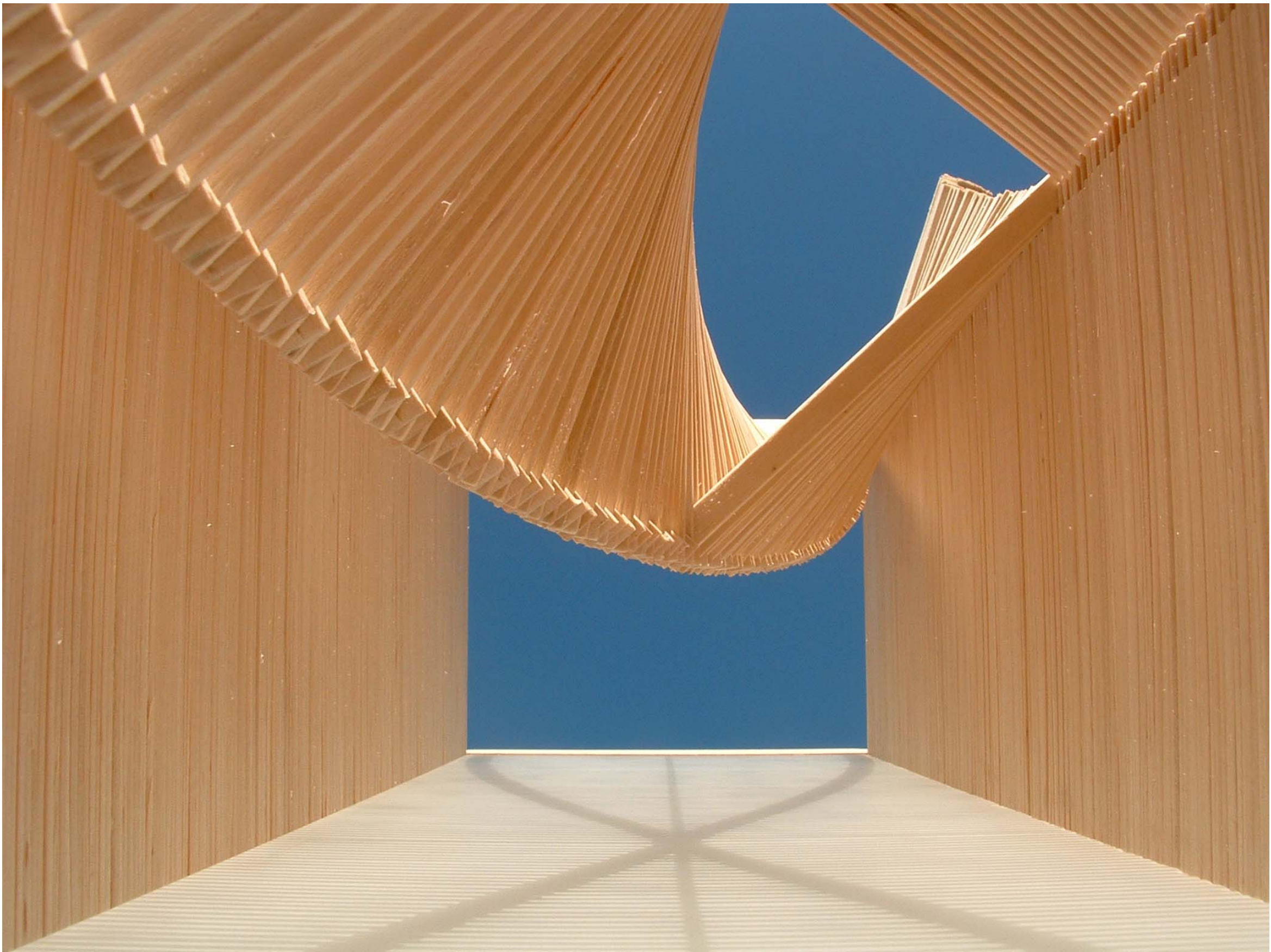




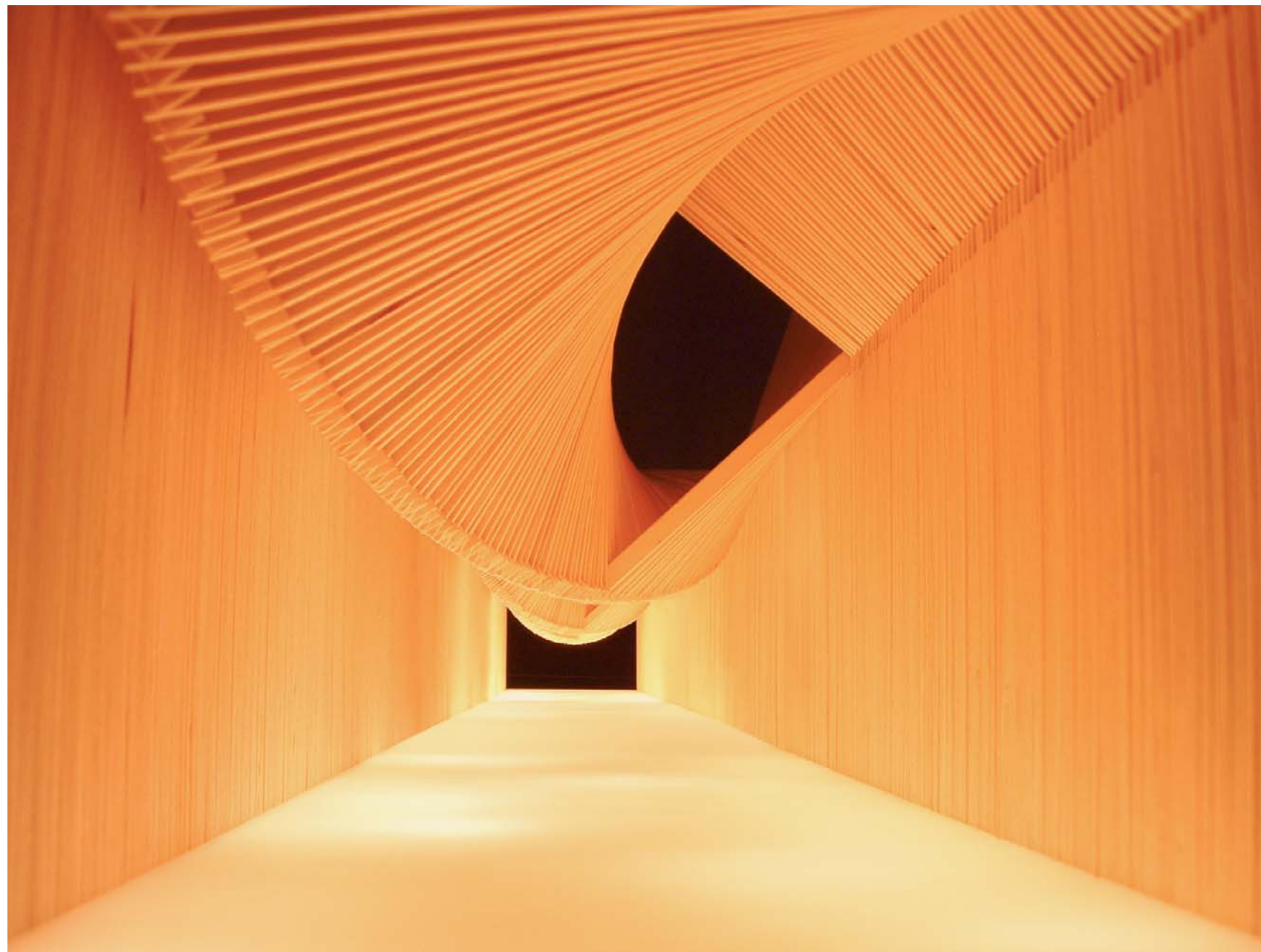
Model 6.0

1008 pieces (4 types)

To test the limits of this method of construction, I decided to create a structure in which the roof spins 180 degrees along the length of the building; the bottom becomes the top, and vice versa. Many of the subsequent design decisions were based on this idea. First, intermediate beams are required to connect the spinning roof to the walls. Because these are all of uniform length, the arcs formed by their endpoints are entirely dependent on the original spiral. Second, the walls had to be of sufficient height to keep the rotating beams from getting uncomfortably close to the floor inside. The generator for this shape is the spiral itself; there is no separate generator element.

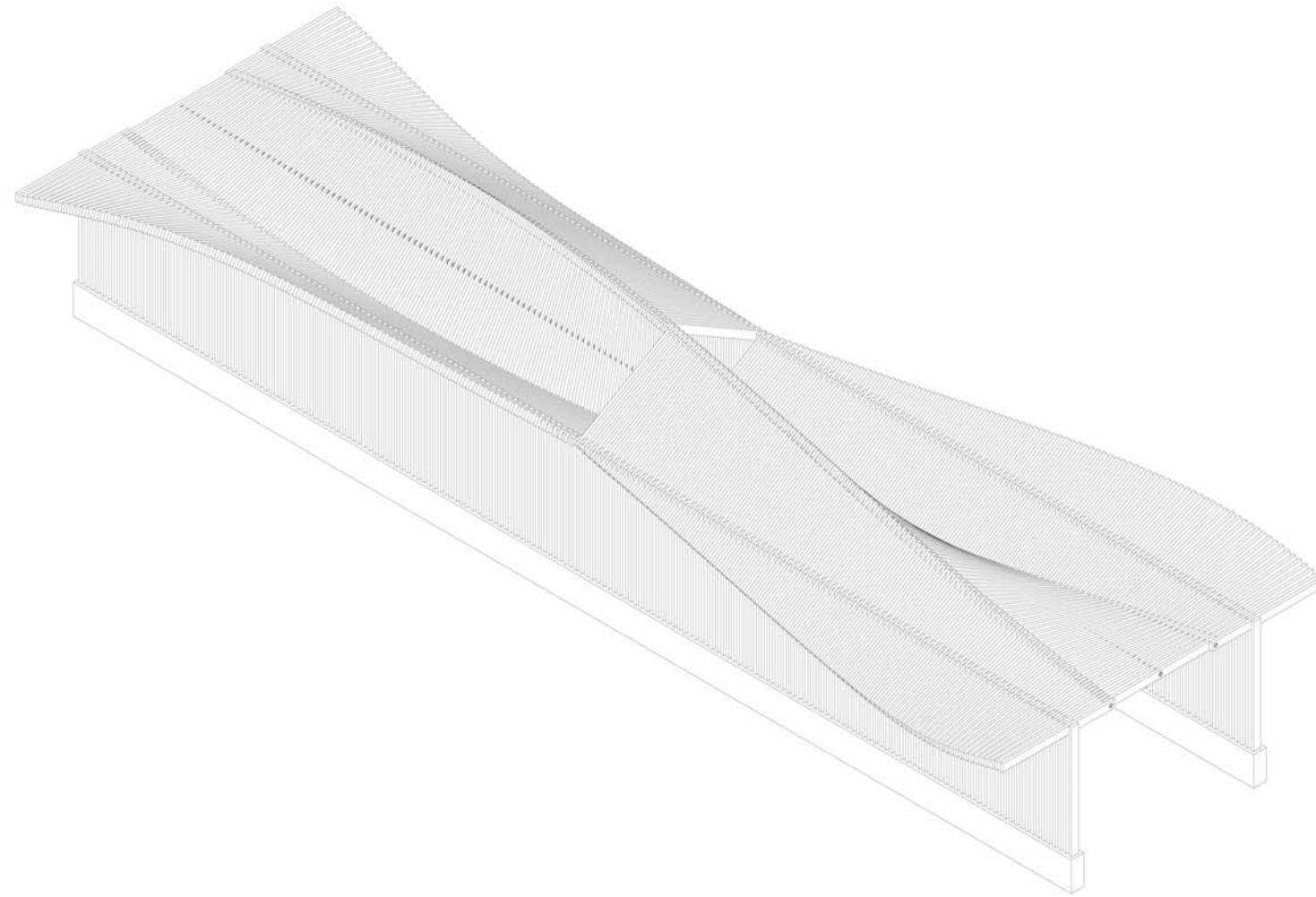


More than any other design, this model was visualized as a series of frames in a movie, in which the center beams rotate at a constant rate and the connector beams (hinged to each center beam and resting on the walls) move according to their own constraints. In the physical model, time is replaced by space, and we see the entirety of the movement at once.



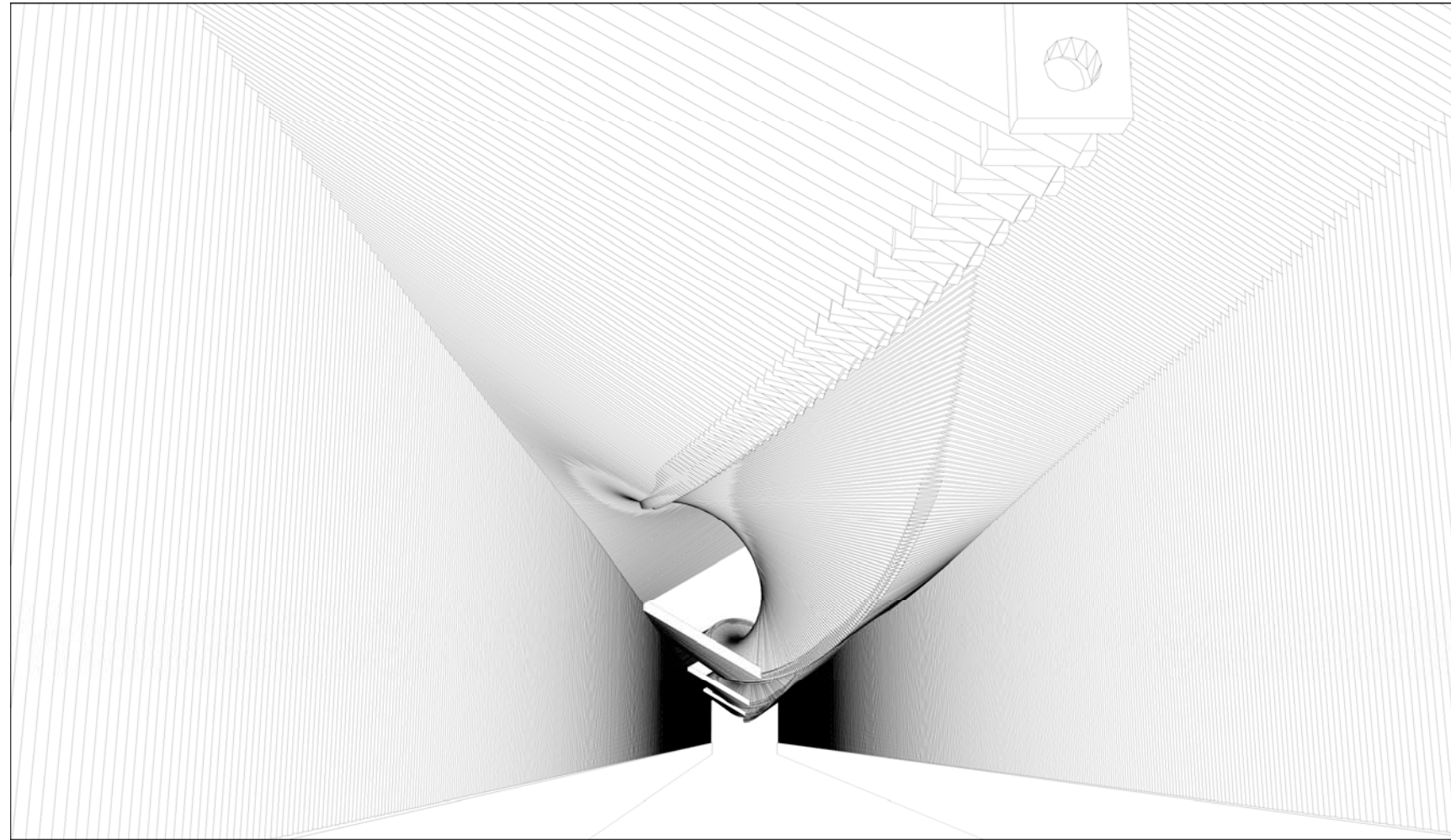
Model 6.1
3024 pieces (4 types)

Because model 6.0 is a 180 degree spiral, it can be repeated infinitely. Here, the length of the model is tripled by compositing multiple photos together. The effect is subtle; we see just a hint of the repeating arcs.



Model 7.0
922 pieces (1 type)

One shortcoming of model 6.0 became apparent only after it was built. Because the edges of the center beams are very close to the walls, the connector beams rotate very sharply at the ends. In this model, the center beams are shorter, which allows the endpoints of the connector beams to form much smoother arcs at the roof eaves. This model represents a very pure formulation of the thesis, because all members – columns, center beams and connector beams – are of uniform dimension.



Model 7.1
2766 pieces (1 type)

Like model 6.0, 7.0 can be repeated infinitely. Note that, while the interior perspective for 6.1 appears to spin clockwise, 7.1 spins counterclockwise. (This is simply a matter of which direction the building is viewed from.) Also, it is interesting to observe the differences between representing this space photographically and representing it digitally. Because the software, like hand drafting, draws only the edges of shapes, the individual members eventually converge to a uniform black. In the photographic studies, the members simply blur into one another, creating a uniform tone which is the average of their color.

Application

The final application of these ideas consisted of multiplying model 5.0 up to building scale and then working out the required details. To ensure that the building's mechanical systems didn't interfere with its architectural expression, all lighting, HVAC and sprinklers were contained within the structural members and concealed with removable panels.

One problem with this approach is the connection between beams and columns. Because they are alternating, there is no direct way to move from one to another. For this reason, the connection between the two is a structural bearing ring made of delrin. (Delrin is an acetal resin engineering plastic manufactured by DuPont, often marketed as a metal substitute.) This allows each beam to rotate smoothly before being fixed in place, and also allows wiring and pipes to be run up the interior of the columns, then cross over to the interior of the beams without ever being seen by the building occupants.

As noted earlier, it was decided that polycarbonate panels should be run between the beams and columns to create a thermal envelope while admitting diffuse light. This created a problem, because the panels had to accommodate a constantly changing geometry with a standard detail. Ultimately, I discovered that each member could have an aluminum channel set into one side to accept the polycarbonate panel, and the opposite side could simply be supported by field-installed aluminum angles. The rule for the contractor is to fit each panel into the channel, then ensure that the panel remains level – thus allowing a constant polycarbonate panel width, and just a few custom cuts at the ends.

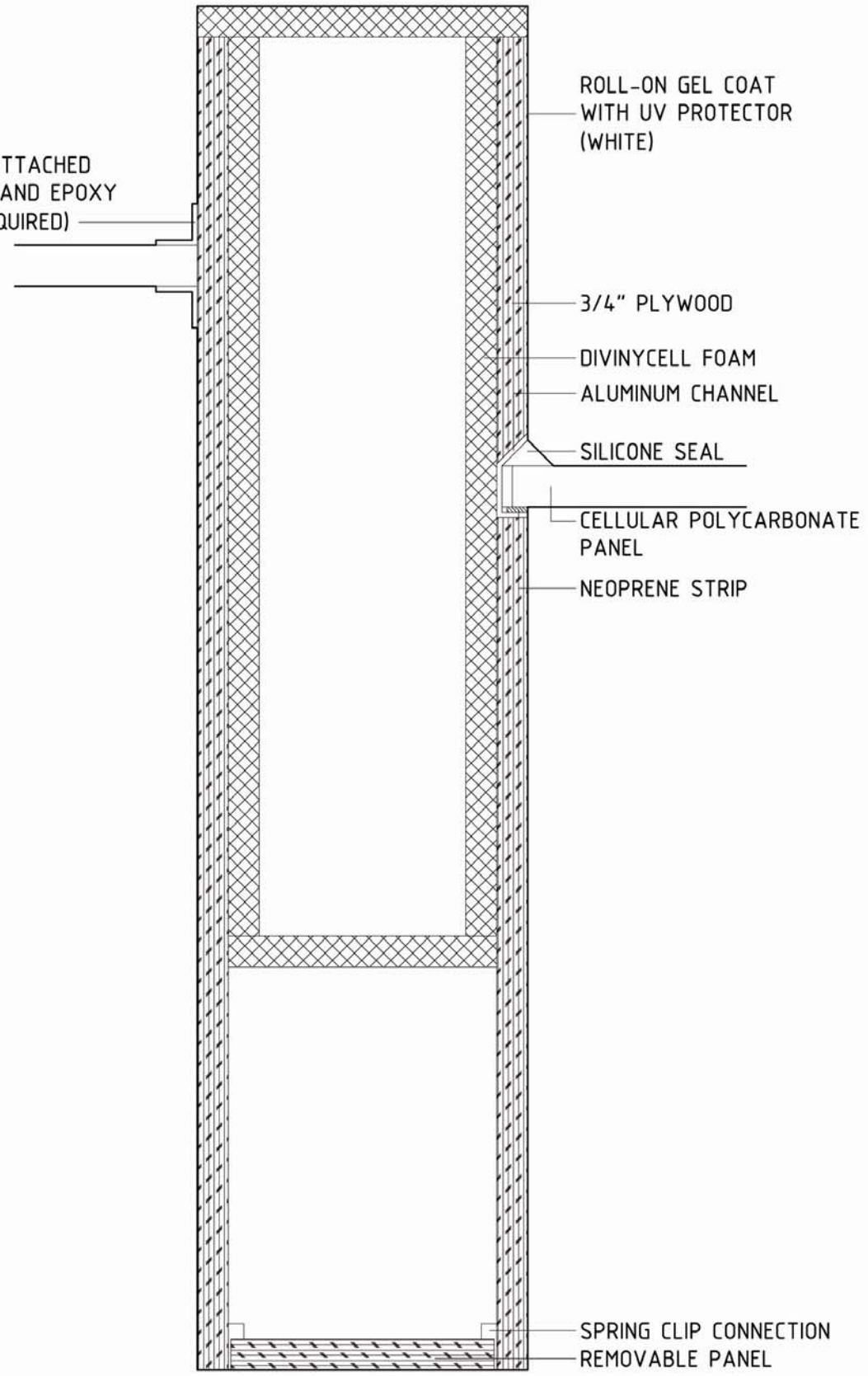
The interior structure of the members is an internally stiffened diviny cell box. (Diviny cell is a pvc material which is commonly sold in sheets. It is approximately twice as expensive as plywood, but it is strong, stiff, lightweight, insulating and waterproof. For these reasons, it is widely used in the maritime and aerospace industries.)

The sides of the diviny cell box are bonded to regular panels of ¾" birch plywood, which further enhances the member's bending strength. The removable panels are connected to the plywood, and the exposed end grain at the top is protected by the top flange of the diviny cell. Once the polycarbonate is installed, it is masked off. Then, the exposed plywood is protected by a roll-on gel coat with UV protector (which appears to be the best strategy for minimizing maintenance).

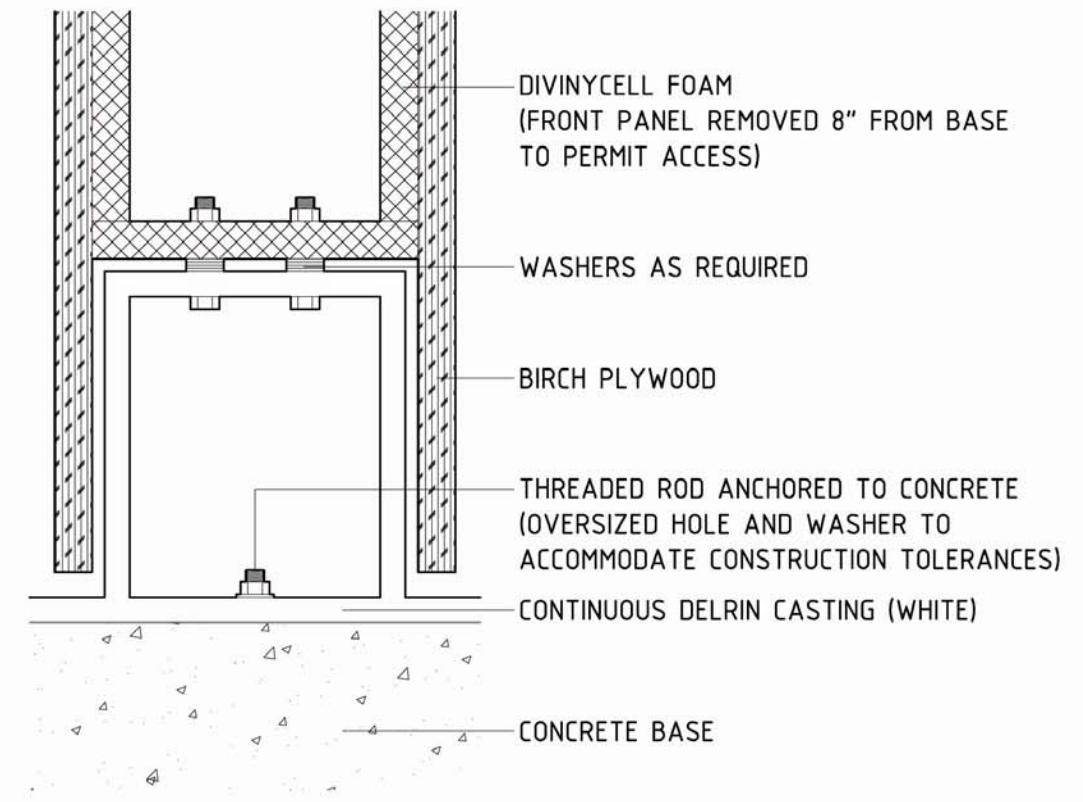
The base of each column is supported by mass-produced delrin castings which in turn rest on the concrete foundations. To accommodate construction tolerances, a reveal has been designed which allows for washers to precisely set the column height.

The ends of the building are clad with a planar glass curtain wall, and the floor is exposed, polished concrete with brass pour stops. The purpose of these simple, reflective surfaces is to celebrate the nature of the roof and walls as much as possible.

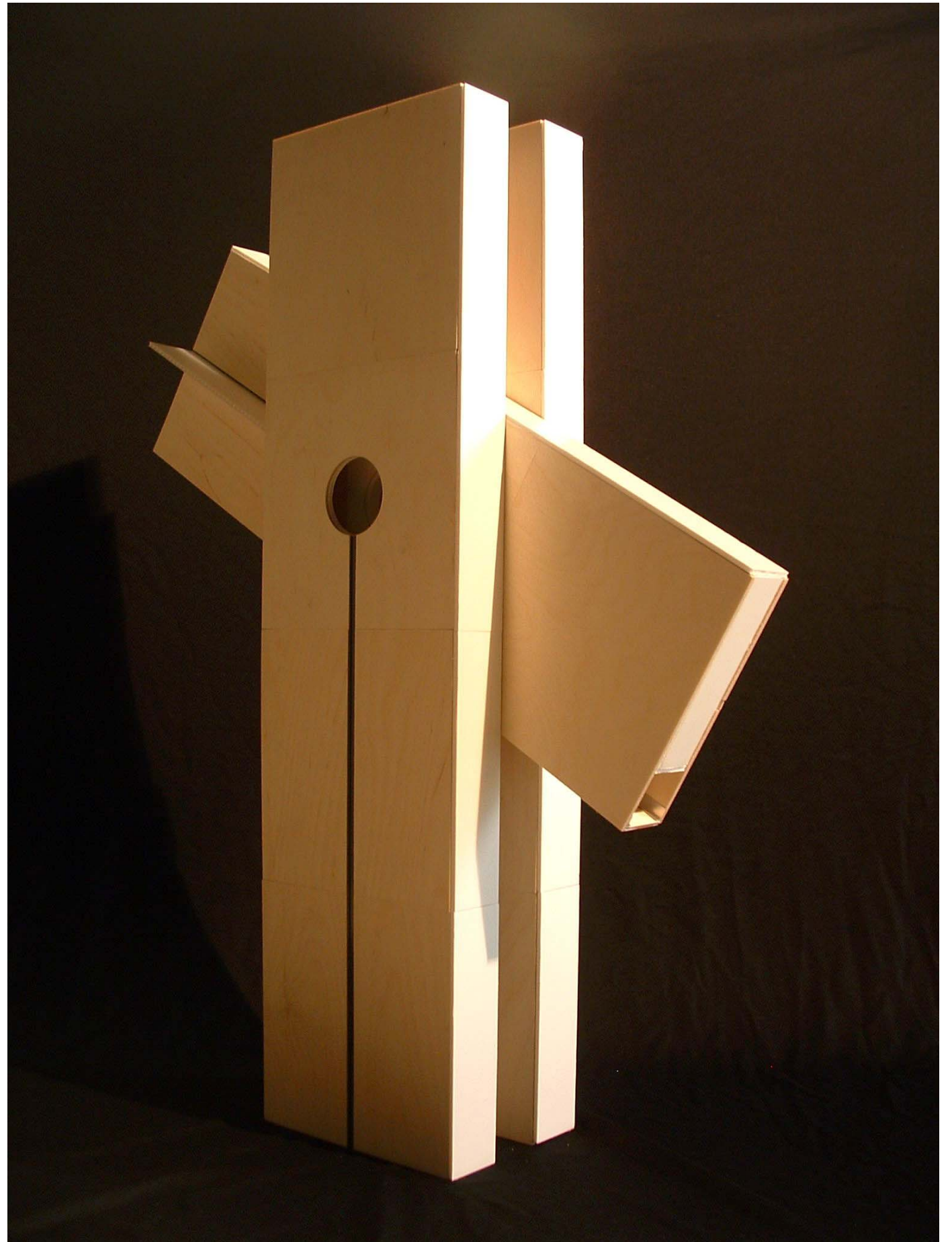
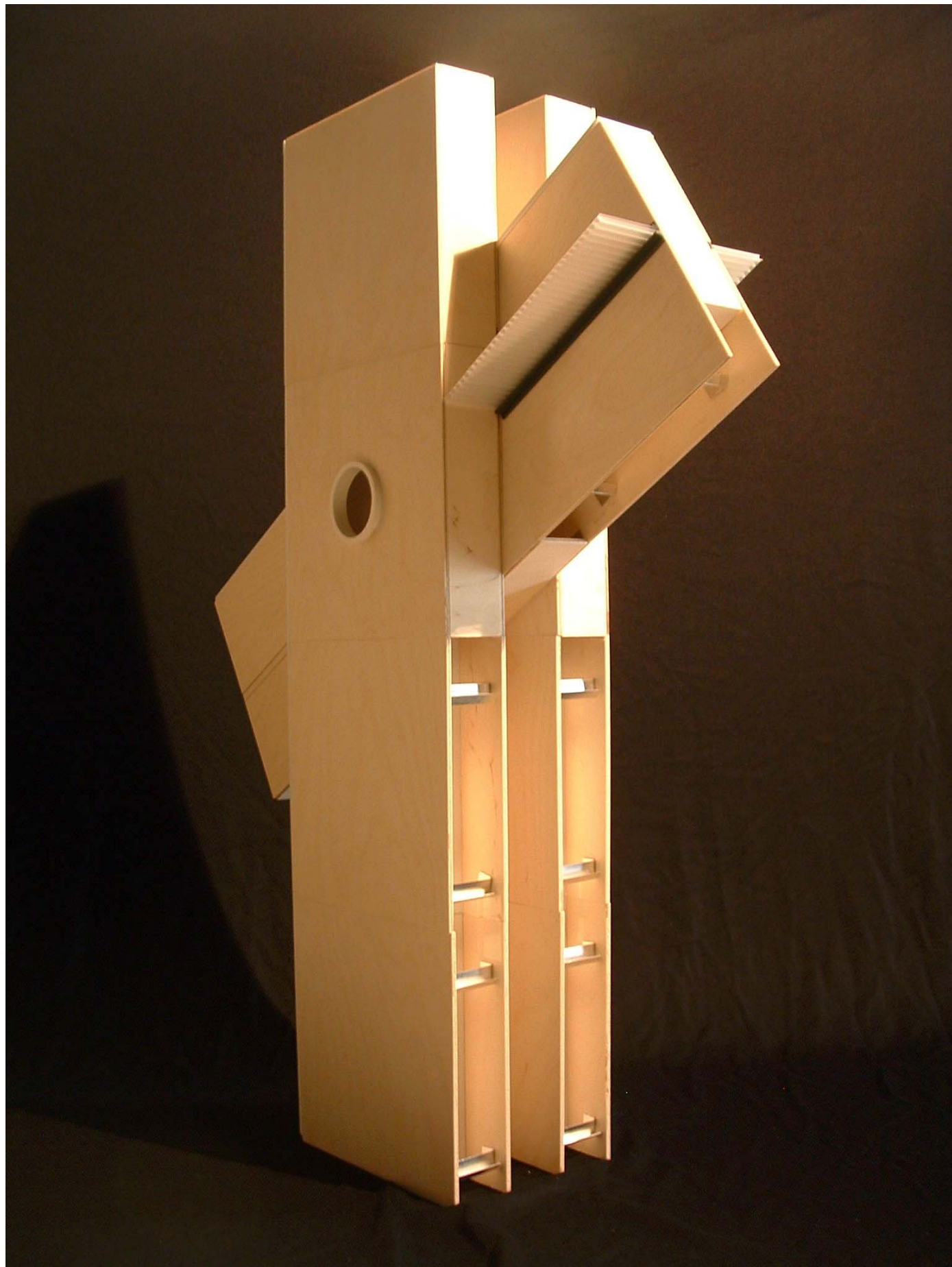
ALUMINUM ANGLES ATTACHED
WITH SNCO SCREWS AND EPOXY
(NO PILOT HOLES REQUIRED)



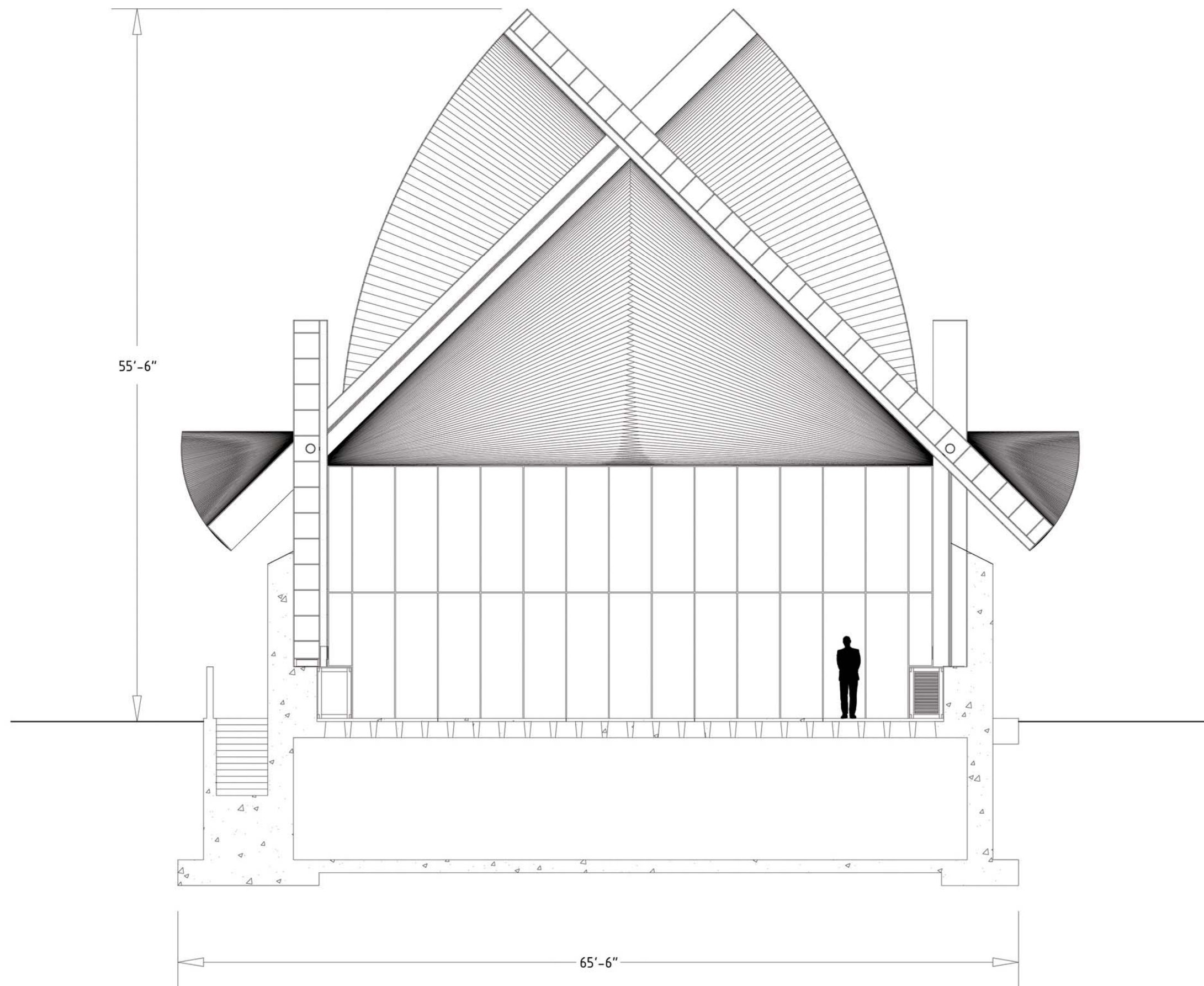
BEAM CROSS SECTION



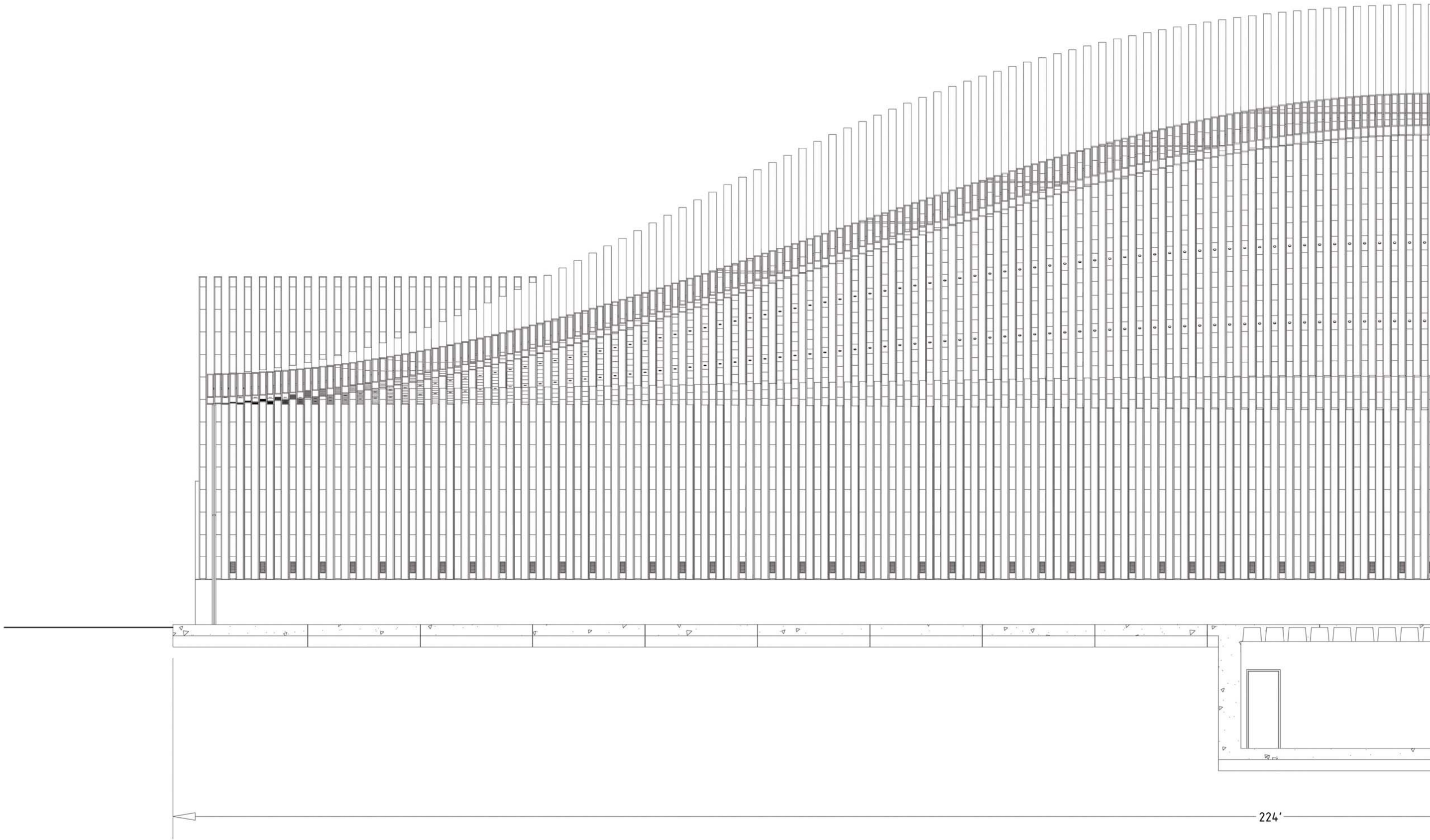
COLUMN BASE

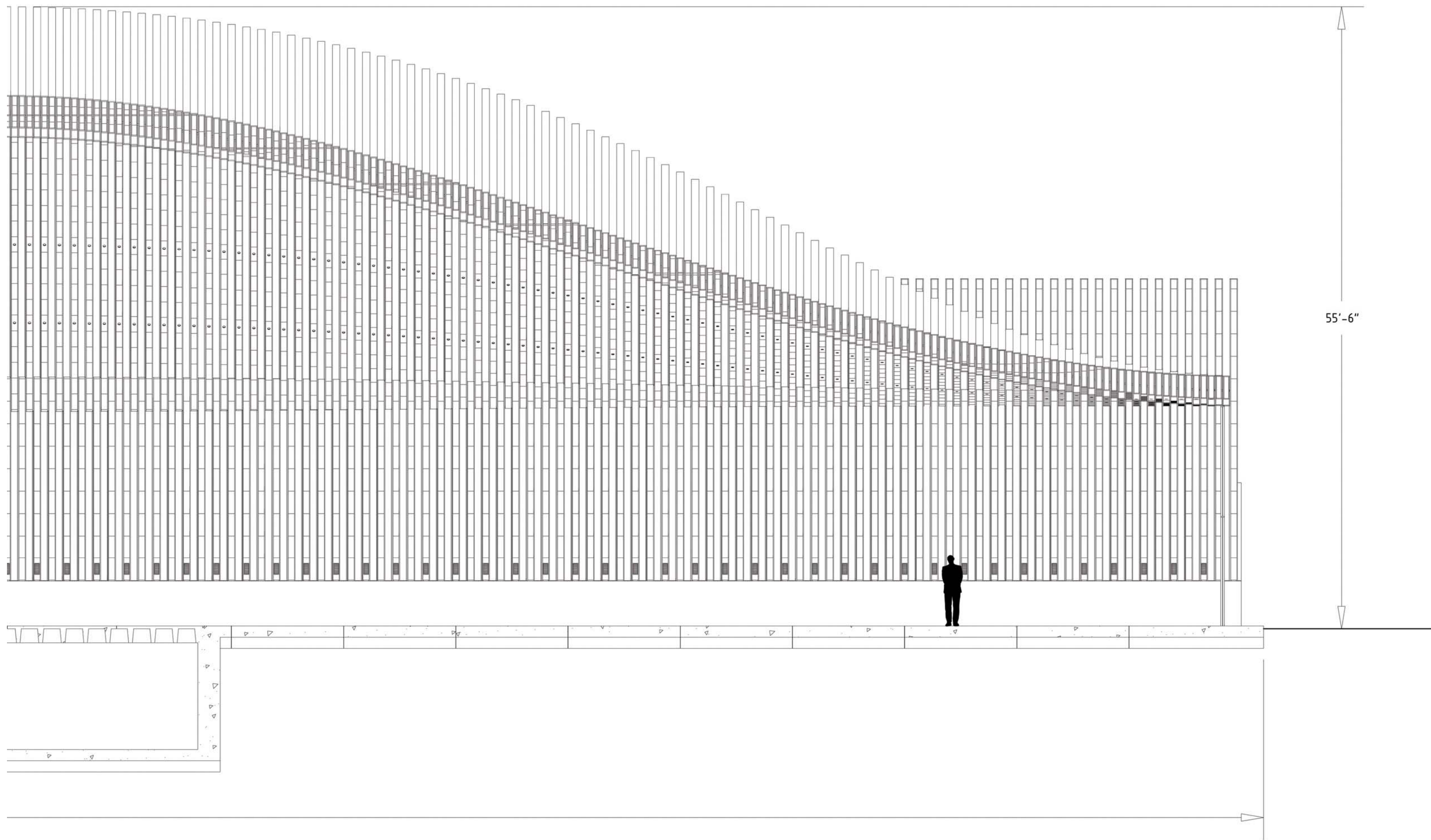


1/4 Scale Construction Model

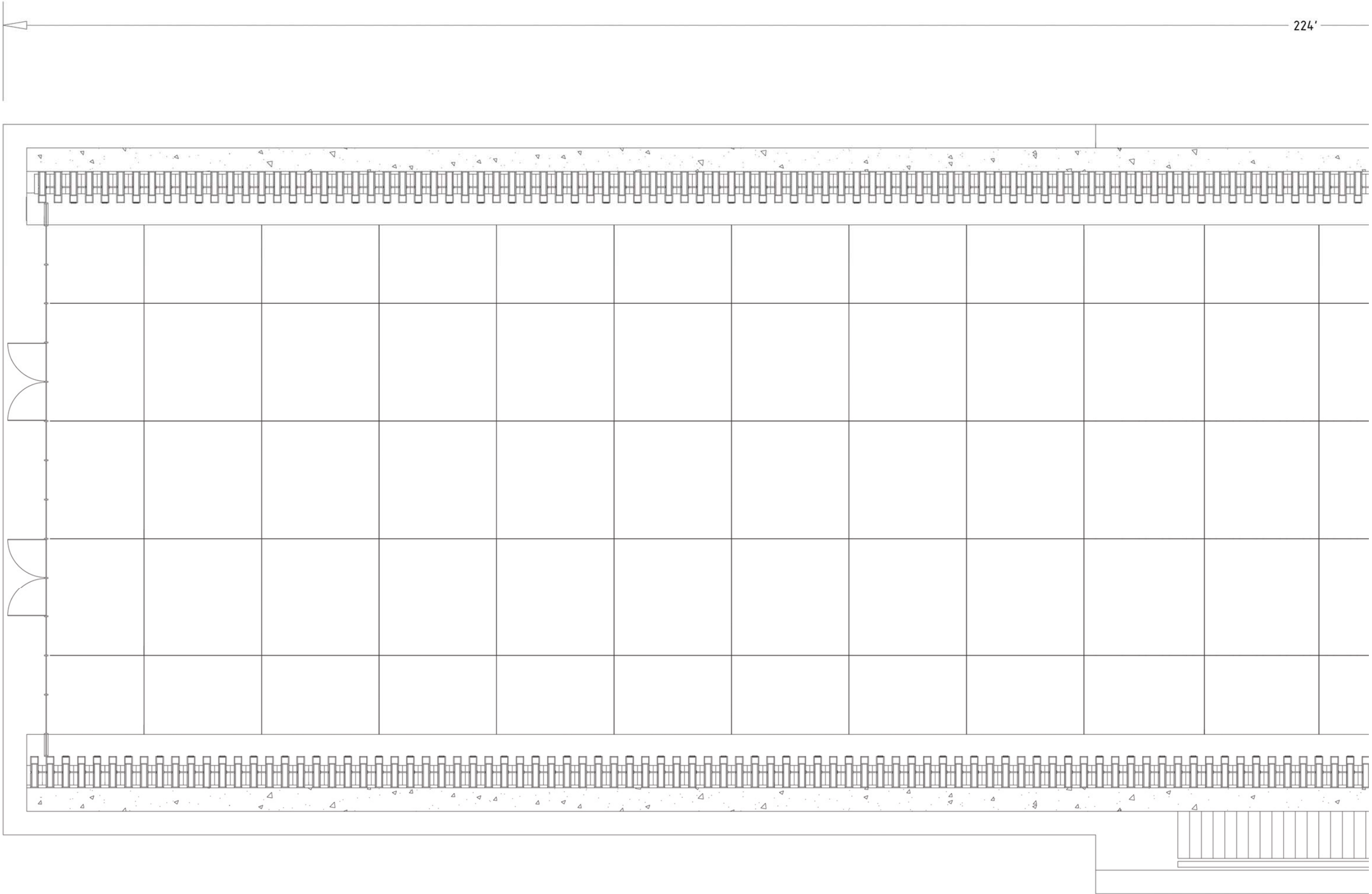


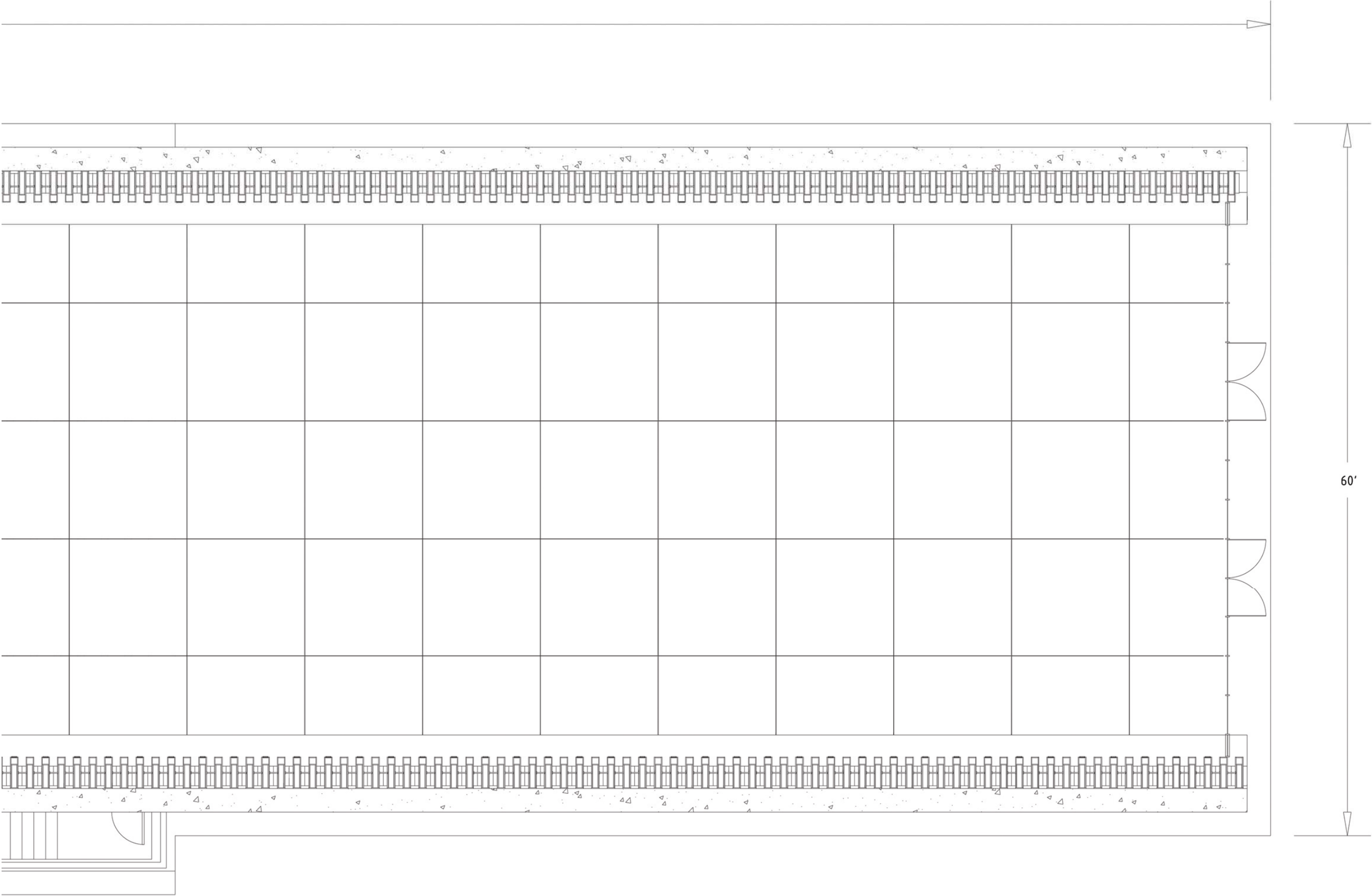
Final Model: Transverse Section
23,258 pieces



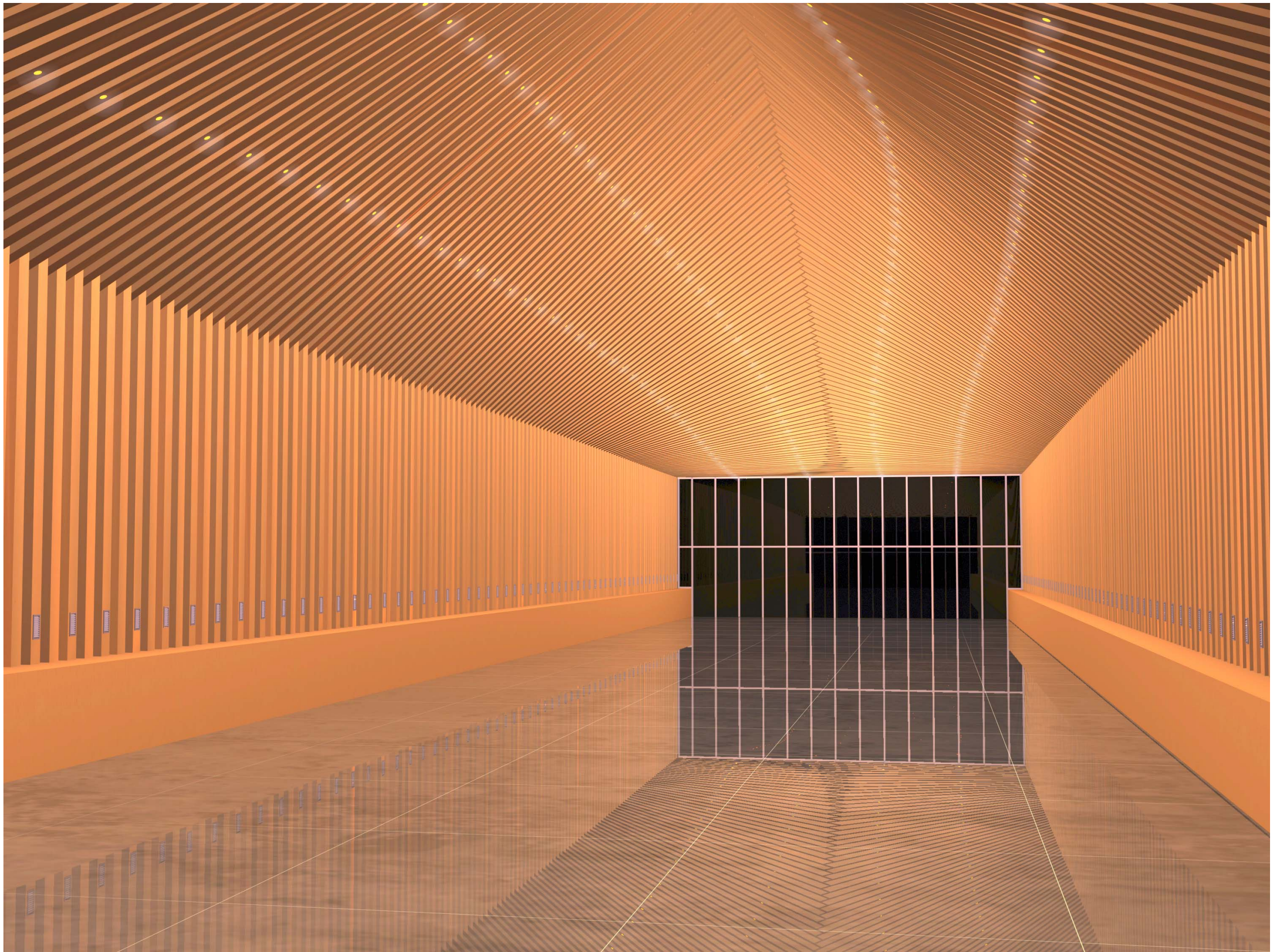


Longitudinal Section





Plan



Conclusion

If there is a general lesson to be learned from my thesis, it is this: the transition from concept to final execution is fraught with difficulty. Building the initial models was relatively straightforward when compared to the laborious task of detailing the final structure. Although I was able to create a thermal envelope with a minimum of custom parts, an inevitable consequence of my design concept is the creation of hundred and hundreds of seams, edges and gaps – all of which must be adequately waterproofed. Any savings gained from the mass-produced elements would likely be consumed by the endless amounts of epoxy and silicone sealant required to prevent leaks.

One substantial benefit of this project has been the experience of thinking in section, rather than in plan. All too often, architects draw a plan to accommodate the building's program, then extrude this plan upward by default. This project shows that an extremely simple plan can still create a visually rich interior space by carefully designing and varying the section.

(All photographs are by the author.)

Vita

Benjamin Mohr was born on May 17, 1978 in Philadelphia, Pennsylvania. In May of 2001, he received a Bachelor of Science Degree in Architectural Engineering from the University of Kansas. He worked as a design engineer for two years in Boston, Massachusetts before coming to Virginia Tech to pursue a master's degree in Civil Engineering, followed by a master's degree in Architecture.