HALO

Re-forming Architectural Space with Light Caustics

by ZHAO MA

B.Eng. in Advanced Engineering
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Submitted to the Department of Architecture in partial fulfillment of the requirements for the degree of Master of Architecture at the MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2017

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ABSTRACT

What form can light take?

Light has been an eternal theme in architectural design. Light defines, shapes, and transforms space in various ways. However, the way light has been used in human history has not changed: the variation of space is a result of the interaction between light and shadow along with the geometry and materials that defines the space itself.

Through the BLOCKING of light comes the variation of shadows.

Is it possible to extend the possibility of light from a basic level?

This thesis questions one of the fundamental uses of light in architectural space: how can we use light beyond the realm of shuttering? With the implementation of a set of state-of-the-art algorithms in computer graphics field, the thesis presents a serious of explorations in how refraction can re-form the architectural experience using the movement of light in both still and dynamic ways.

Through the REDISTRIBUTION of light comes the variation of time.

Thesis Advisor: Brandon Clifford
Title: Assistant Professor of Architecture

Acknowledgement

I would like to thank everyone who has offered their generous help and made my thesis exploration an enriching experience that would continue to benefit me in the future.

To my advisor, Brandon Clifford, for always having an open door when I'm in doubt. I could not hope to articulate such a complex project without your insightful guidance and criticism. Your rigorous pursuit for intelligence will always be my inspiration.

To my reader Caitlin Mueller, as well as my thesis advisor for my Master of Engineering degree, I cannot thank you more as my life at MIT as been filled with your help and guidence so much.

To my reader, Mark Jarzombek, your invaluable comments really helped transform my interests into architectural ideas and set the project onto the right course.

To my last minute helpers, a huge thank you to those who helped me in the lead-up to the final presentation and on the day of: Joseph Swerdlin, Xu Zhang. Your support meant a lot.

And lastly but most importantly, to my family, my parents, for lovingly and unconditionally supporting and standing by me in all my endeavors.

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Background

How nature uses light?

As a typical type of atmospheric optics created by the natural light, halos bestow a delicate beauty to the skies and tell us about the crystals inhabiting the clouds.

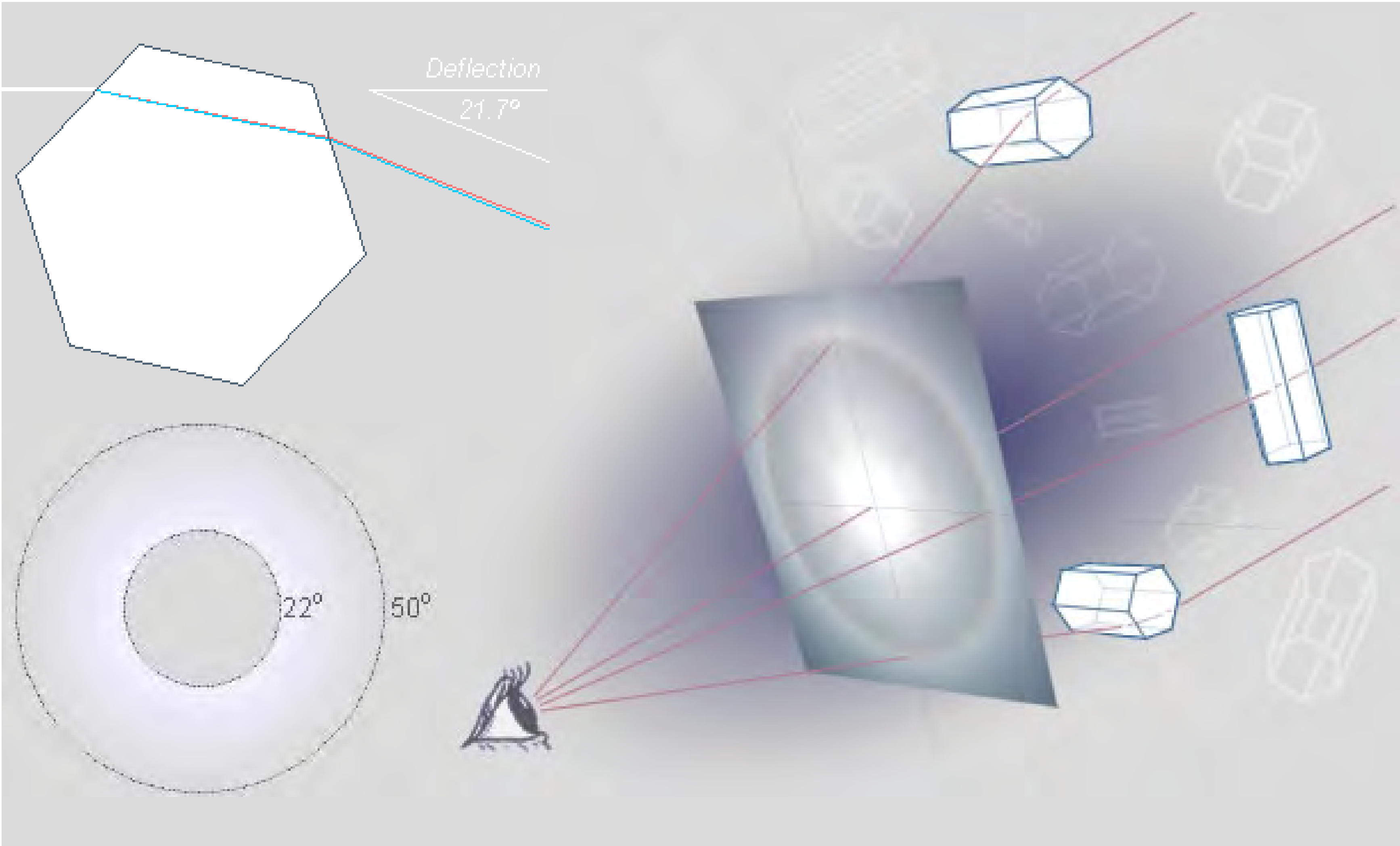
Ice halo displays range from the familiar circle around the sun or moon to rare and prized events when the whole sky is webbed by intricate arcs.

Tiny ice crystals in the atmosphere create halos by refracting and reflecting light.

Halo & Caustic

How nature uses light?

As a typical type of atmospheric optics created by the natural light, halos bestow a delicate beauty to the skies and tell us about the crystals inhabiting the clouds.



Ice halo displays range from the familiar circle around the sun or moon to rare and prized events when the whole sky is webbed by intricate arcs.

Tiny ice crystals in the atmosphere create halos by refracting and reflecting light.


Upper Suncave Parry arc
Supralateral arc
Sunvex Parry arc
Helic arcs
22° halo
Sun Pillar
http://www.atoptics.co.uk/halo

Scientists have categorised different types of halos with different visual effects.

These halos have similar caustics explanation but each slightly differs from the others.

http://www.viralspell.com/the-arctic-blast-produced-something-really-cool-in-the-skies-above-new-mexico-behold-the-ice-halo/

refraction:

The fact or phenomenon of light, radio waves, etc. being deflected in passing obliquely through the interface between one medium and another or through a medium of varying density.

Similar effects also exist in daily life, through water surface, glass surface, etc.

The essense behind all these natural or artificial effects are the refraction of light, or to be more specific, caustic effects.

caustic:

Formed by the intersection of reflected or refracted parallel rays from a curved surface.

Background

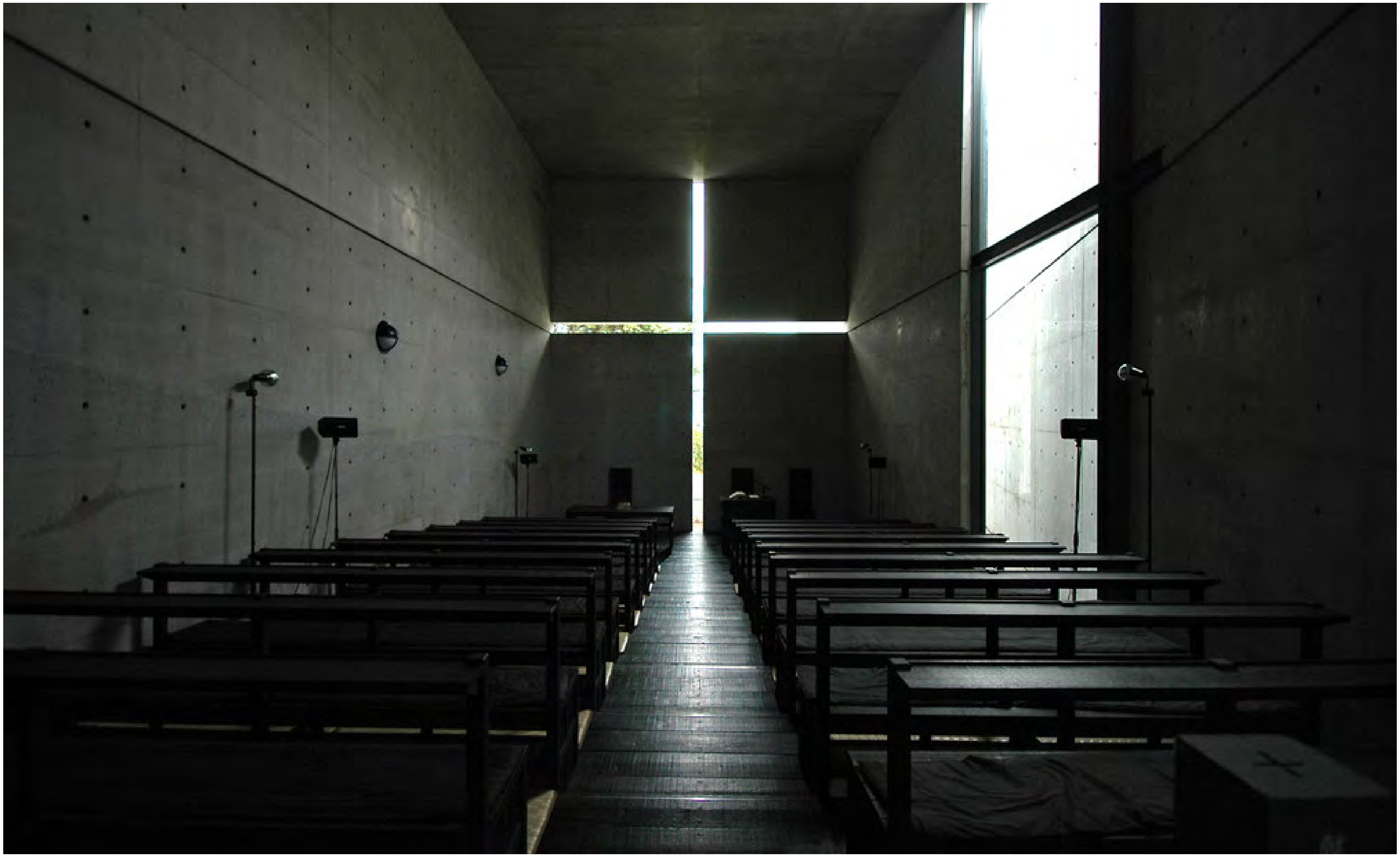
How architecture uses light?

There are tremendous examples to show how we human beings utilise the light to interact with space and create sensational experience within.

But are we done with it?

By examing the existing implementation of light fixtures, installations, artefacts, as well as buildings integreted with light, it is amazed to find we didn't know much about light when it is no longer transmitted only in air.

Light in Architecture

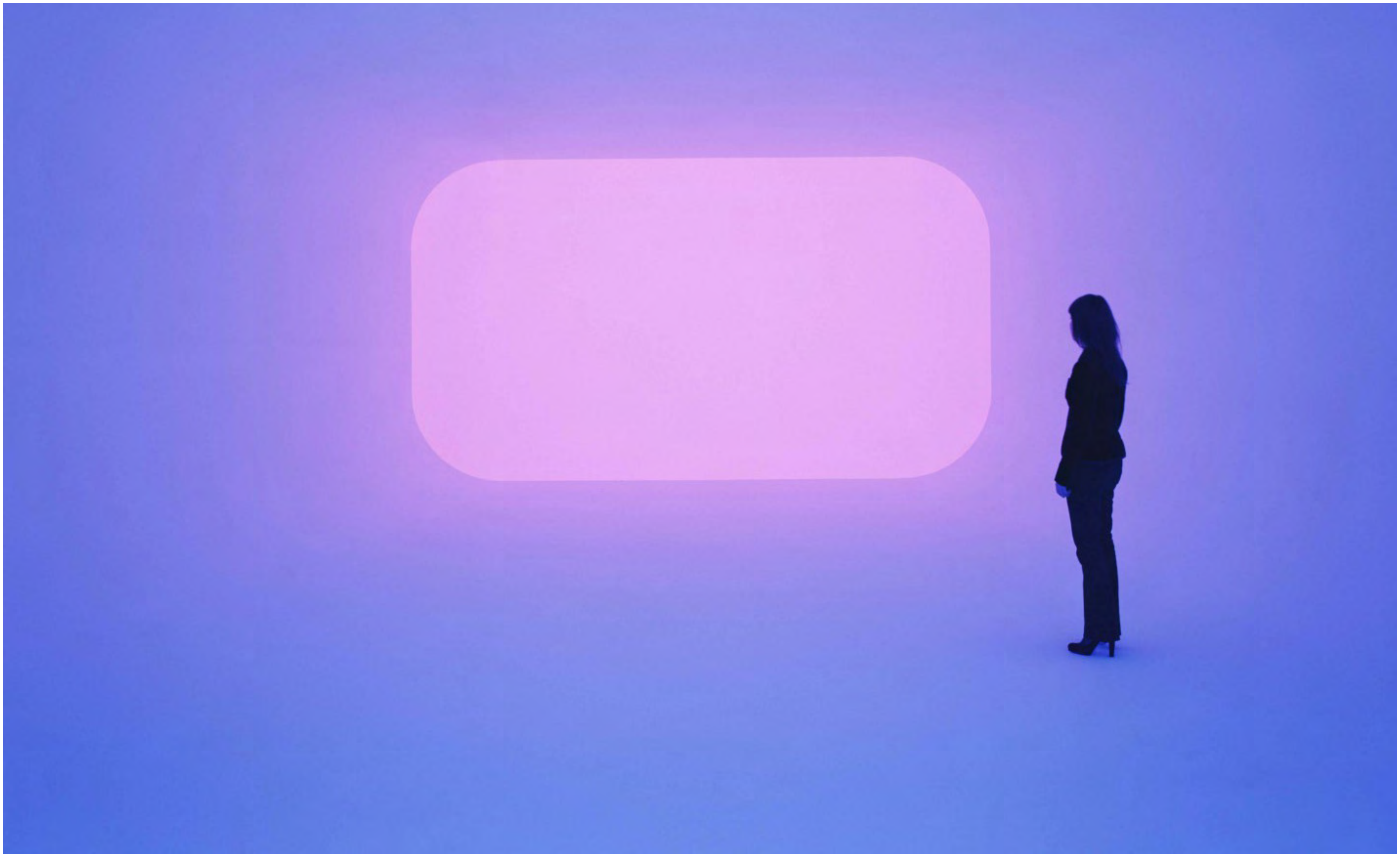


Church of Light - Tadao Ando

"The Church of the Light embraces Ando's philosophical framework between nature and architecture through the way in which light can define and create new spatial perceptions equally, if not more so, as that of his concrete structures."

Intersections - Anila Quayyum Agha

“Within Intersections, no clear boundary or separation exists; our moving bodies change the nature of the pattern as we walk freely through its dense silhouette.”



Tunnel Installation - James Turrel

"The precise frame lines set in contrast to diffuse light in order to let the viewer experience transcendental passages playing with the boundaries and elements of the sky."

Light diminish the sense of space.

The Louvre Abu Dhabi Museum - Ateliers Jean Nouvel

"It is rather unusual to find a built archipelago in the sea;

it is even more uncommon to see that it is protected by a parasol flooded with a rain of lights."

Statement

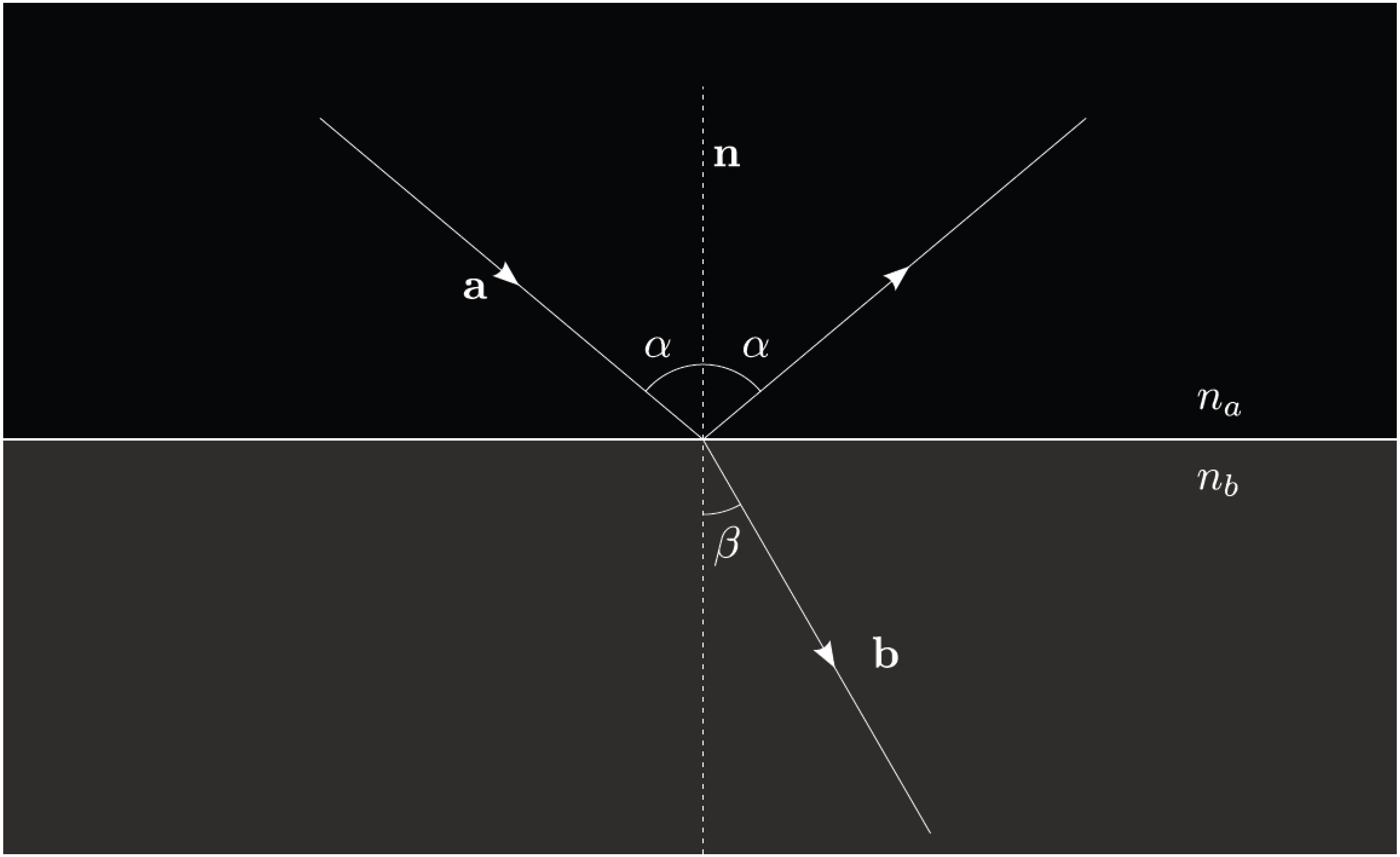
*Architecture should interact with light and shadow beyond the traditional realm to create new type of space. A deeper understanding and control of the light should derive an intuitive design process of architecture with light – **the delight of light.***

Light Exploration

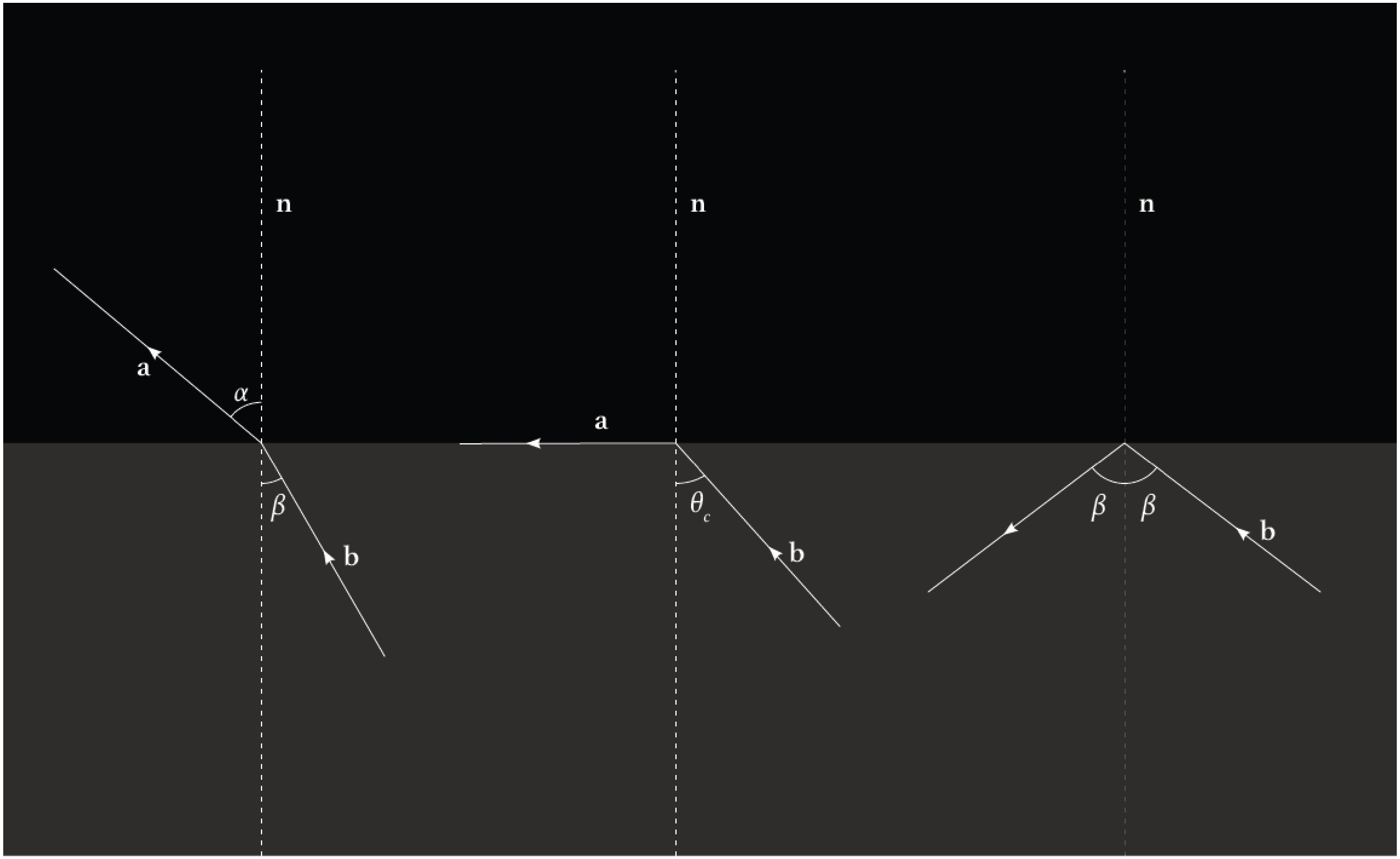
From the fundamental properties of light and a serious of experiments and tests, this chapter explore the basic interaction of lights and refracting surfaces.

Intuition here is very important to help learn how light performs and how we can abstract the physical properties into mathematical form for further development.

The Fundamental Property of Light



Light beam in Reflection & Refraction



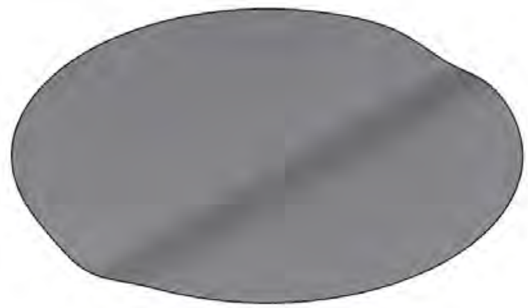
Reflection & Total Reflection

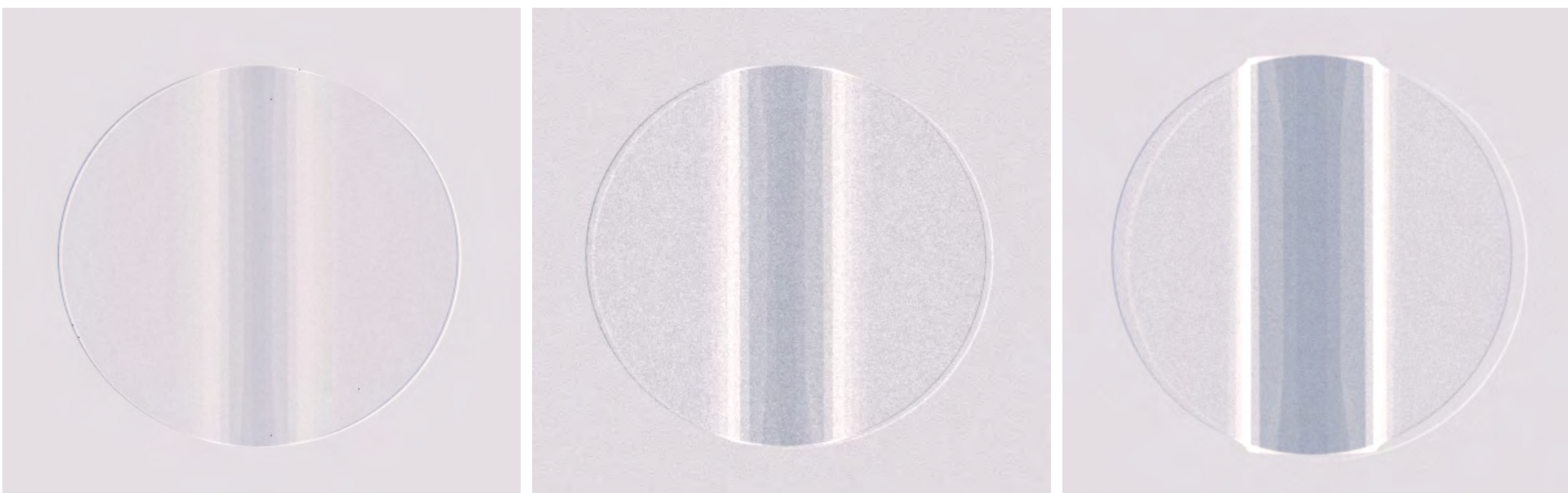
Light Exploration

Modern rendering software can already simulate the physical transmition of light in a very accrurate level.

To get an intuitive sense about how transparent surface with different curvature will re-direct light, we use Maxwell Render 3.0 to simulate the effect of light refraction in order to guide us for the design of light in later part.

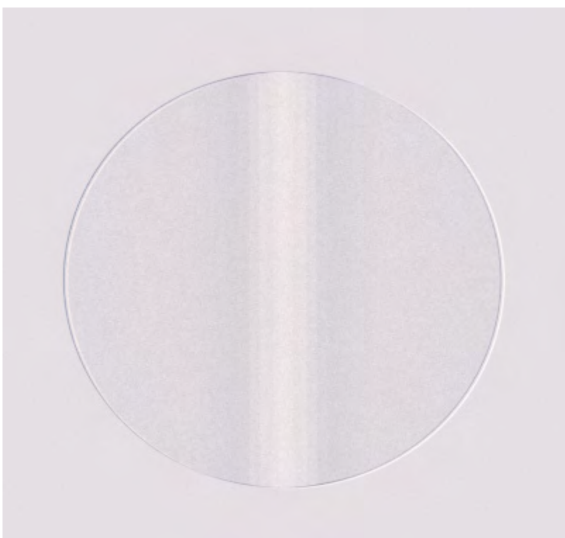
Light Rendering Test





distance = 1 distance = 4 distance = 7

the divergence of light through a concave surface



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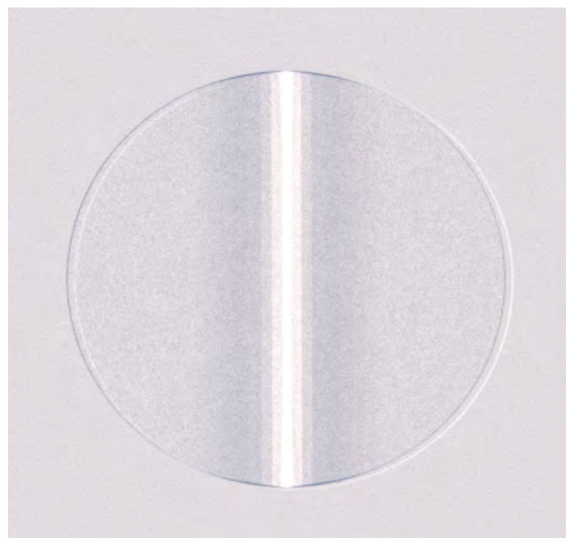

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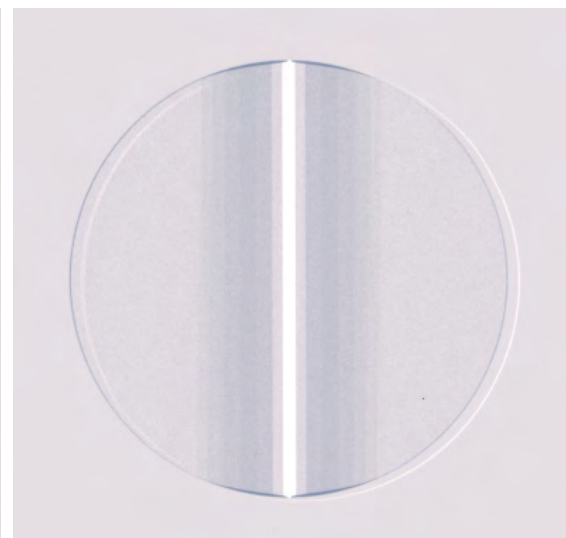
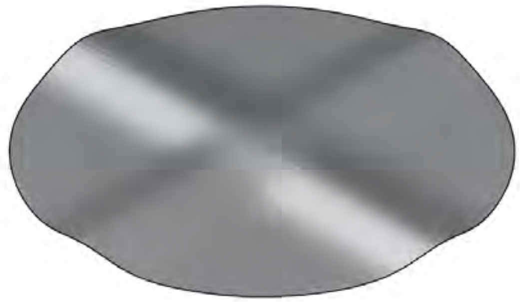
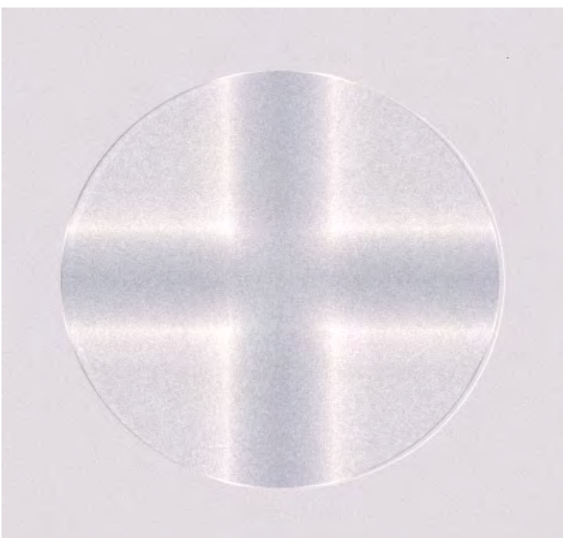


distance = 7

the convergence of light through a convex surface





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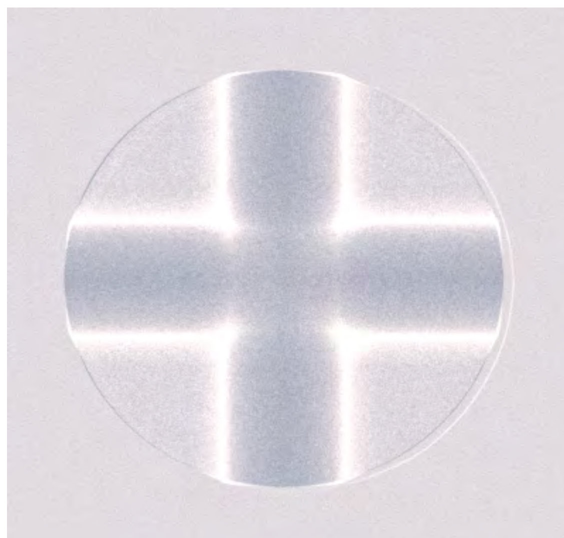

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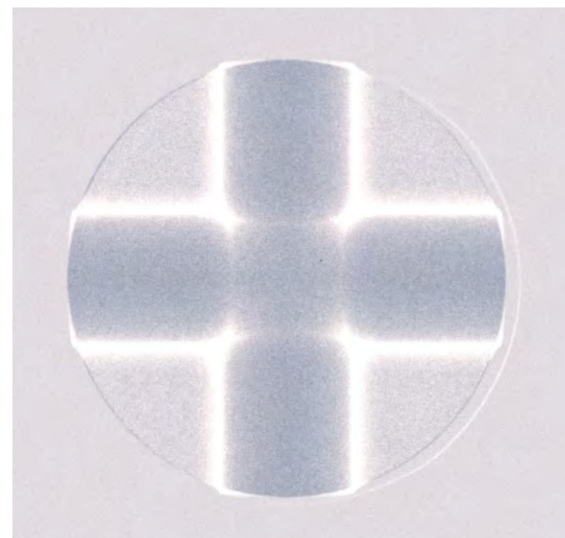
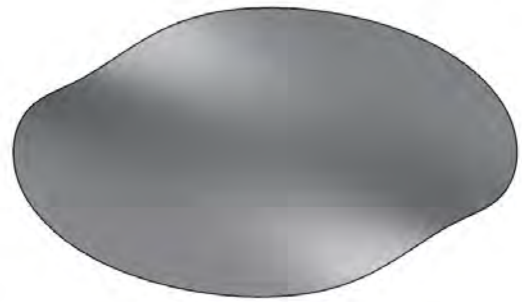


distance = 7

the divergence of light crossing



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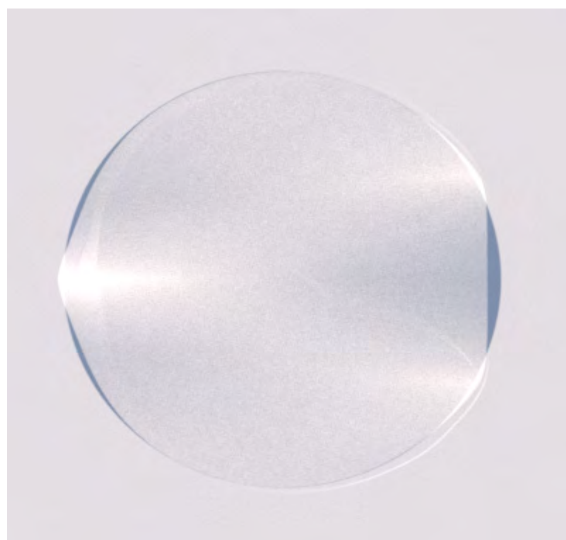

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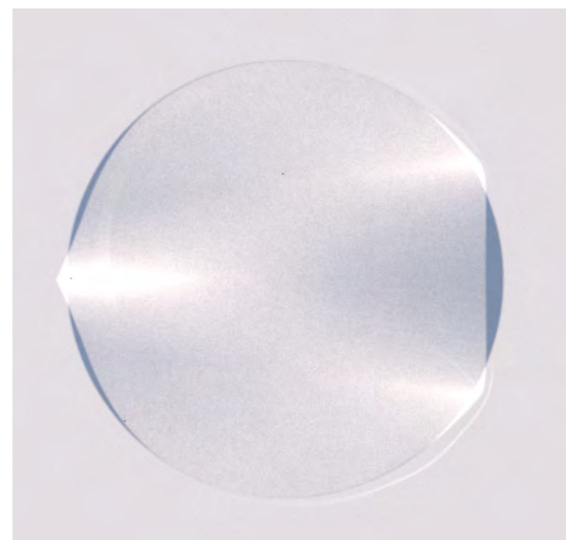
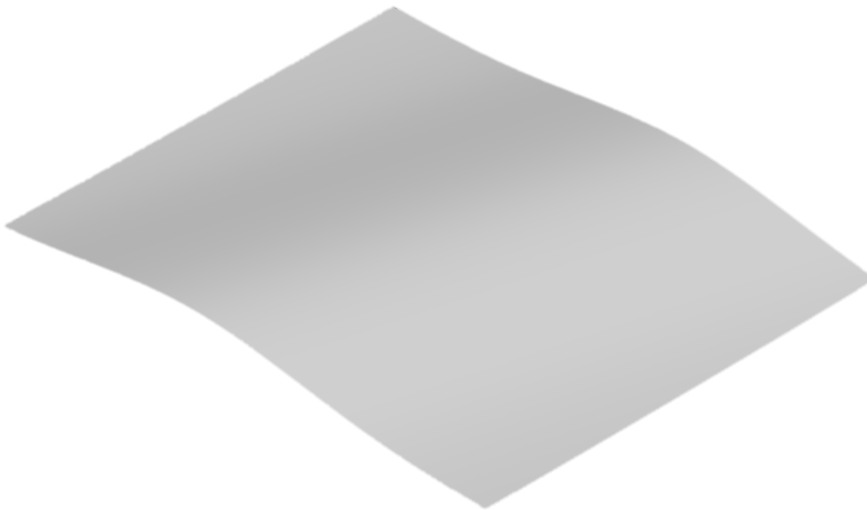
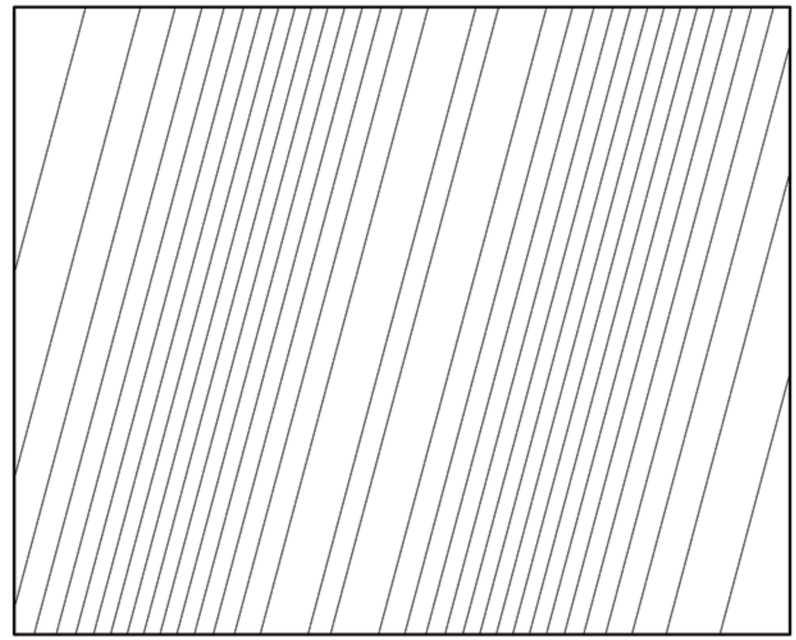
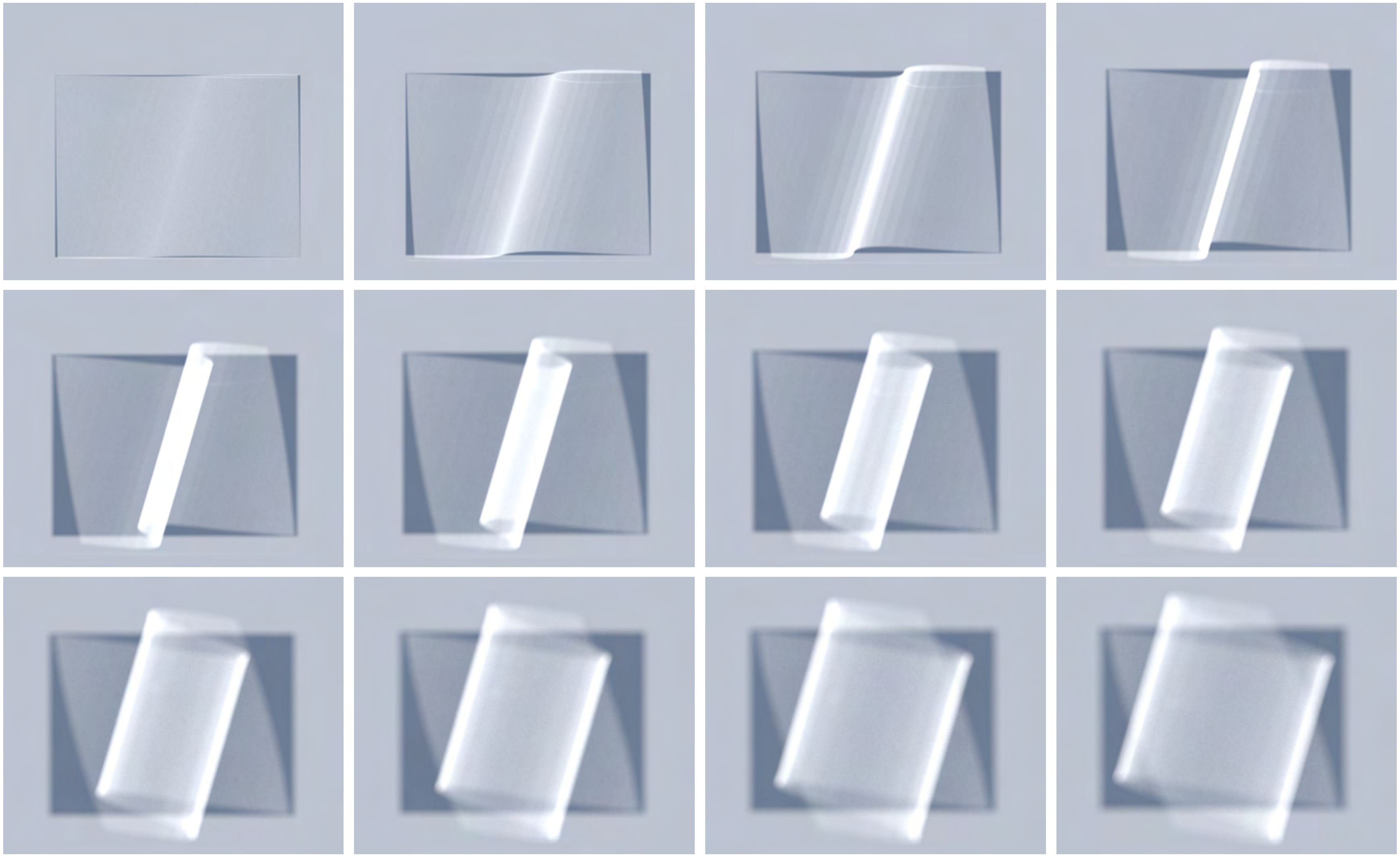


distance = 7

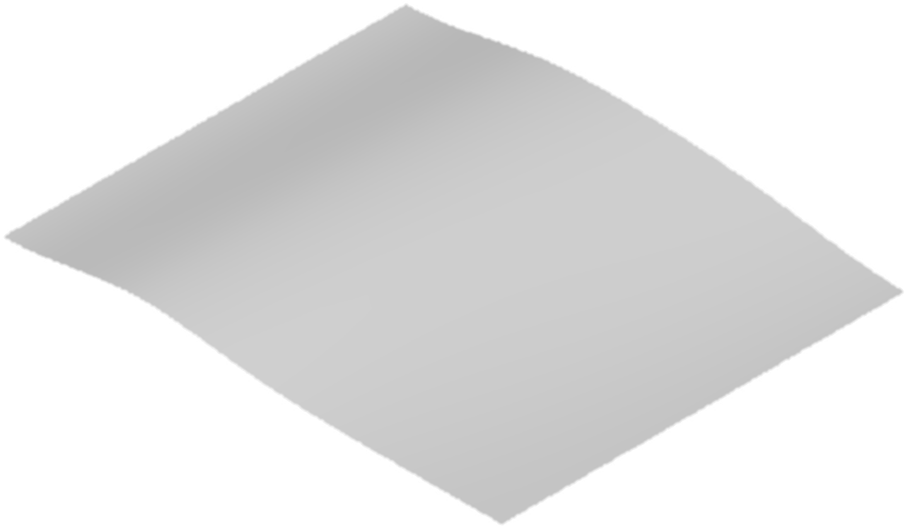
the gradient change through a gradent inclined surface

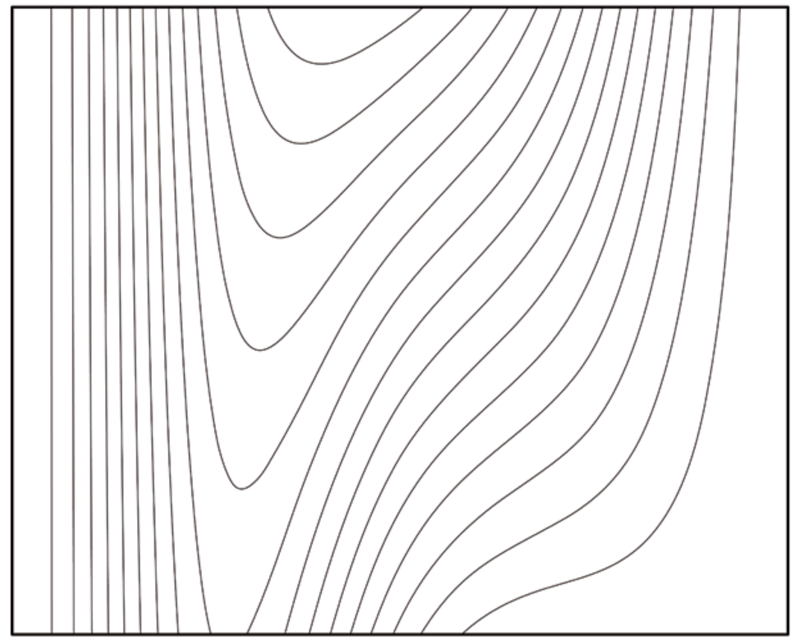


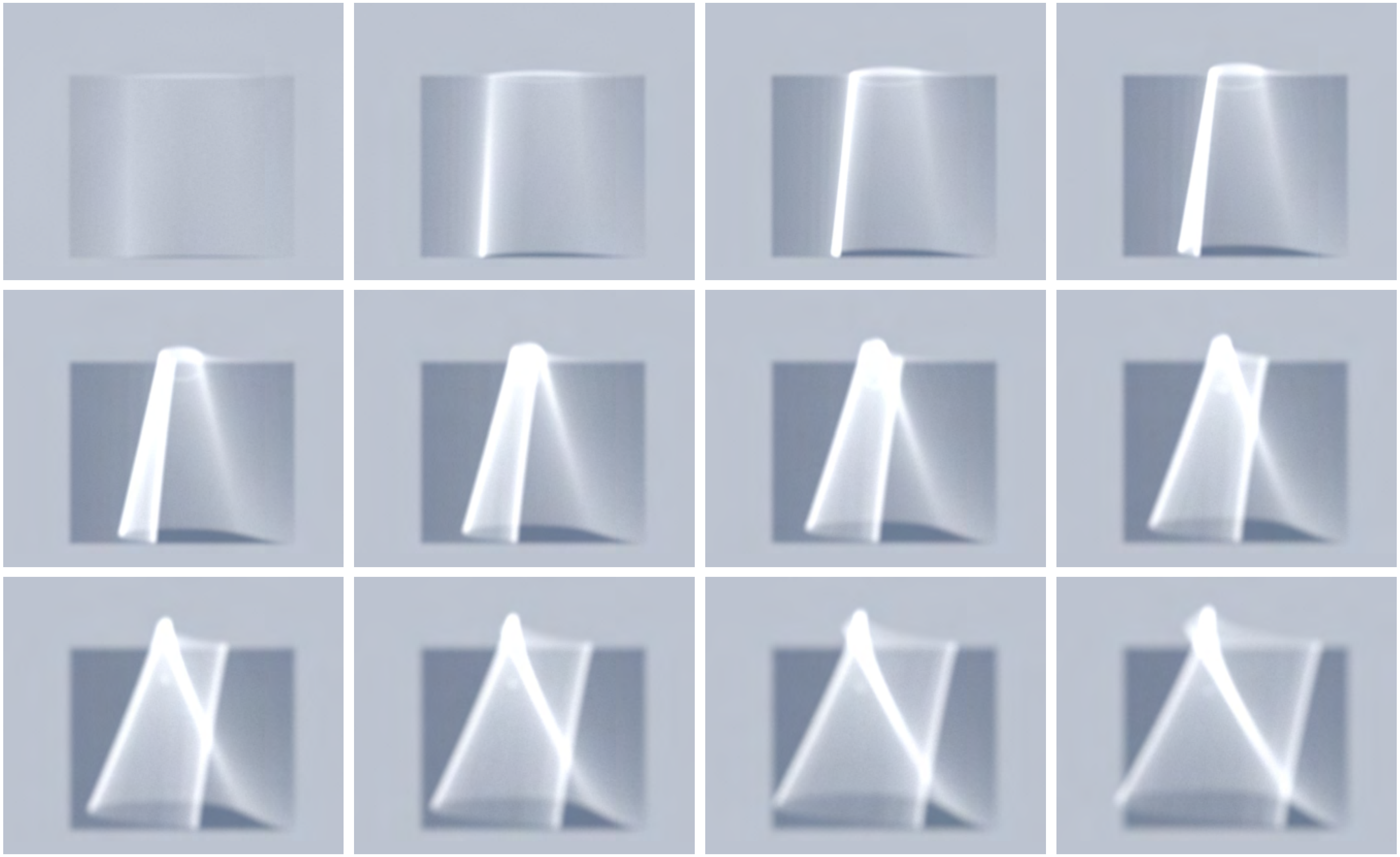




light refraction of different distance through simple surface







light refraction of different distance through simple surface

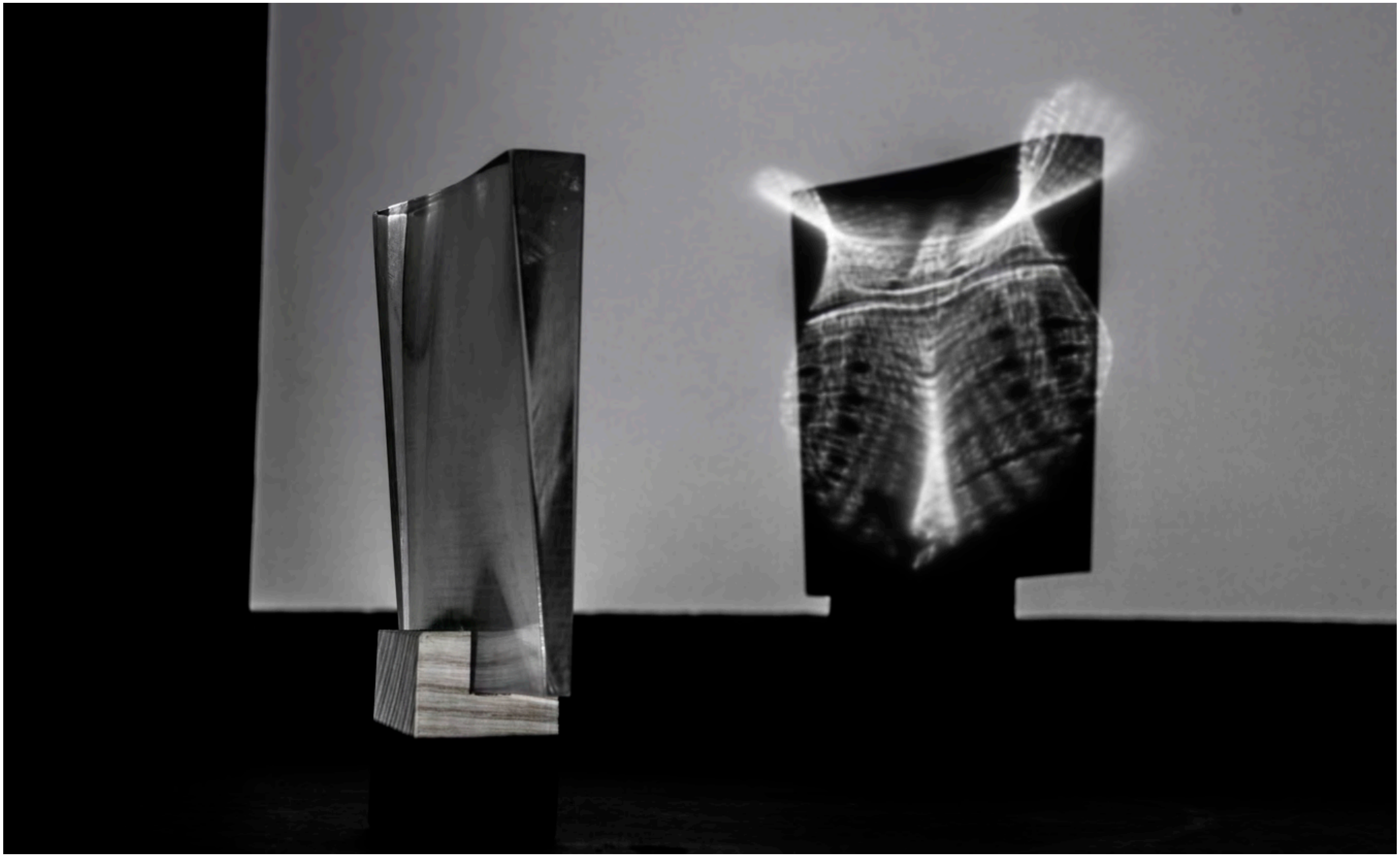


photo of physical test

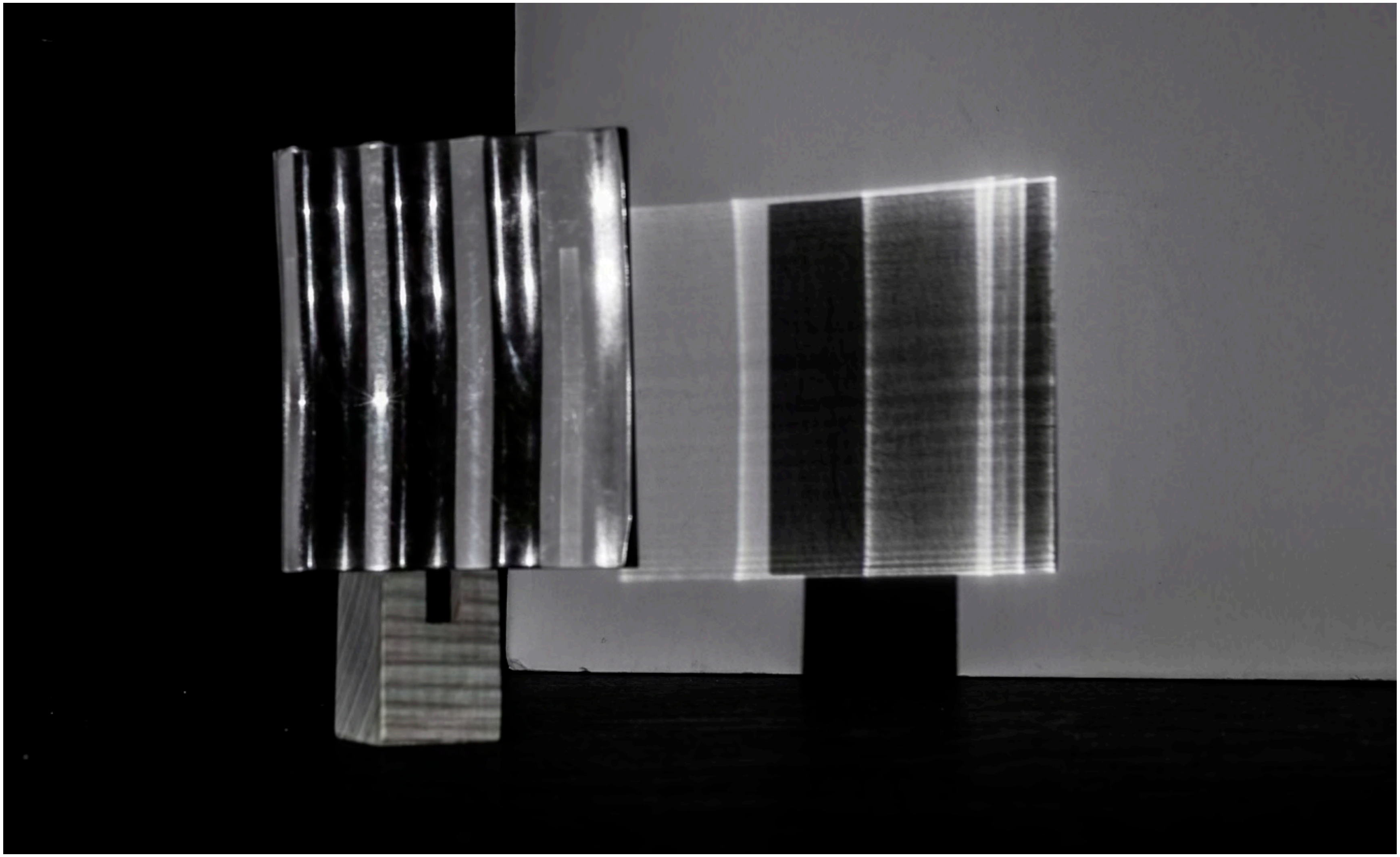


photo of physical test

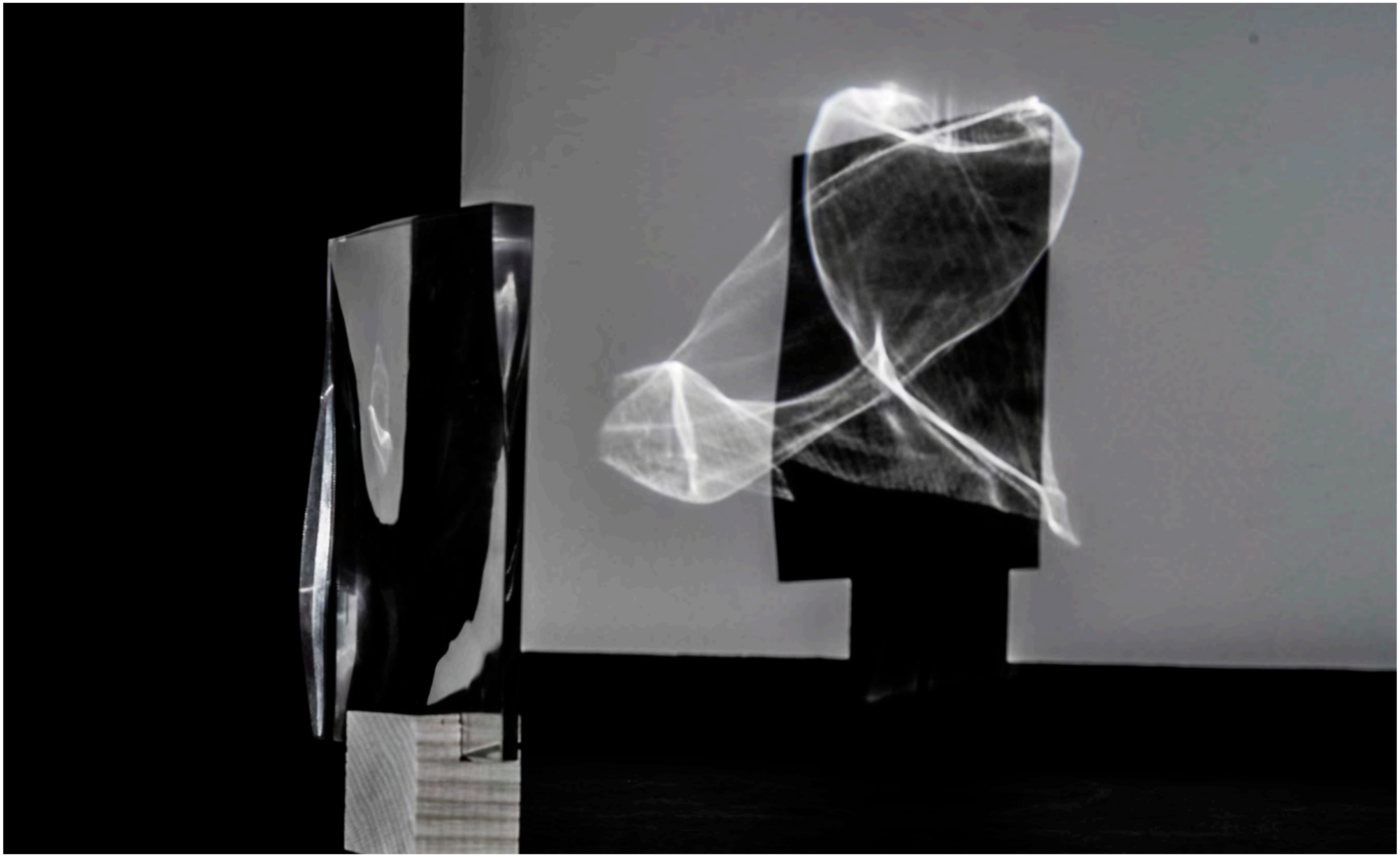


photo of physical test

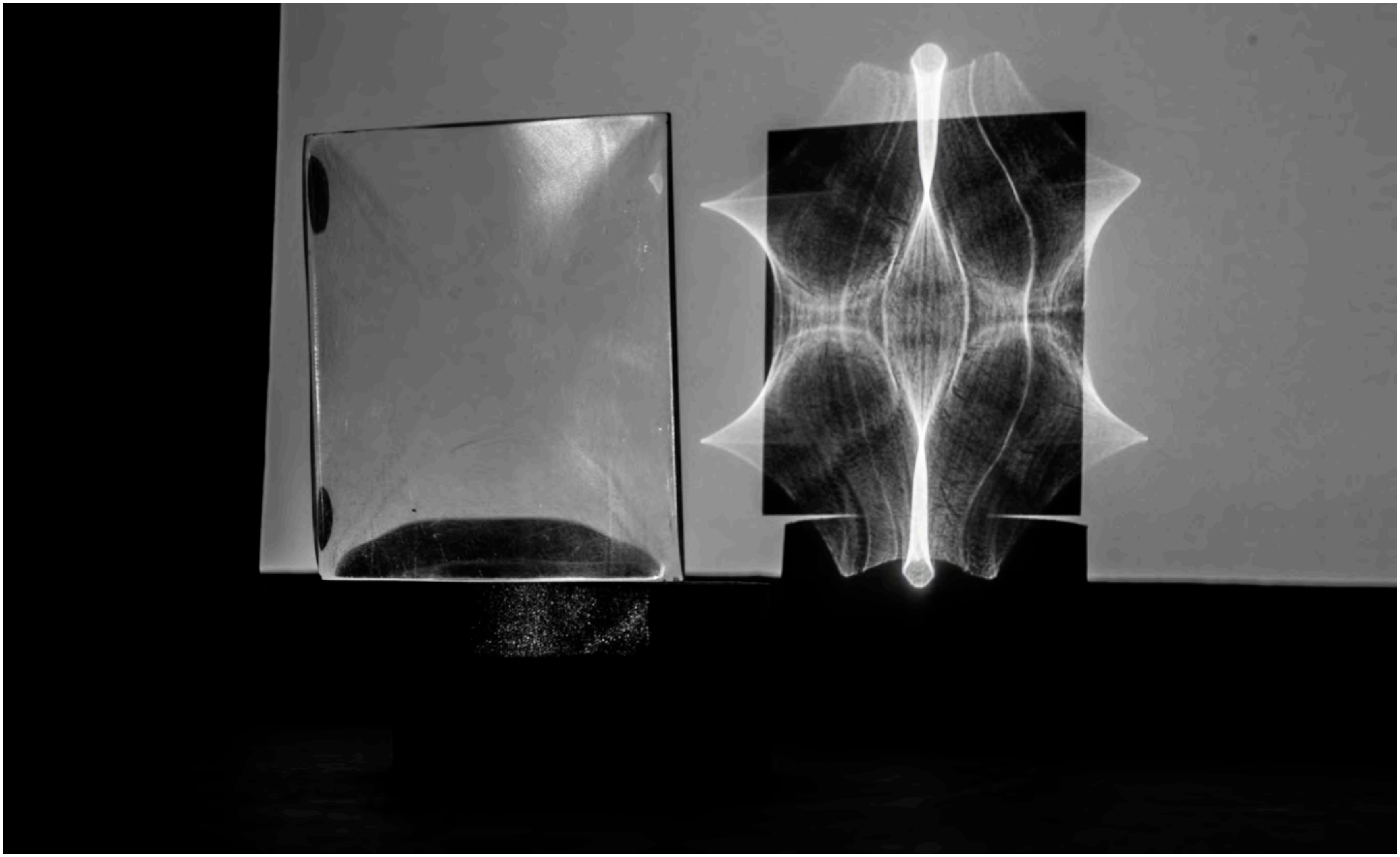
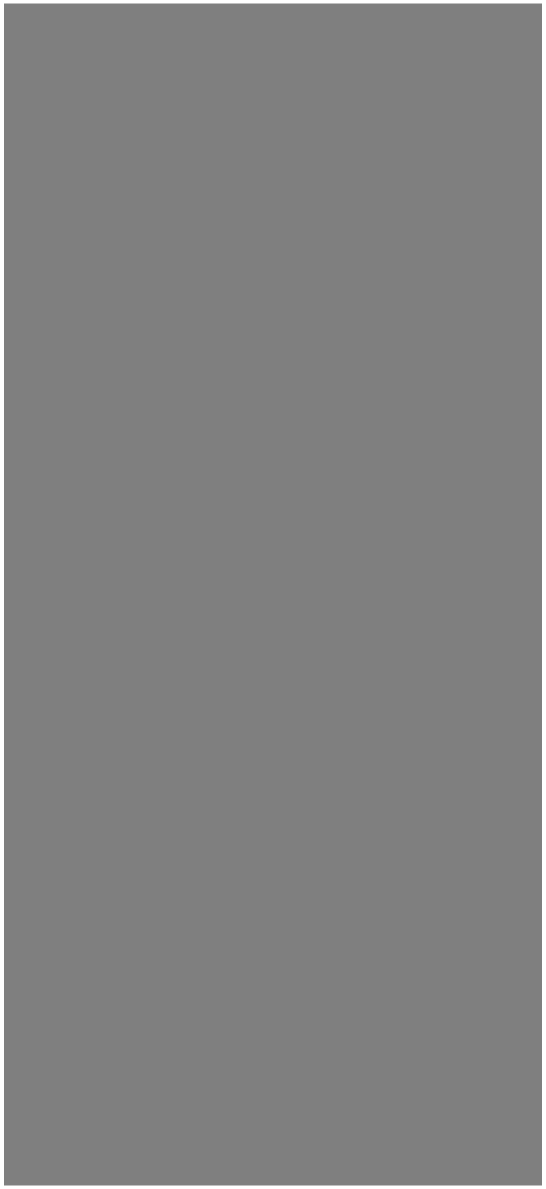
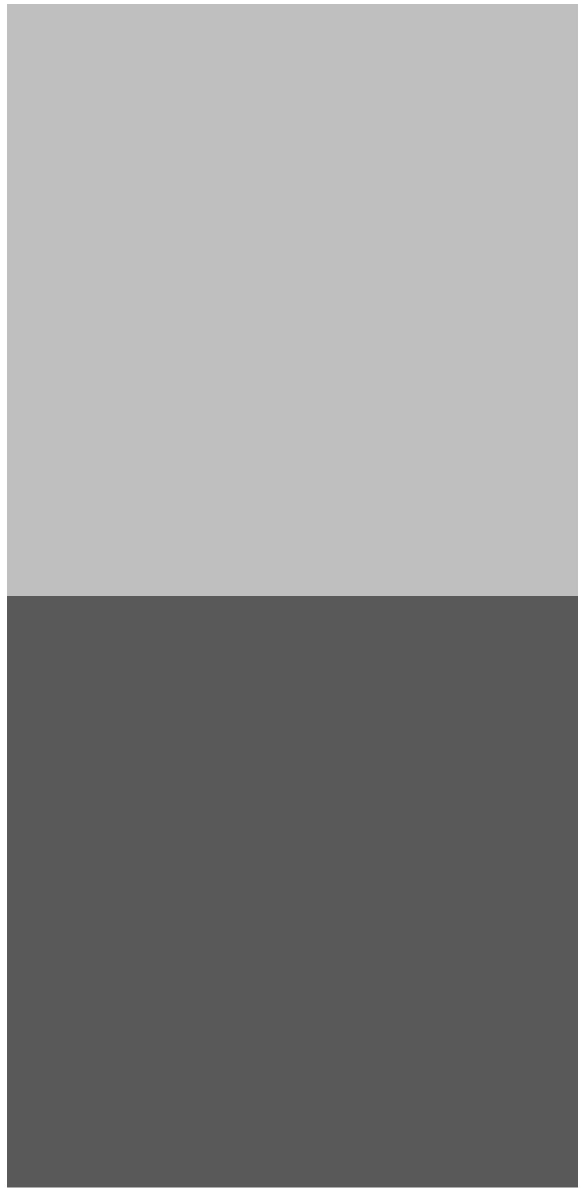
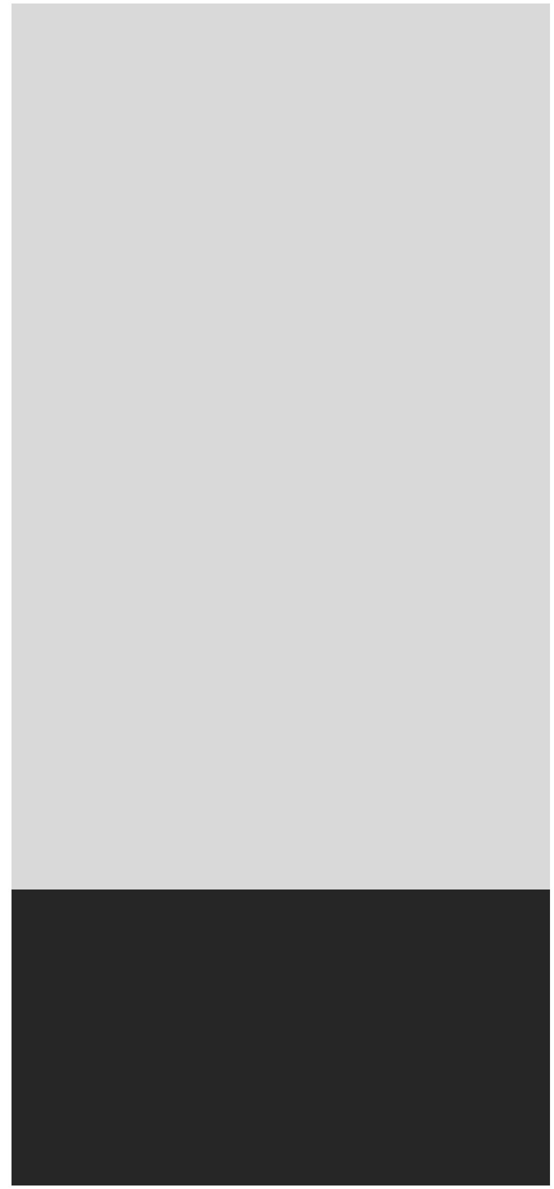


photo of physical test

Light Exploration







The Redistribution of Light

Through the series of rendering simulation, it can be discovered that unlike the method widely used in lighting design/designing light -- through "BLOCKING", the refraction never shutters any light -- it is through the method of "REDISTRIBUTING" that light rays are redirected to different positions. The amound of light shed in the same amount of areas is never changed.

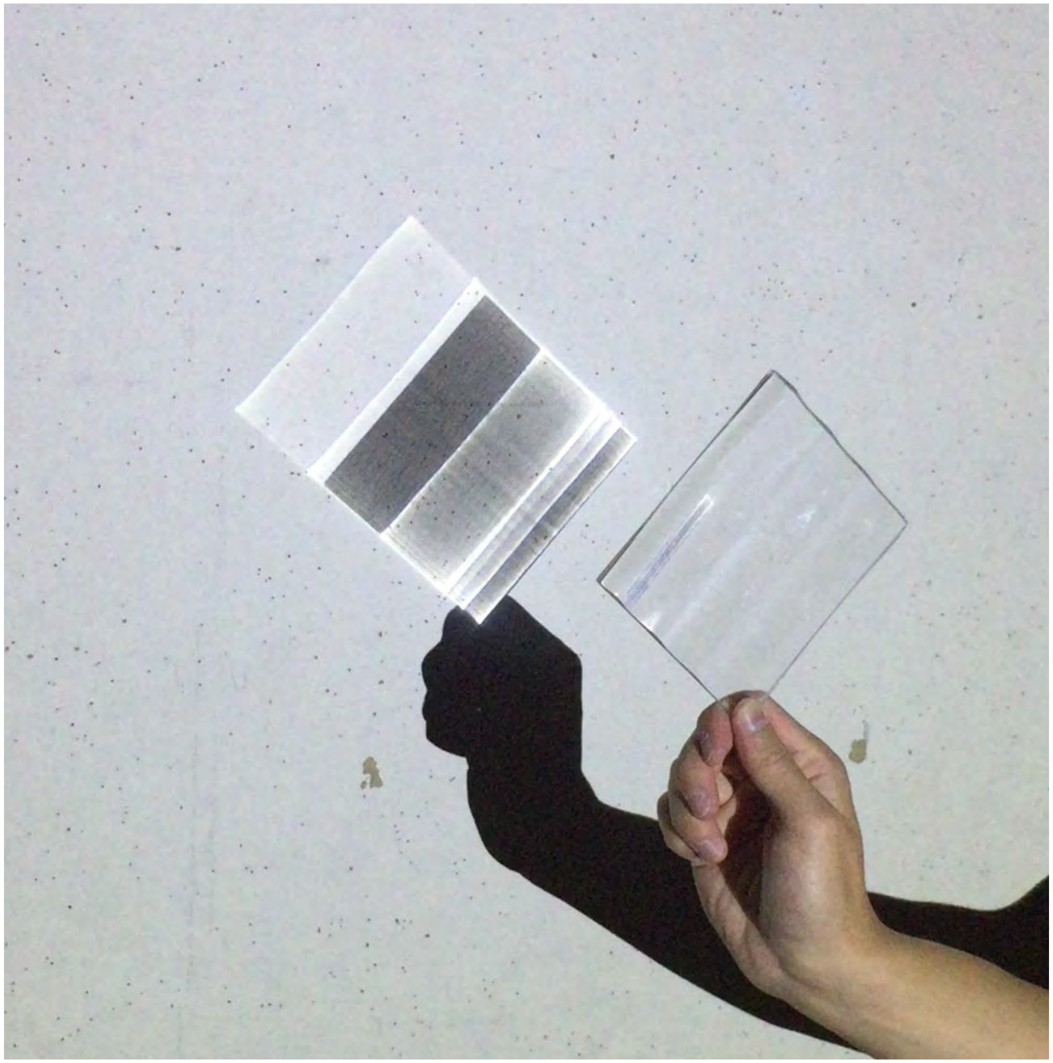
Through the redistribution come light and shadows.

Computation

Design Direction

To control the shape of a caustic design, two central computation need to be addressed:

1. How to simulate, i.e. compute, the caustic generated by a given surface.
2. How to change the surface geometry such that it focuses and diverts incoming light to produce a desired caustic image.



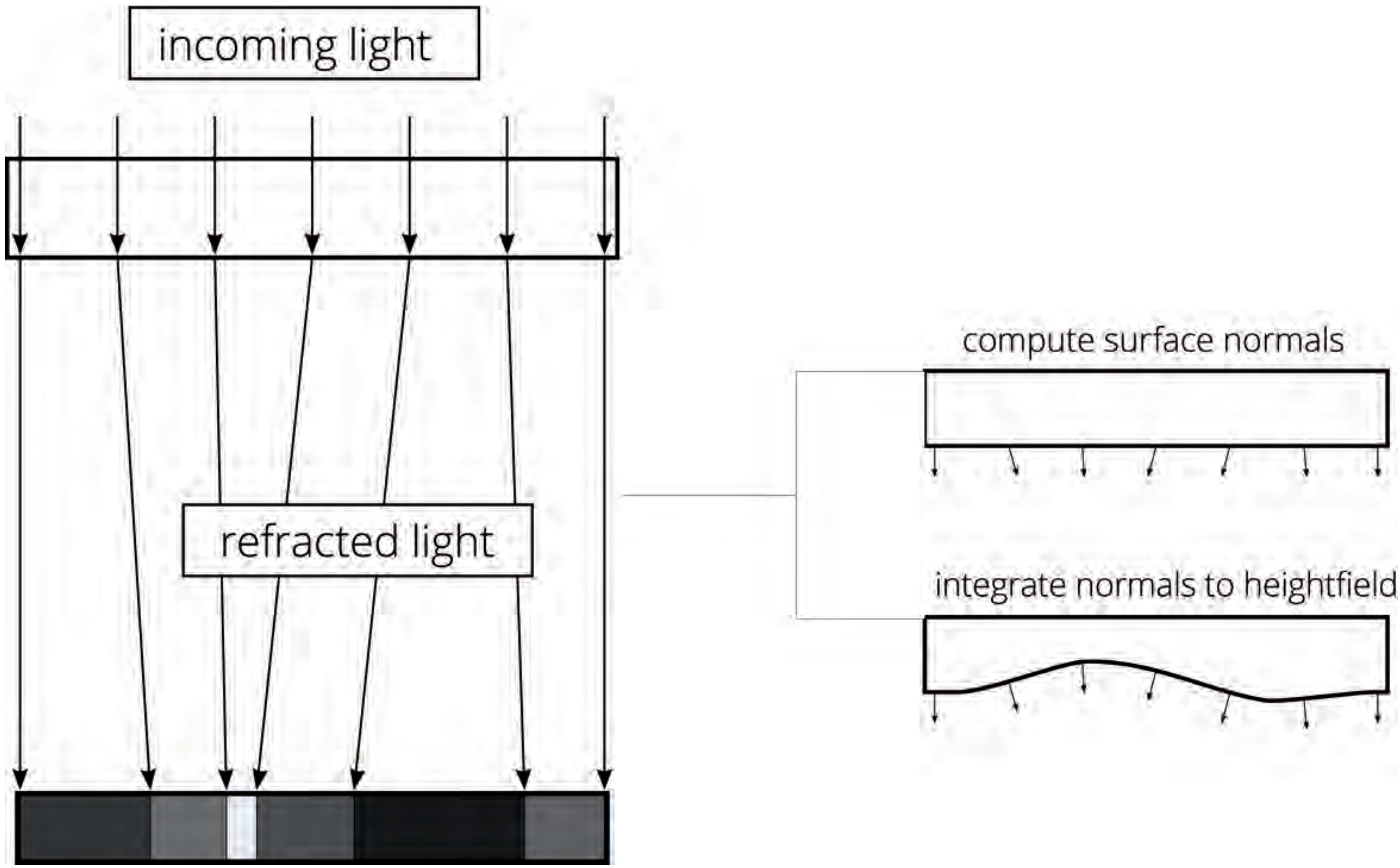
Forward: Refraction Surface -> Caustic Patterns
Design direction: bottom-up

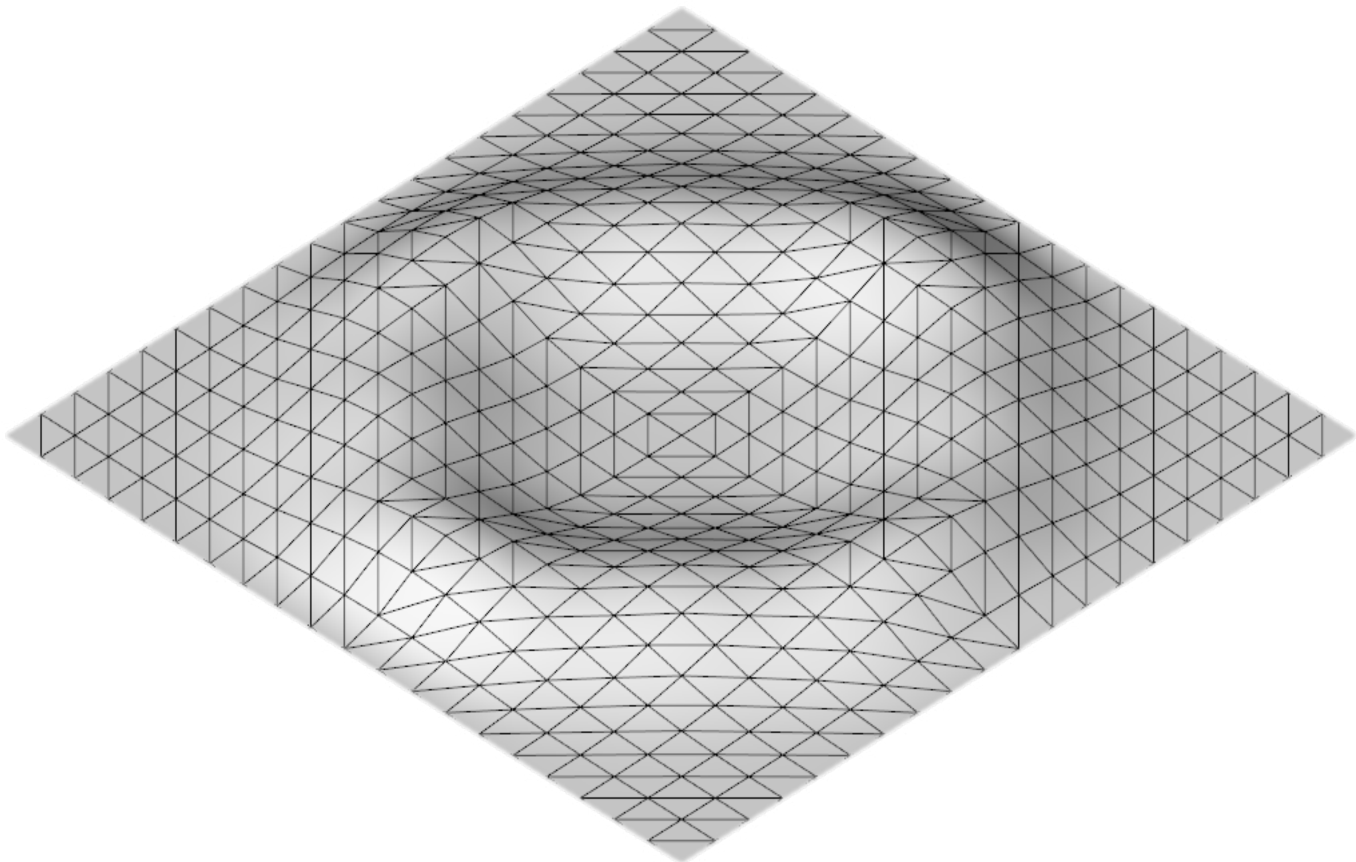
Backward: Caustic Patterns -> Refraction Surface
Design direction: top-down

Computation

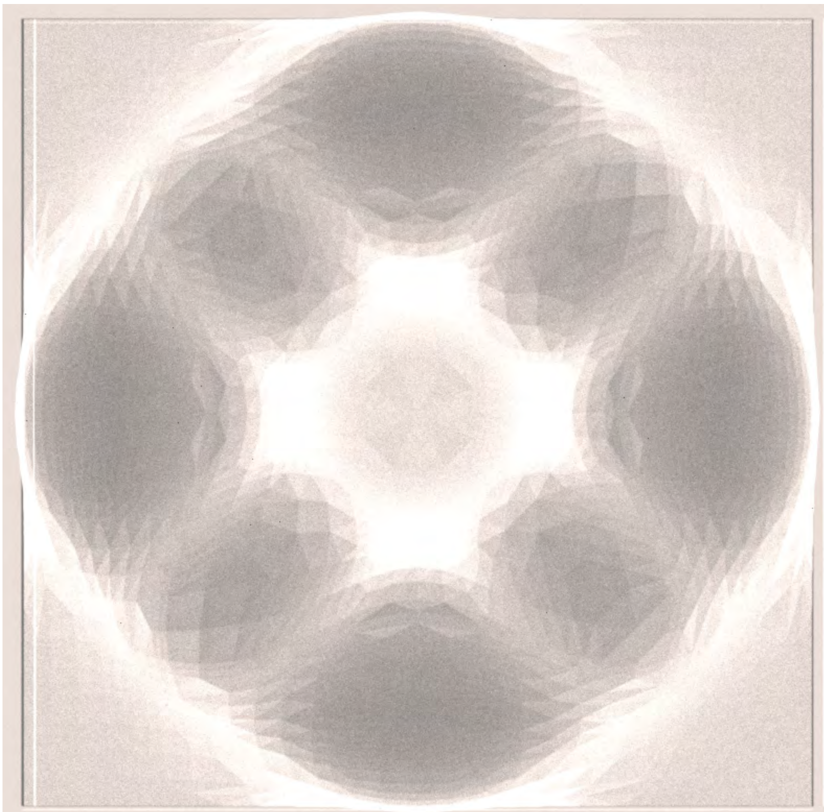
Computing Caustics

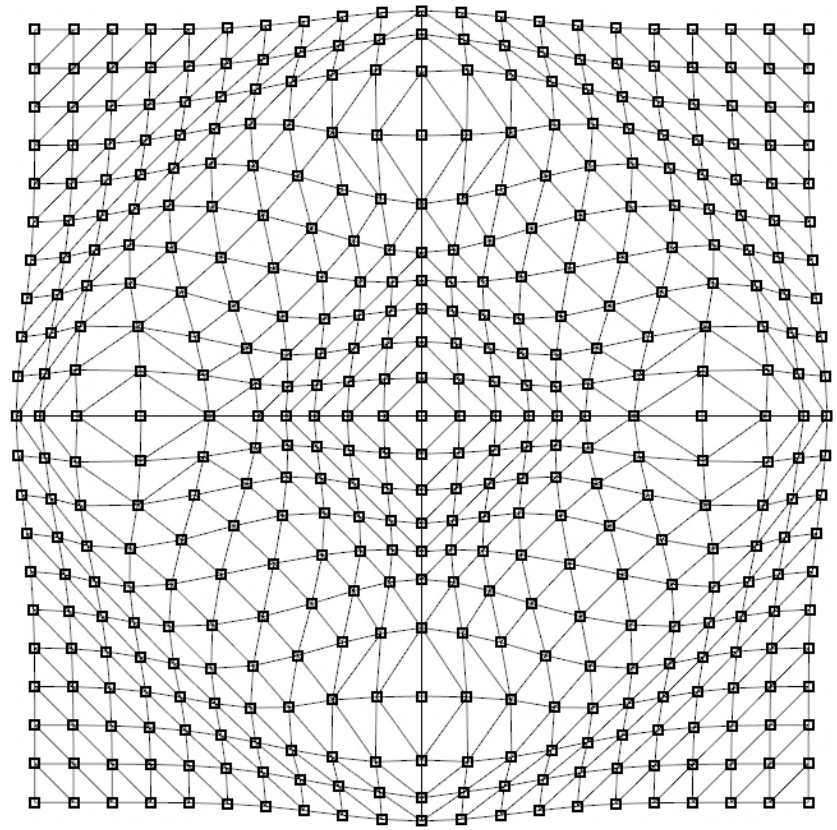
As shown on the next page, for computing caustics, we use a computation model similar to ray tracing but only compute the refraction of the light rays based on the refractive surface.

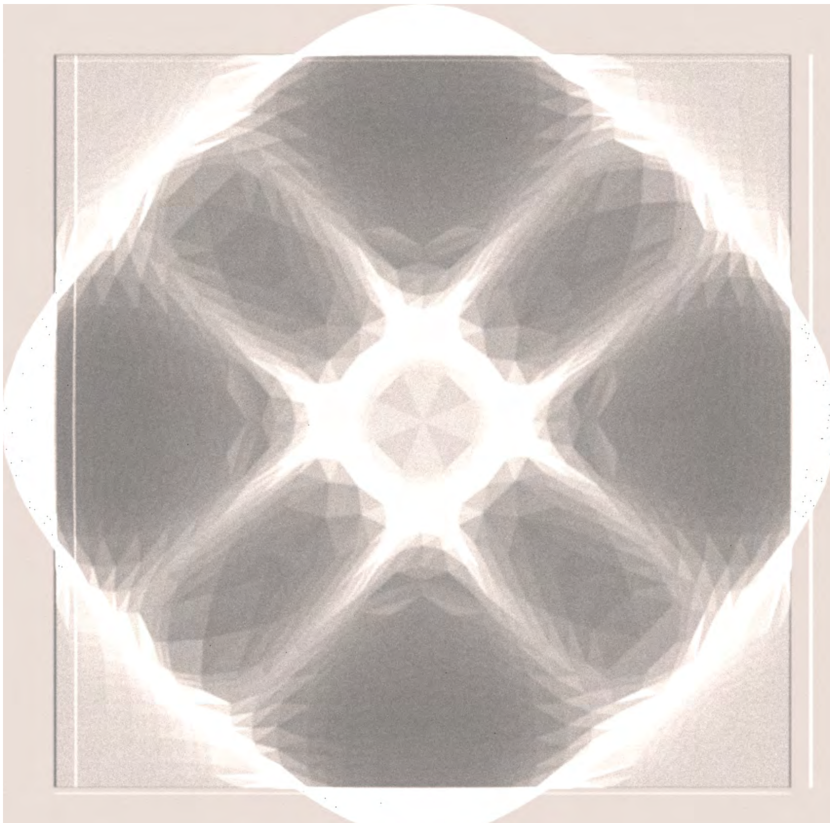

incoming light
refracted light
compute surface normals
integrate normals to heightfield

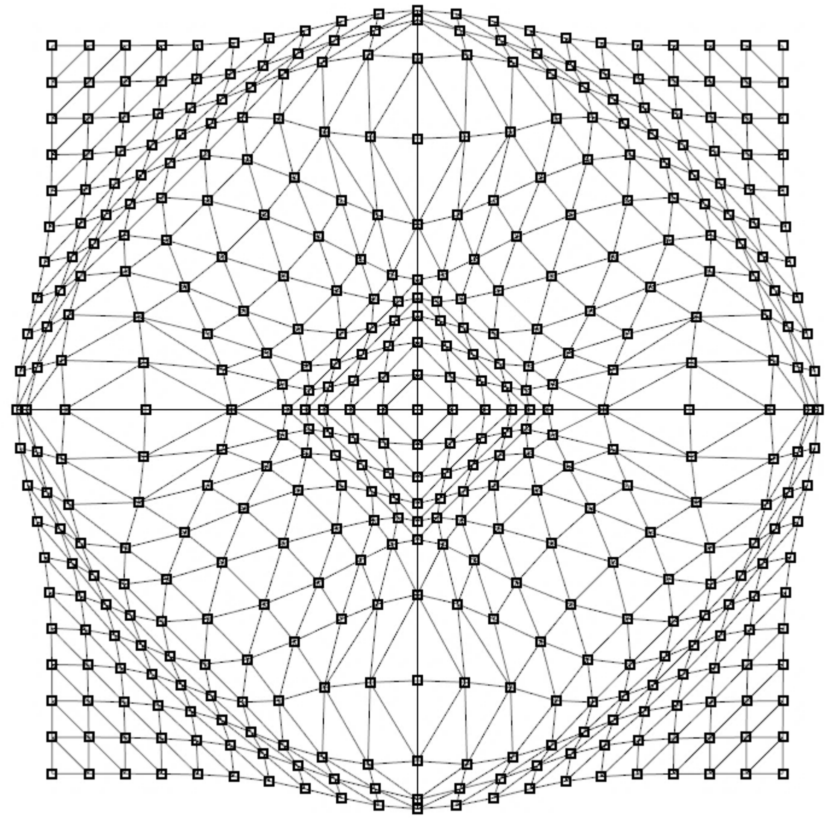


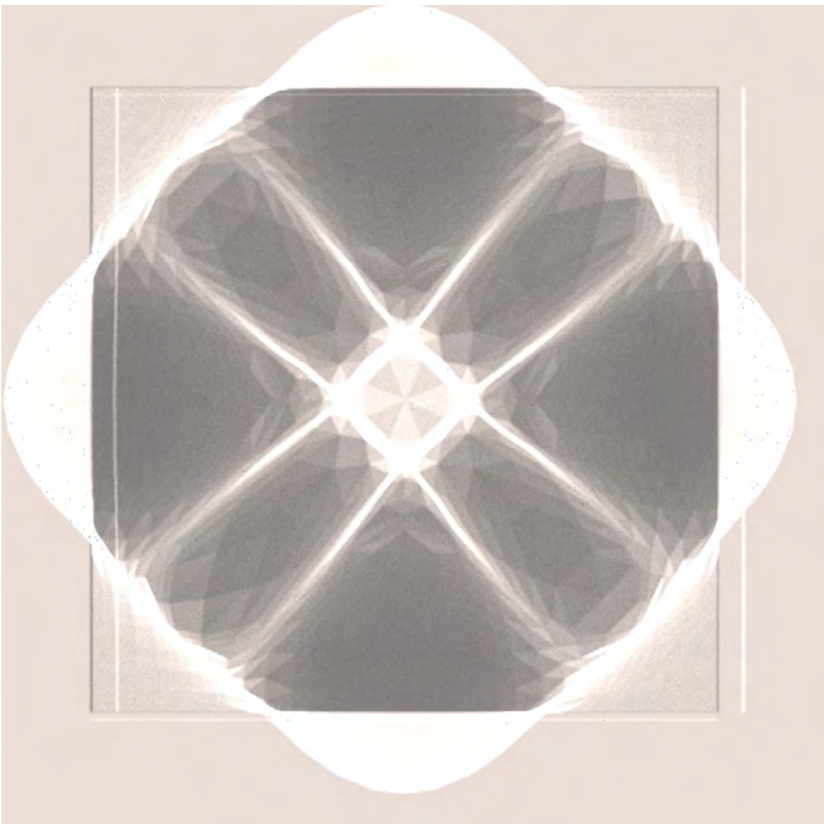
A simple mesh surface is chosen to compare the computation result with the rendering simulation.
The density of the points represents the intensity of the light illumination.

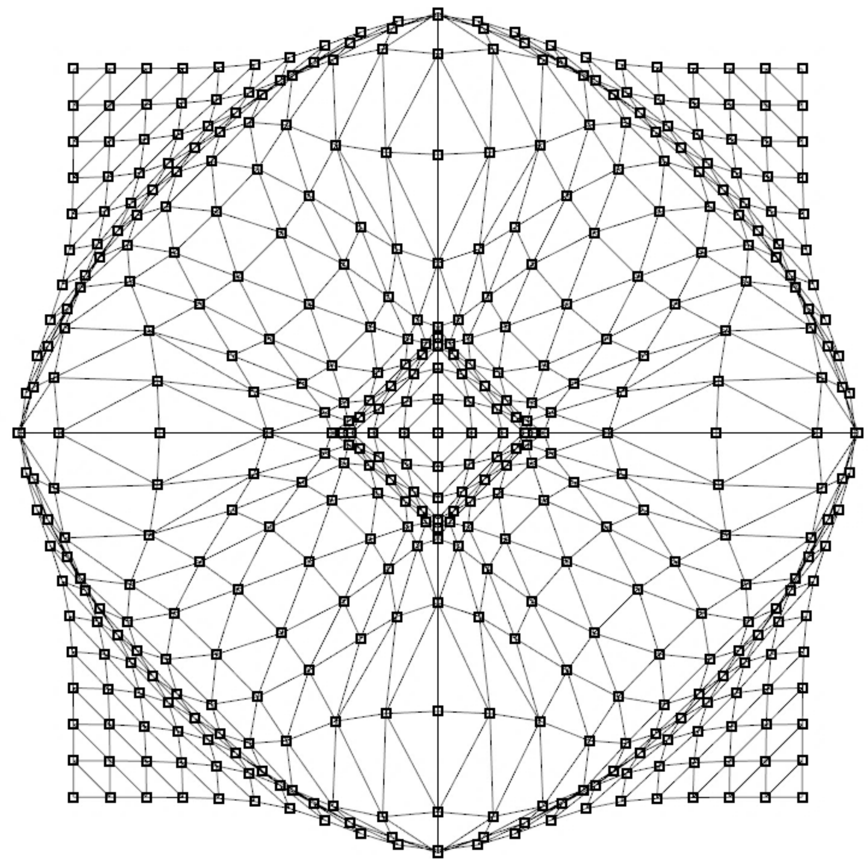


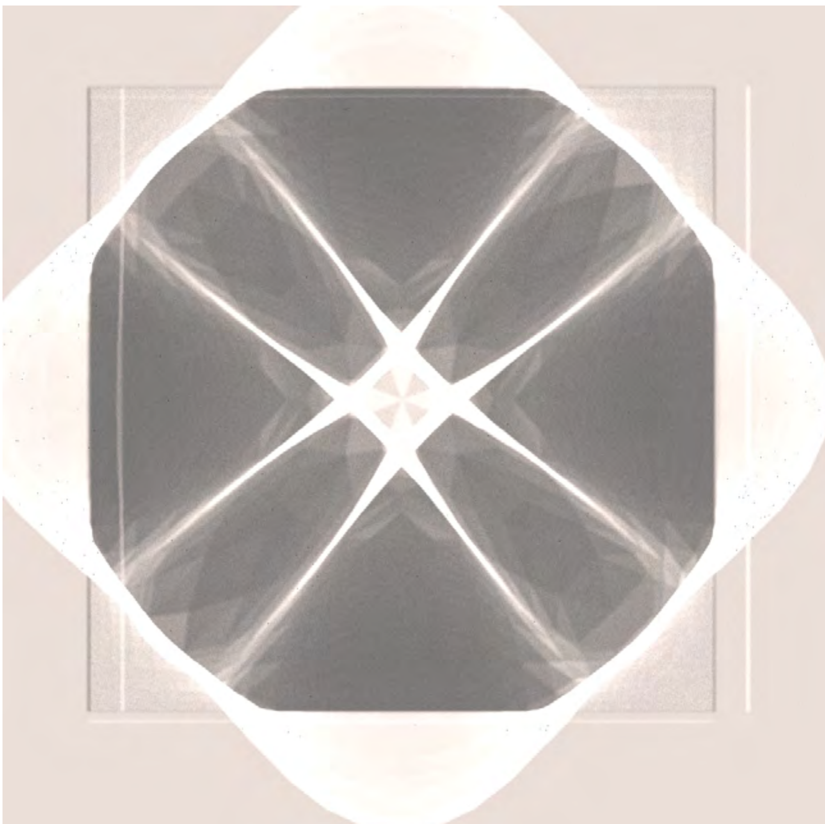


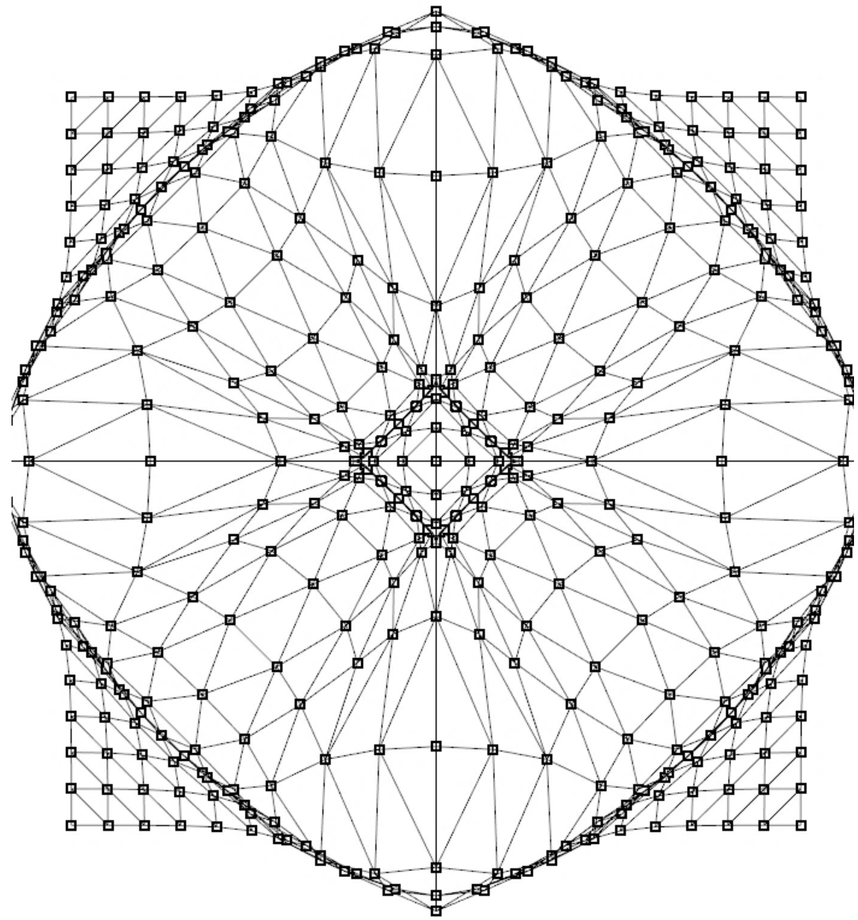




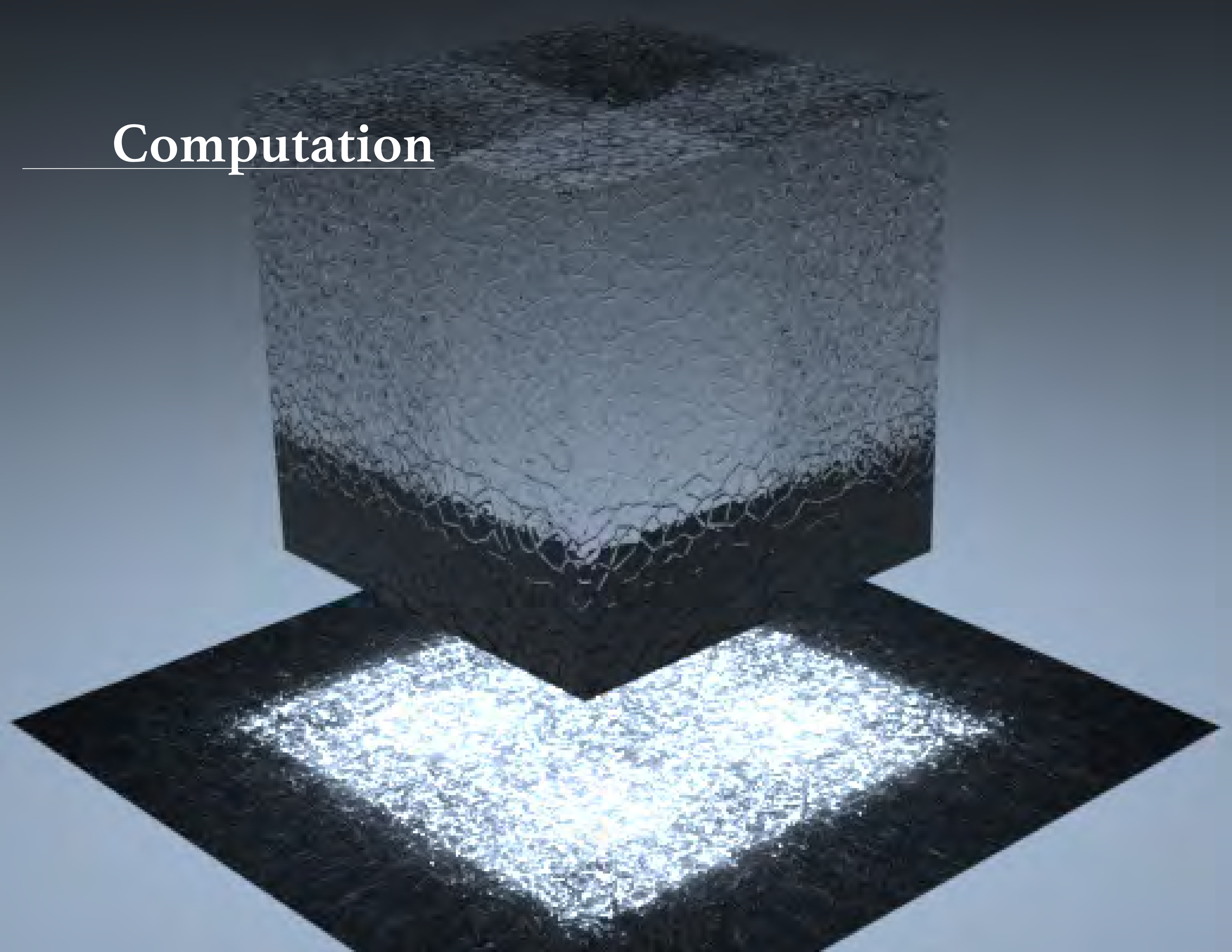






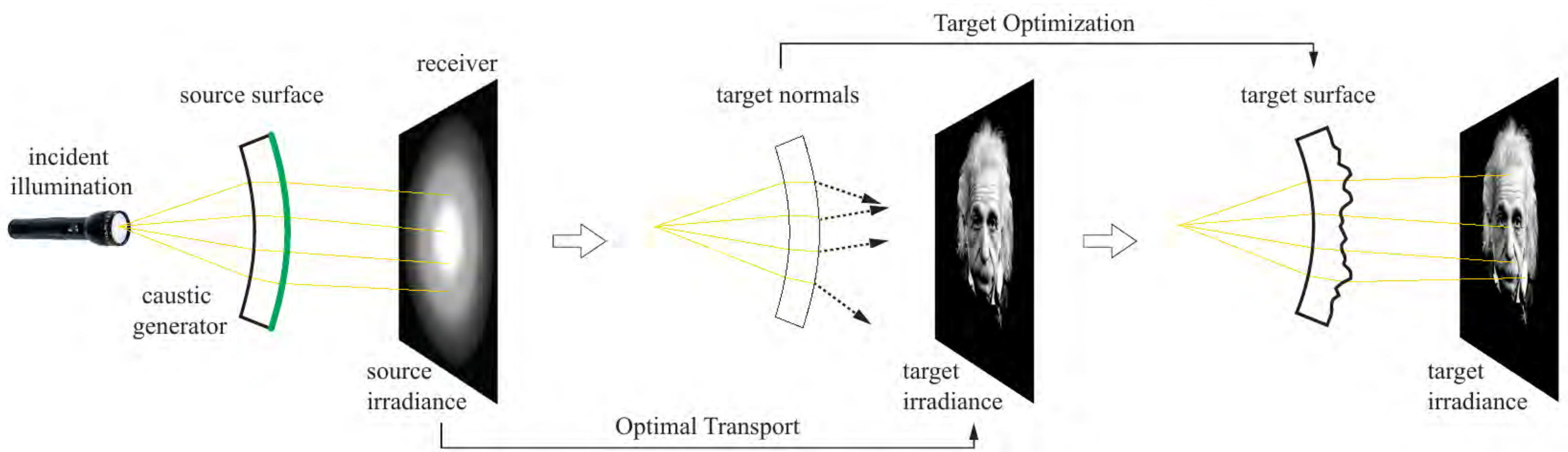


Computation



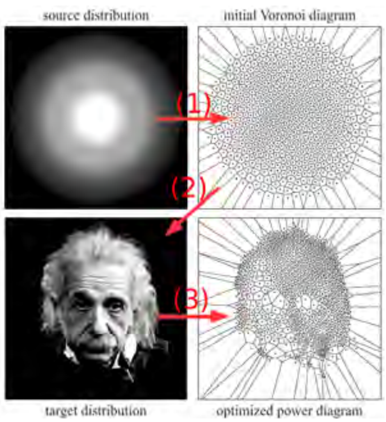
Designing Caustics

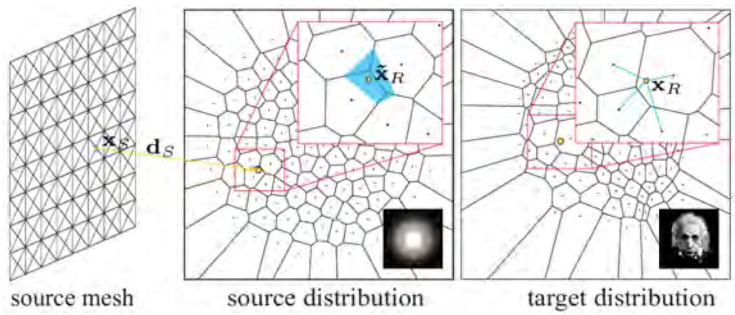
The backward computation – designing a surface that can refract light into specific patterns is achieved by implementing a series of academic papers in computation graphics field. A simple explanation is shown here. More details can be found in the Bibliography part at the end.

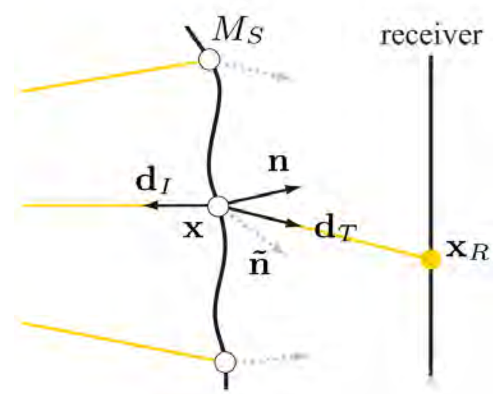


SCHWARTZBURG, Y. et al., High-Contrast Computational Caustic Design, ACM Transaction on Graphics (TOG) 33, 4, 74

algorithm overview







Optimal Transport Map Computation

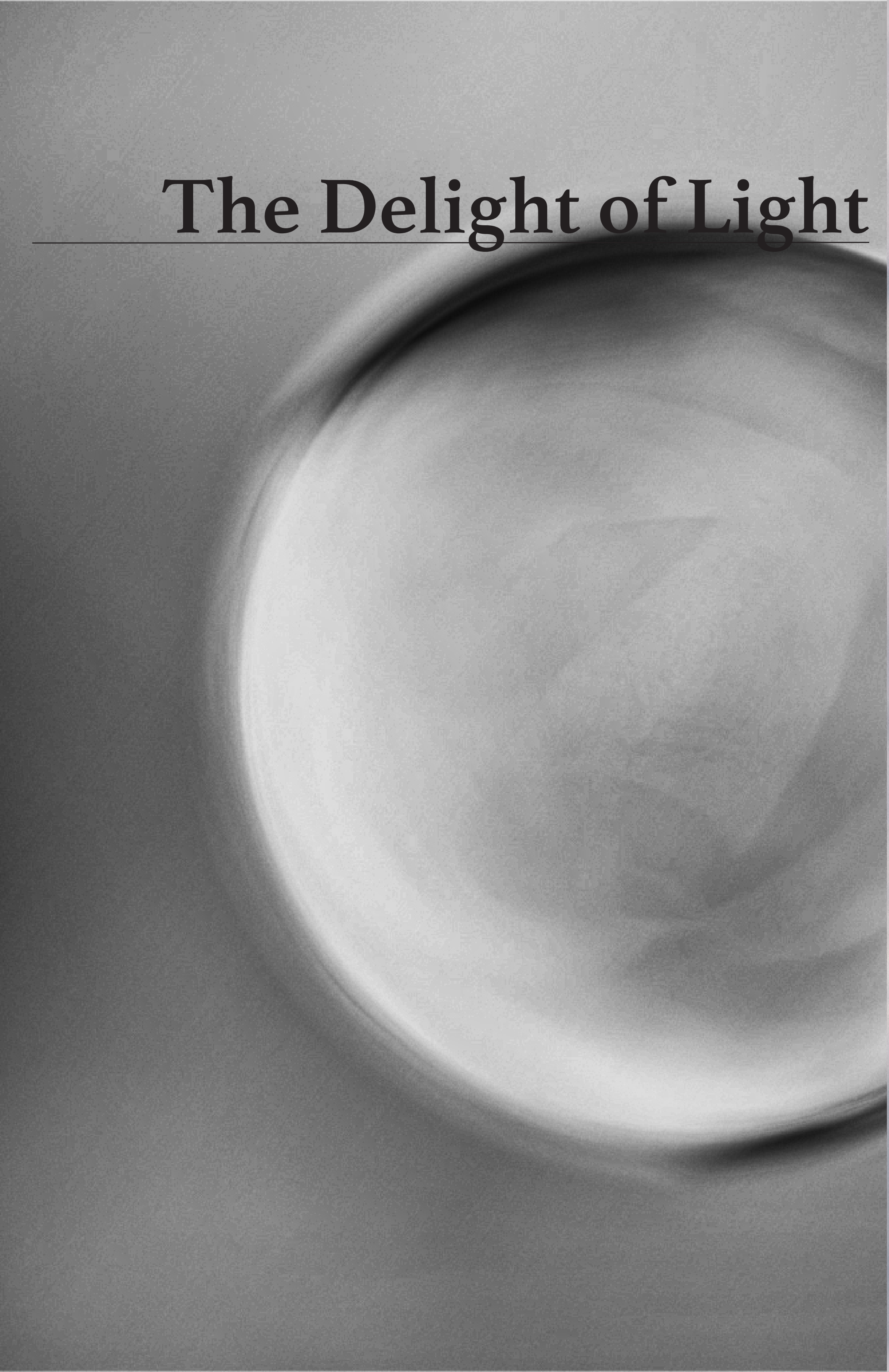
Natural Neighbor Interpolation

Target Optimization

SCHWARTZBURG, Y. et al., High-Contrast Computational Caustic Design, ACM Transaction on Graphics (TOG) 33, 4, 74

three main steps in the algorithm

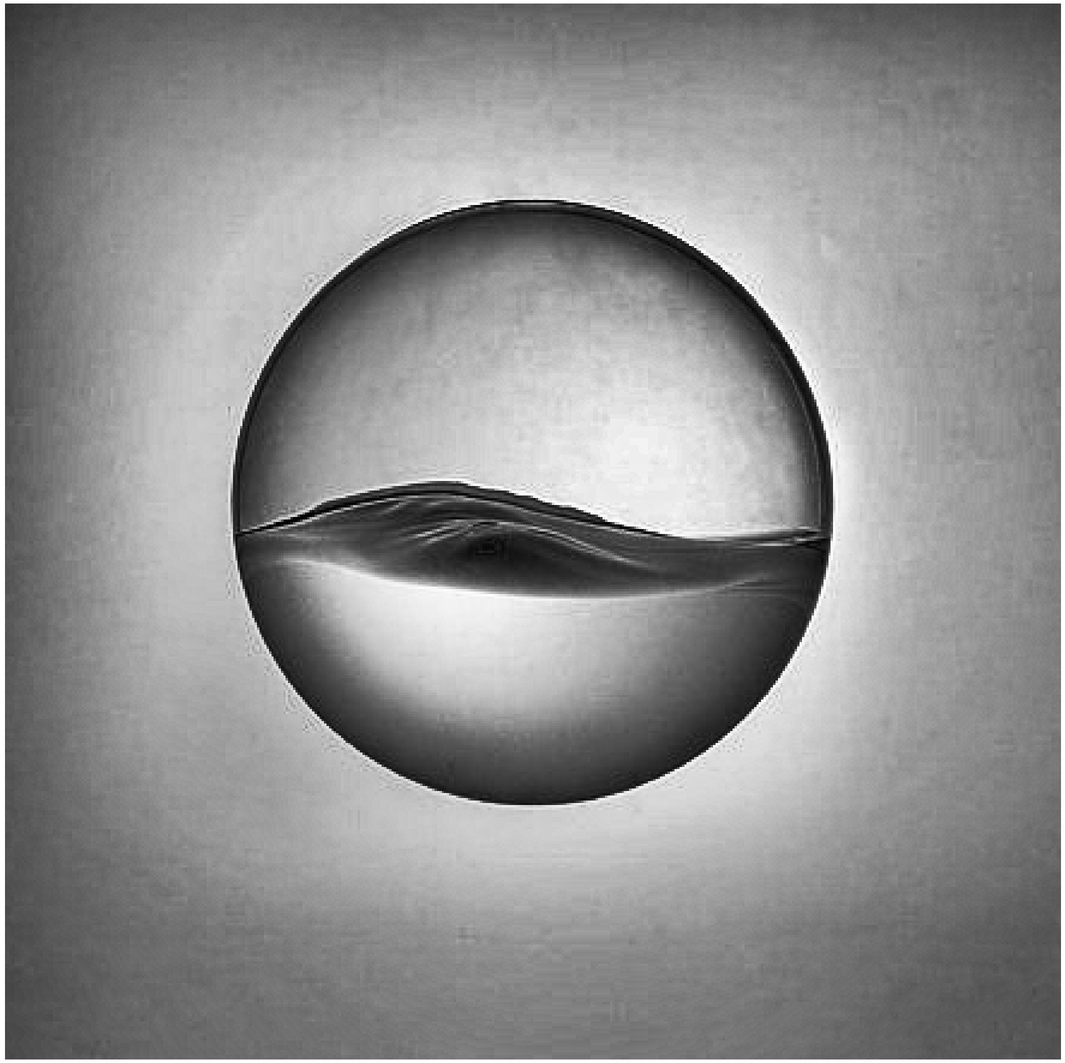
The Delight of Light



Precision

In this section, we use the implemented algorithm directly to see how precise we can control the refraction of light. Three images are chosen as targets to compute the corresponding surfaces that can refract light to, with different sampling density.

Rendering images are compared with the original target images and two of the computed surfaces are manufactured physically to prove the results.

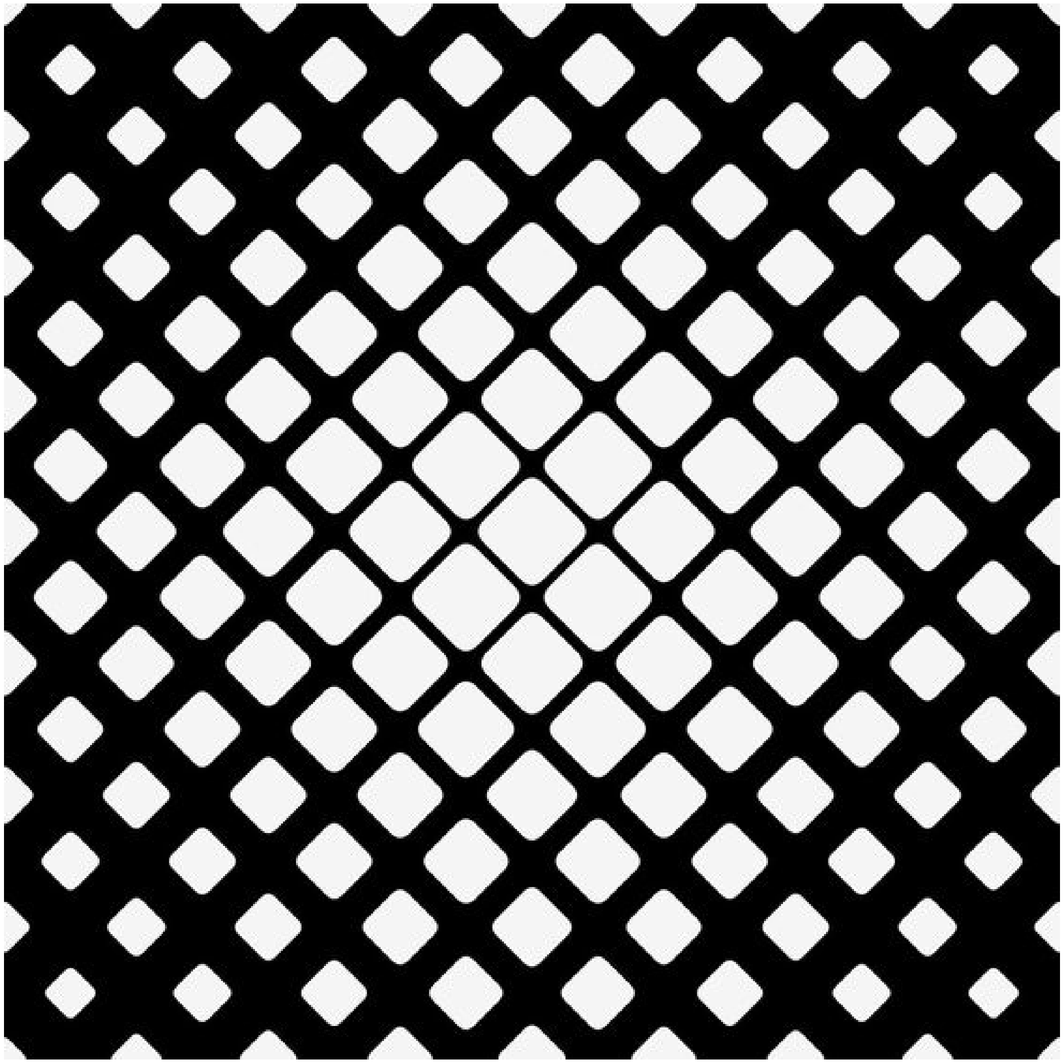


target image

sampling density: 250 x 250

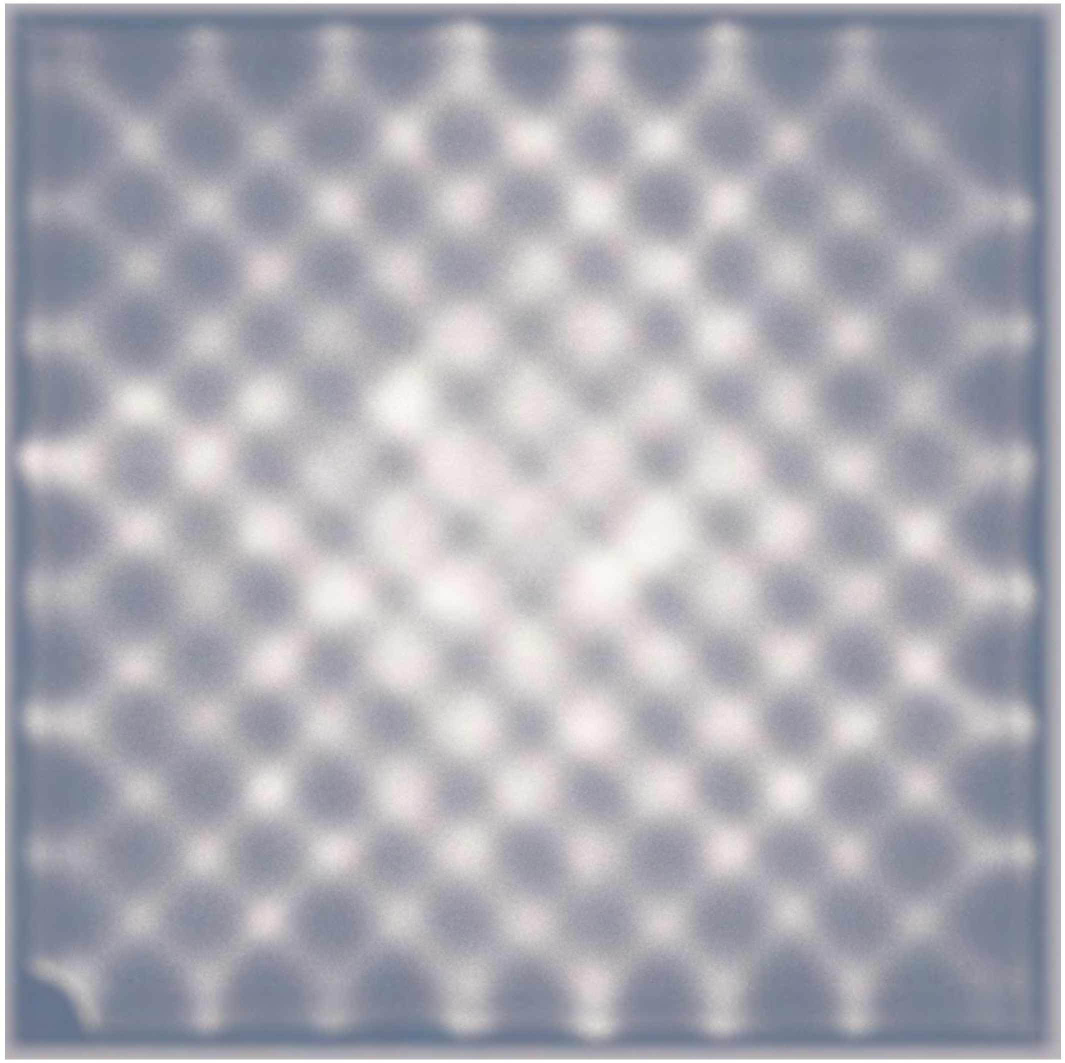
rendering result from mesh surface

mesh density: 200 x 200



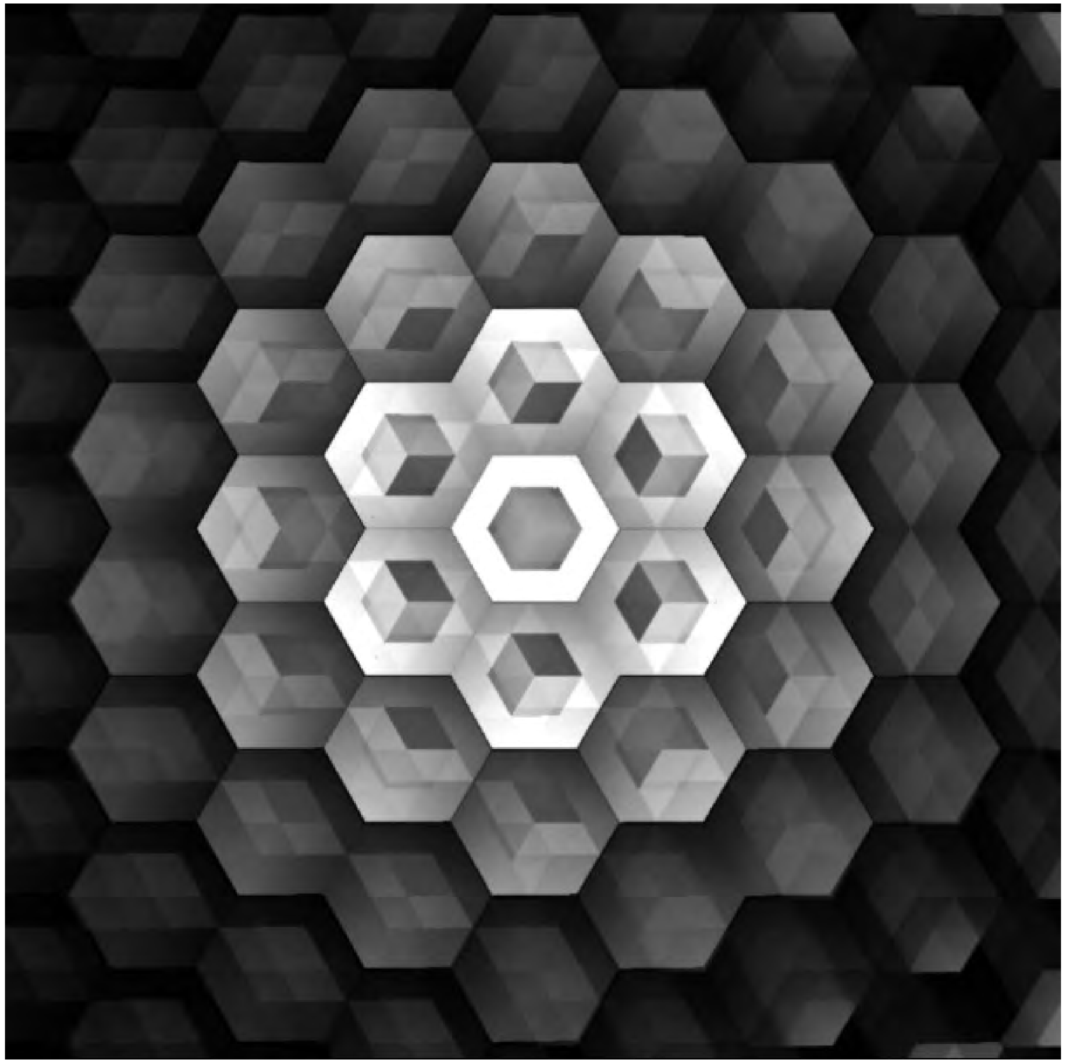
target image (testing precision on boundary)

sampling density: 300 x 300



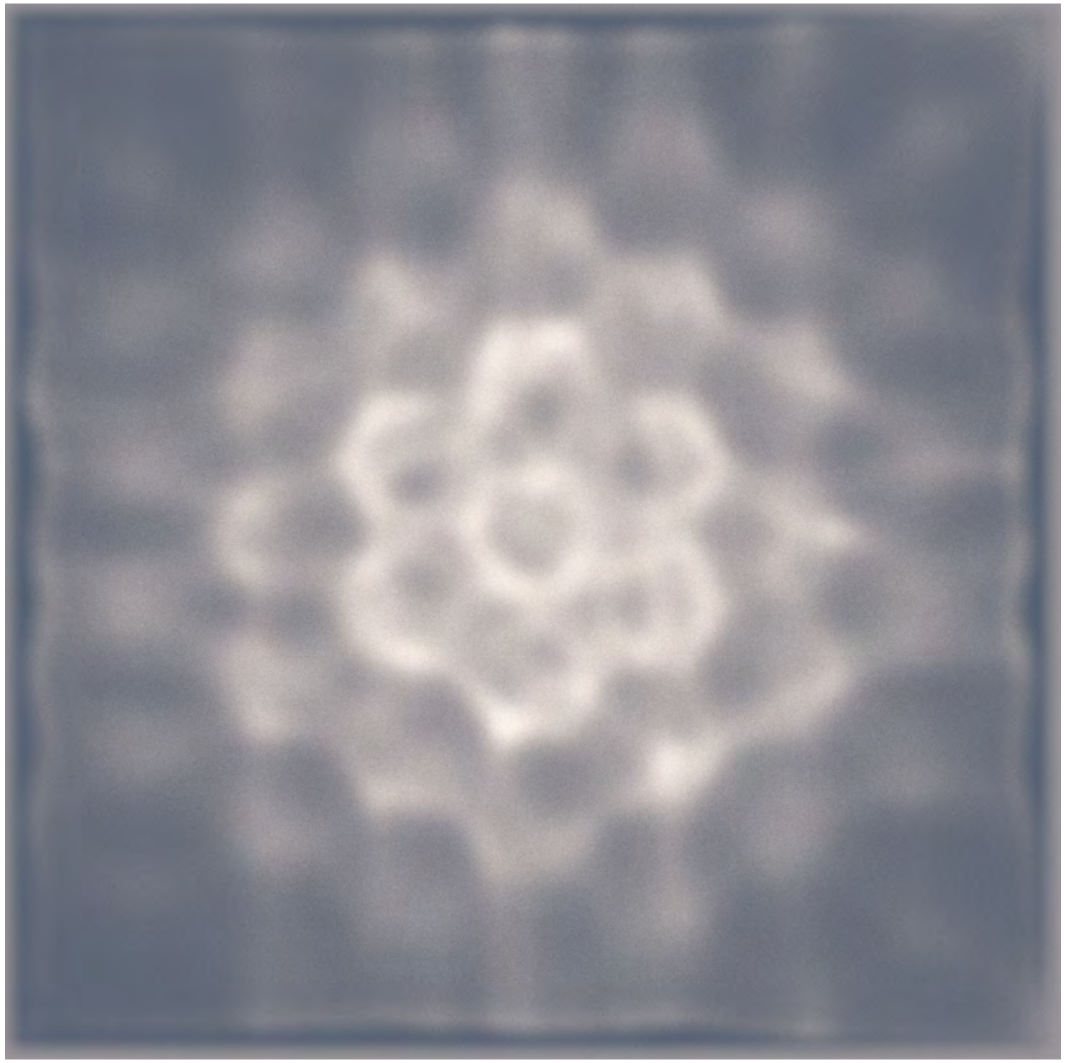
rendering result from mesh surface

mesh density: 300 x 300



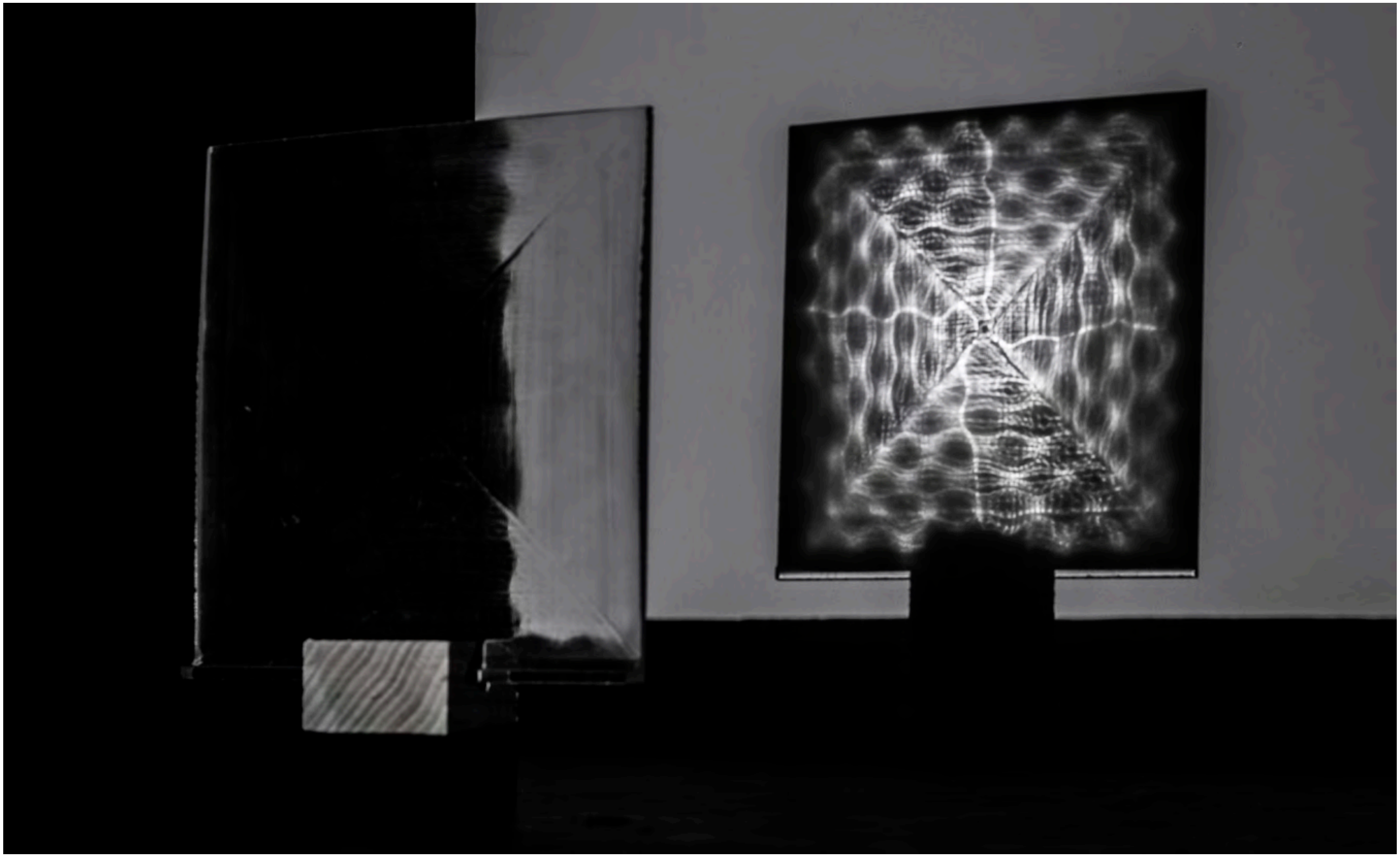
target image (testing precision on boundary & gradient)

sampling density: 350 x 350



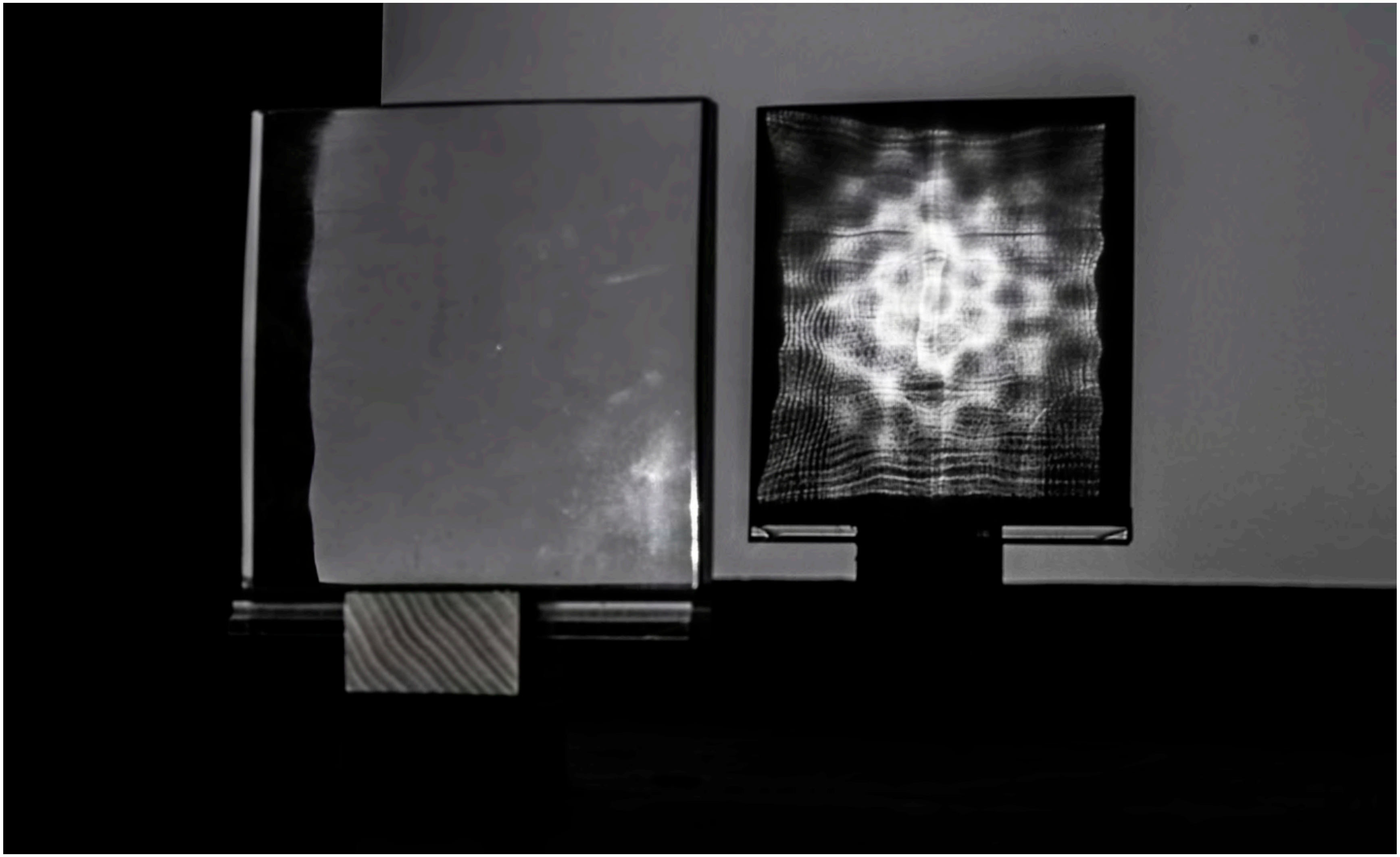
rendering result from mesh surface

mesh density: 350 x 350



physical lighting test

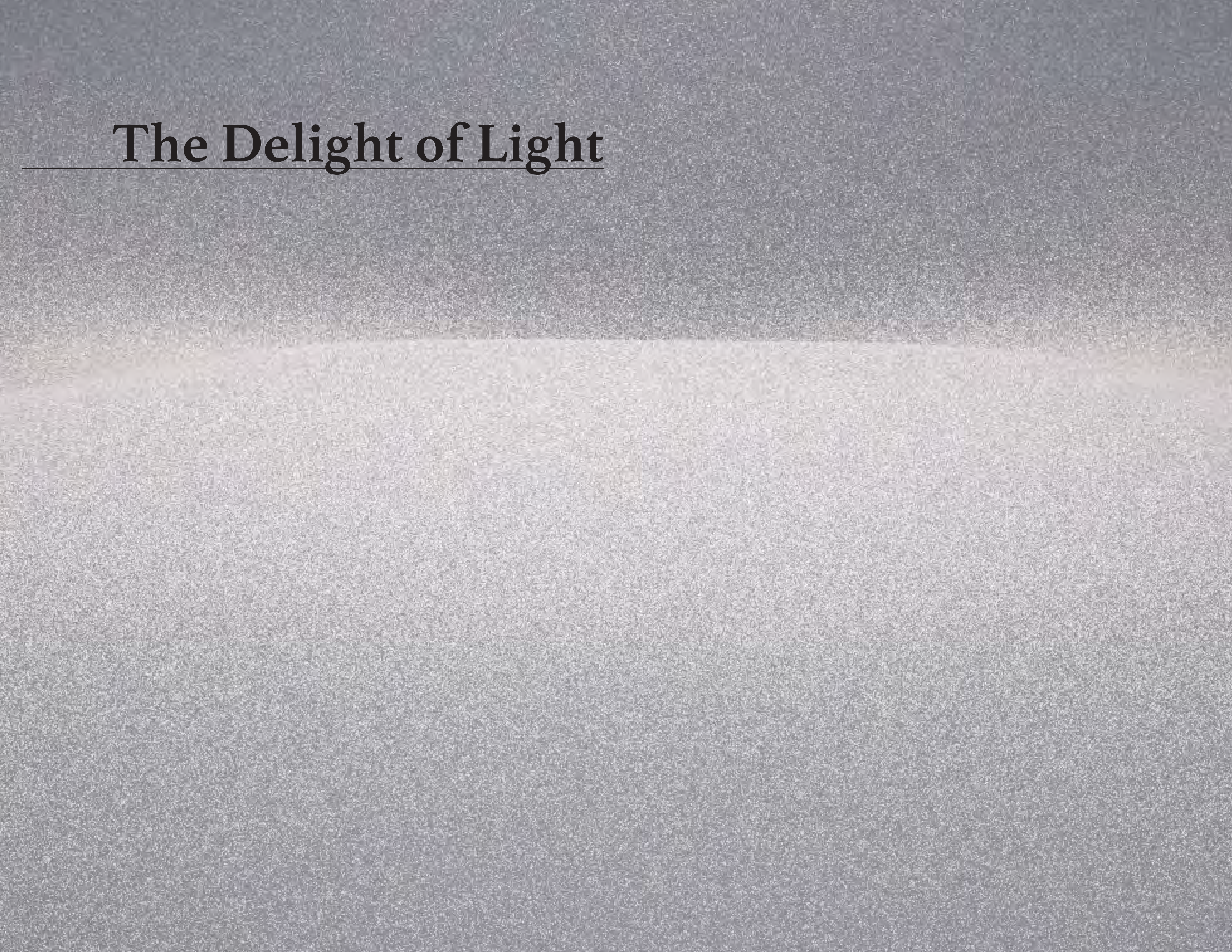
light source: distance spot light (to simulate parallel light)



physical lighting test

light source: distance spot light (to simulate parallel light)

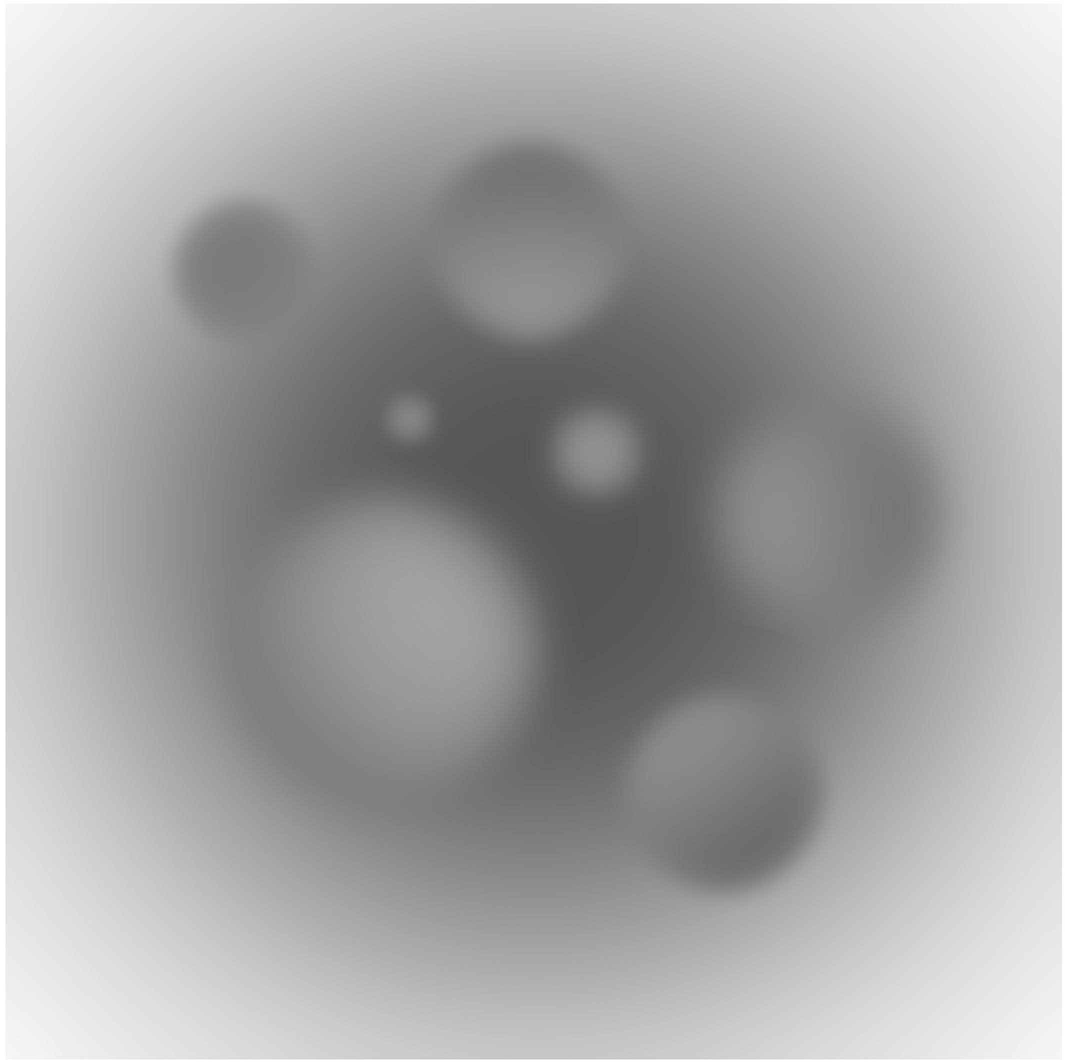
The Delight of Light



Ambiguous

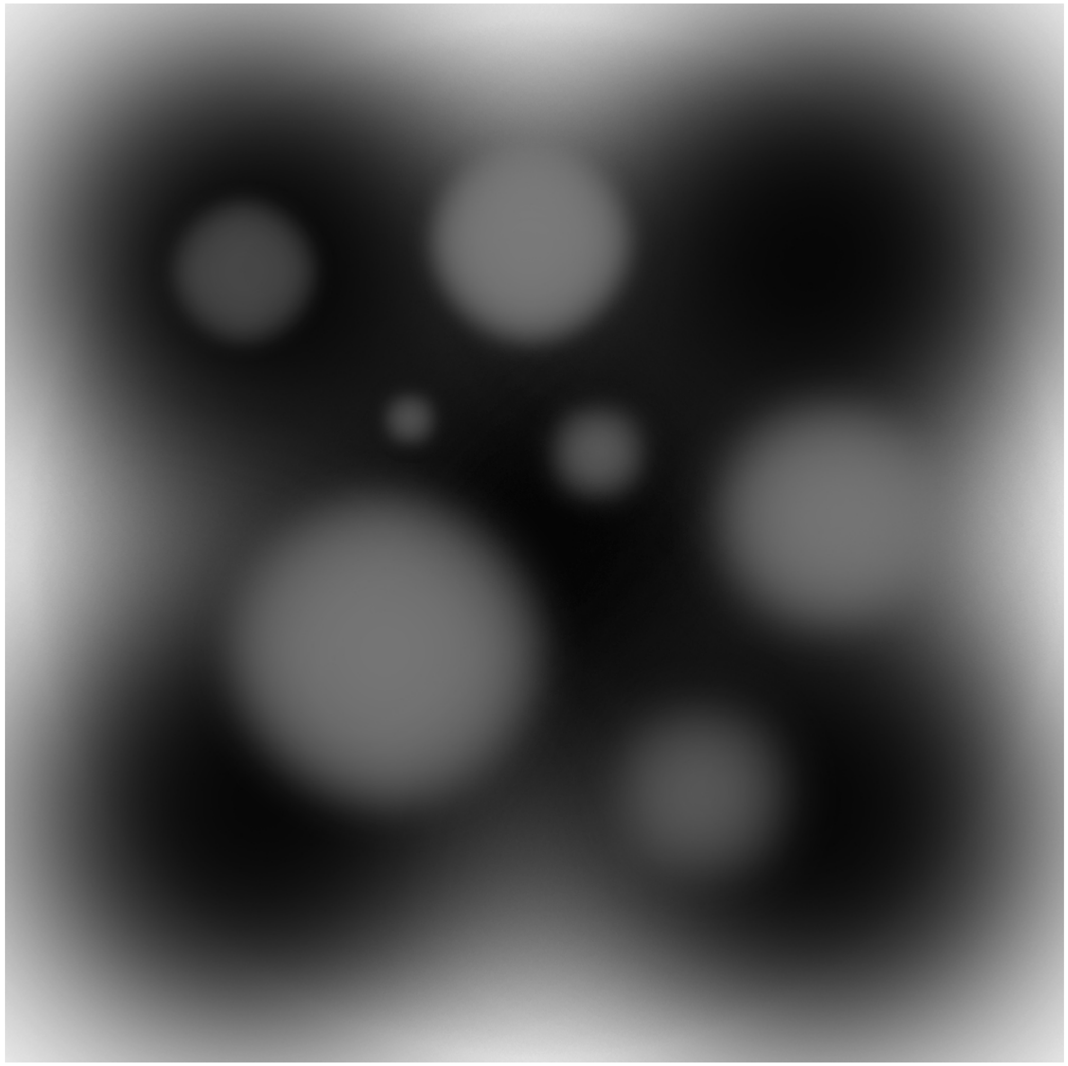
This project discuss the "ambiguous" possibility of "light redistribution" through time and space.

A specified space and a refractive surface are created from two ricipro-cal ambiguous heightmaps. The roof will distribute sunlight to create different ambiguous spatial effects during different times of the day. Transitional velocity also varies because of the the change of the angle between sunlight and the horizontal surface.



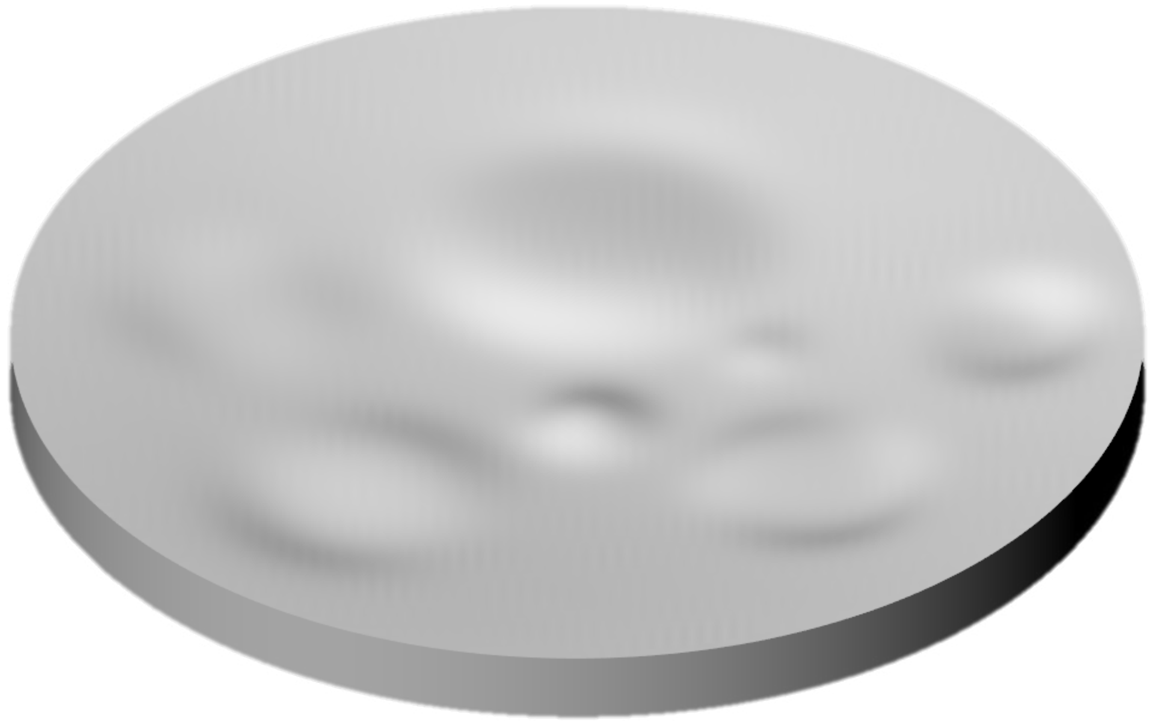
roof

heightmap



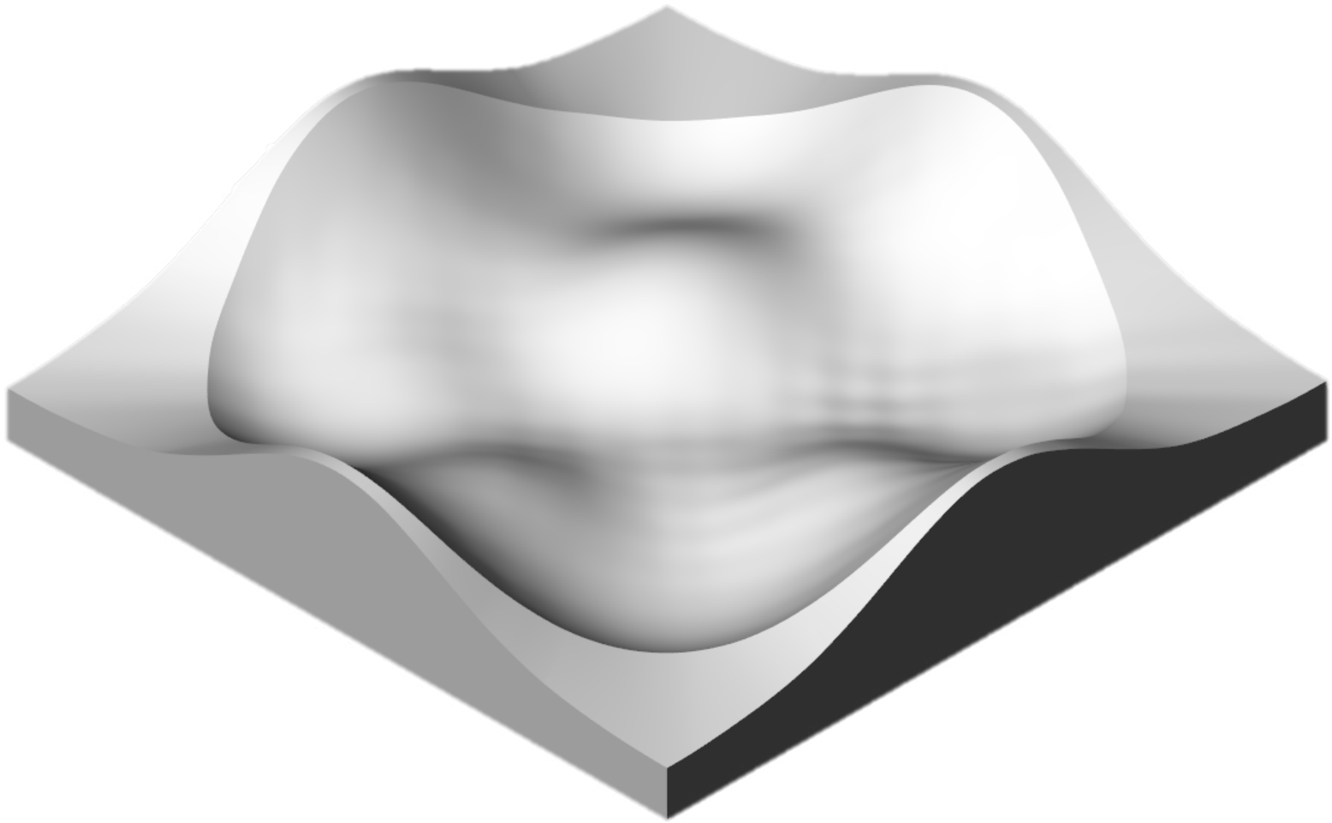
ground

heightmap



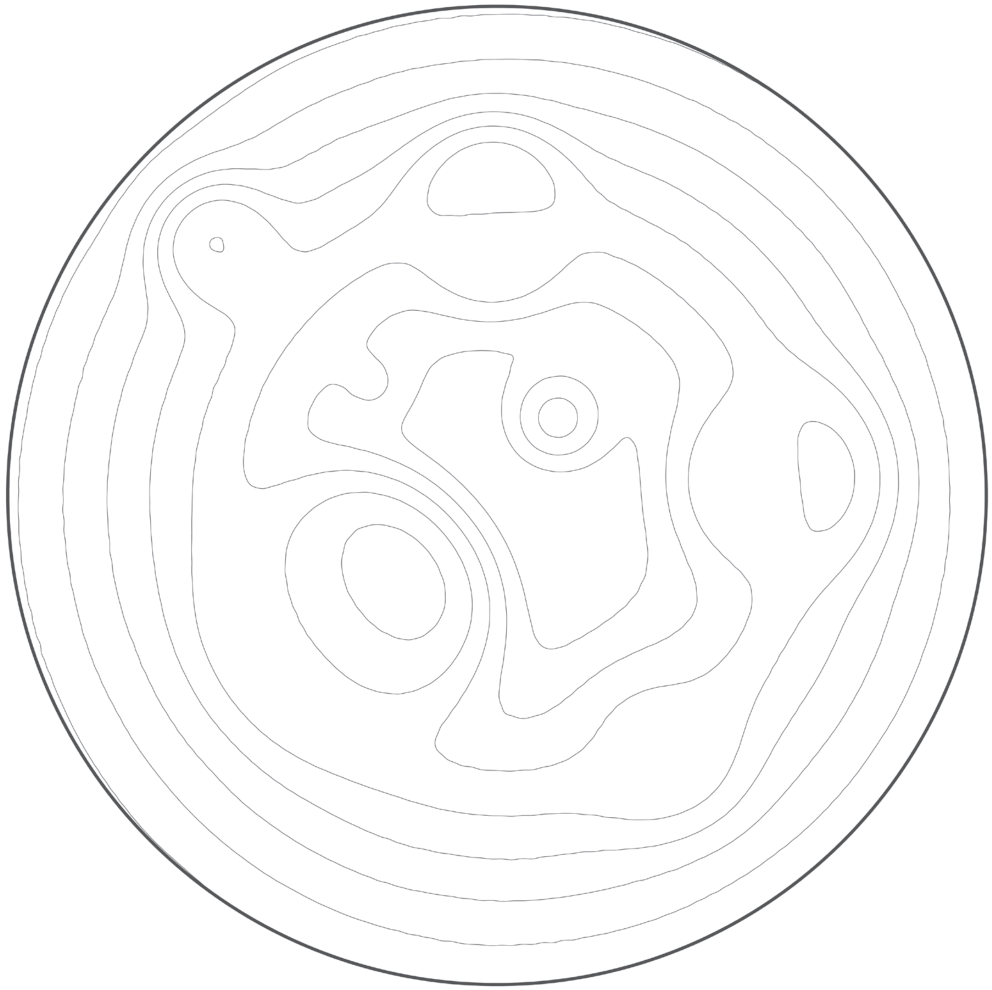
roof

3D mesh model



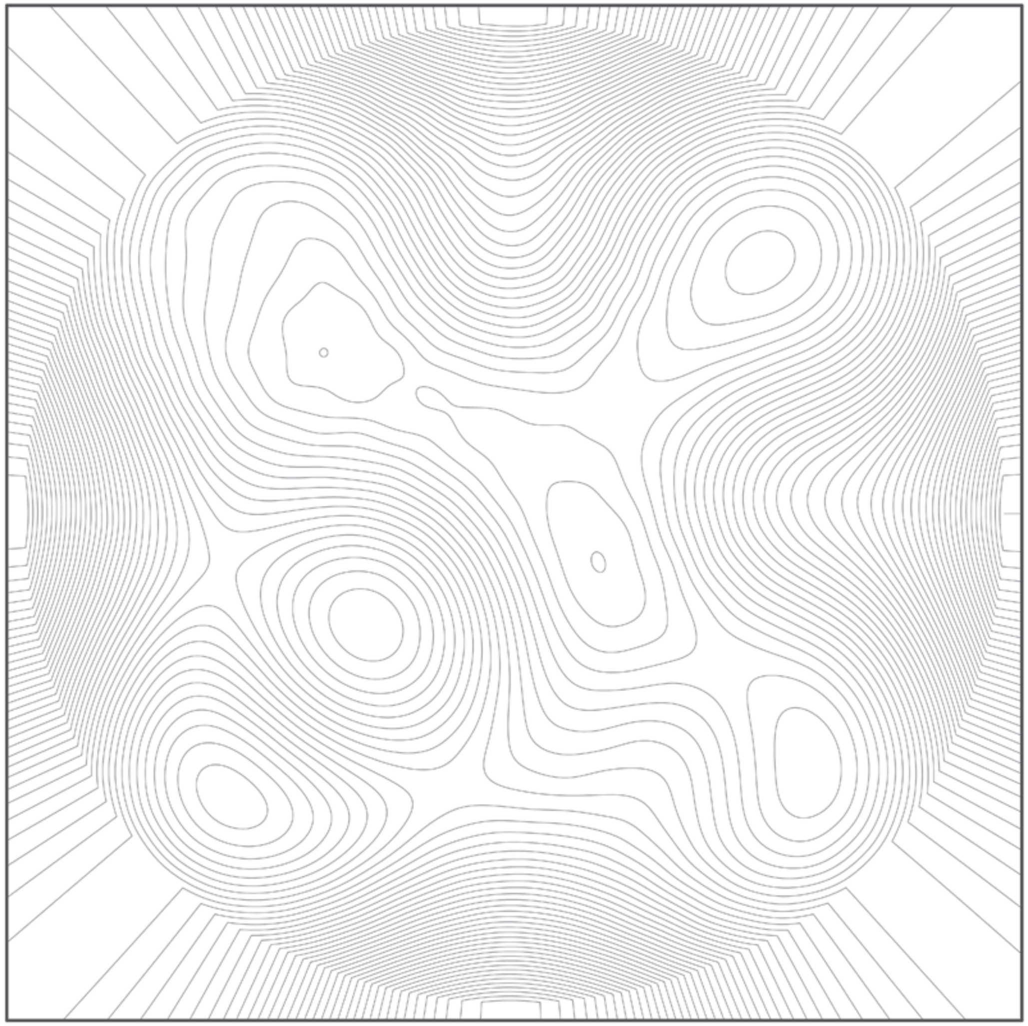
ground

3D mesh model



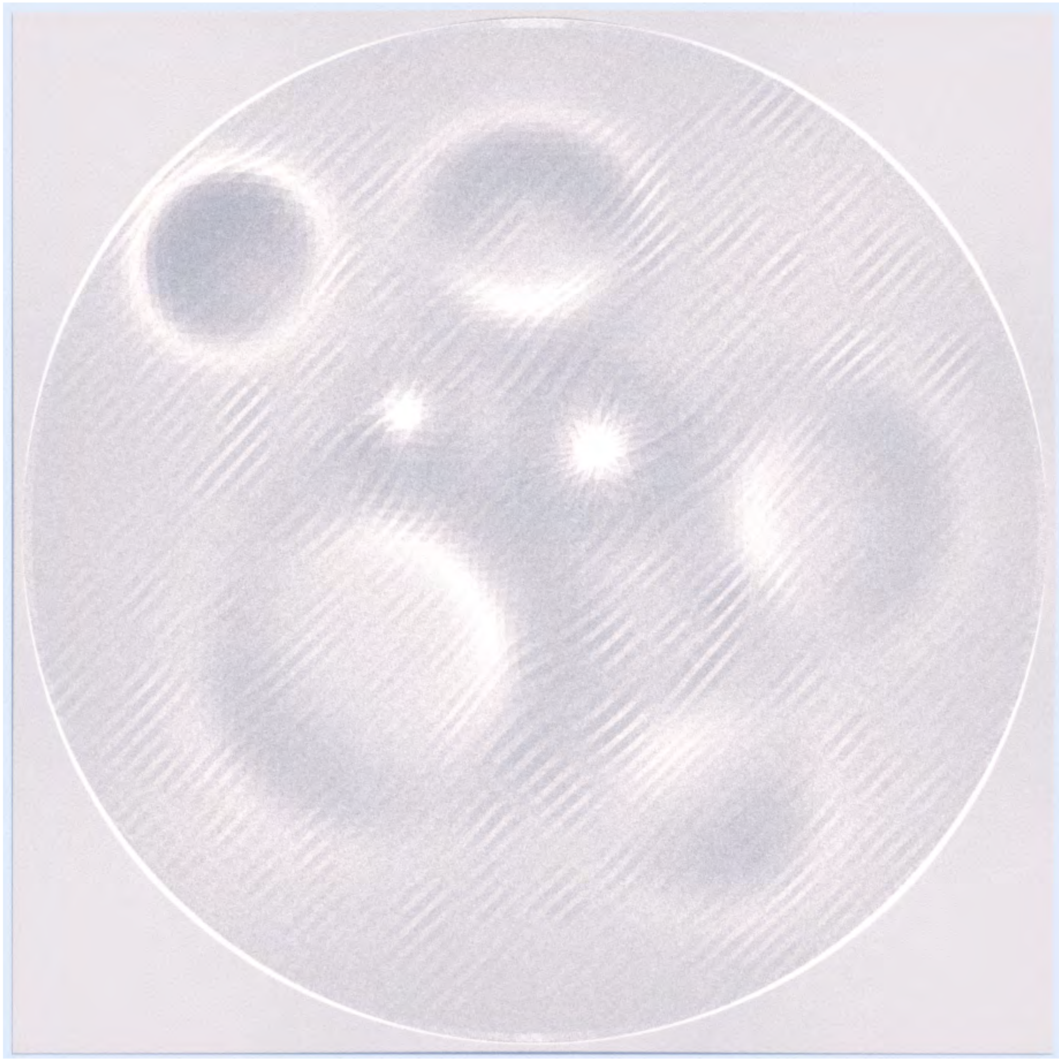
roof

contour



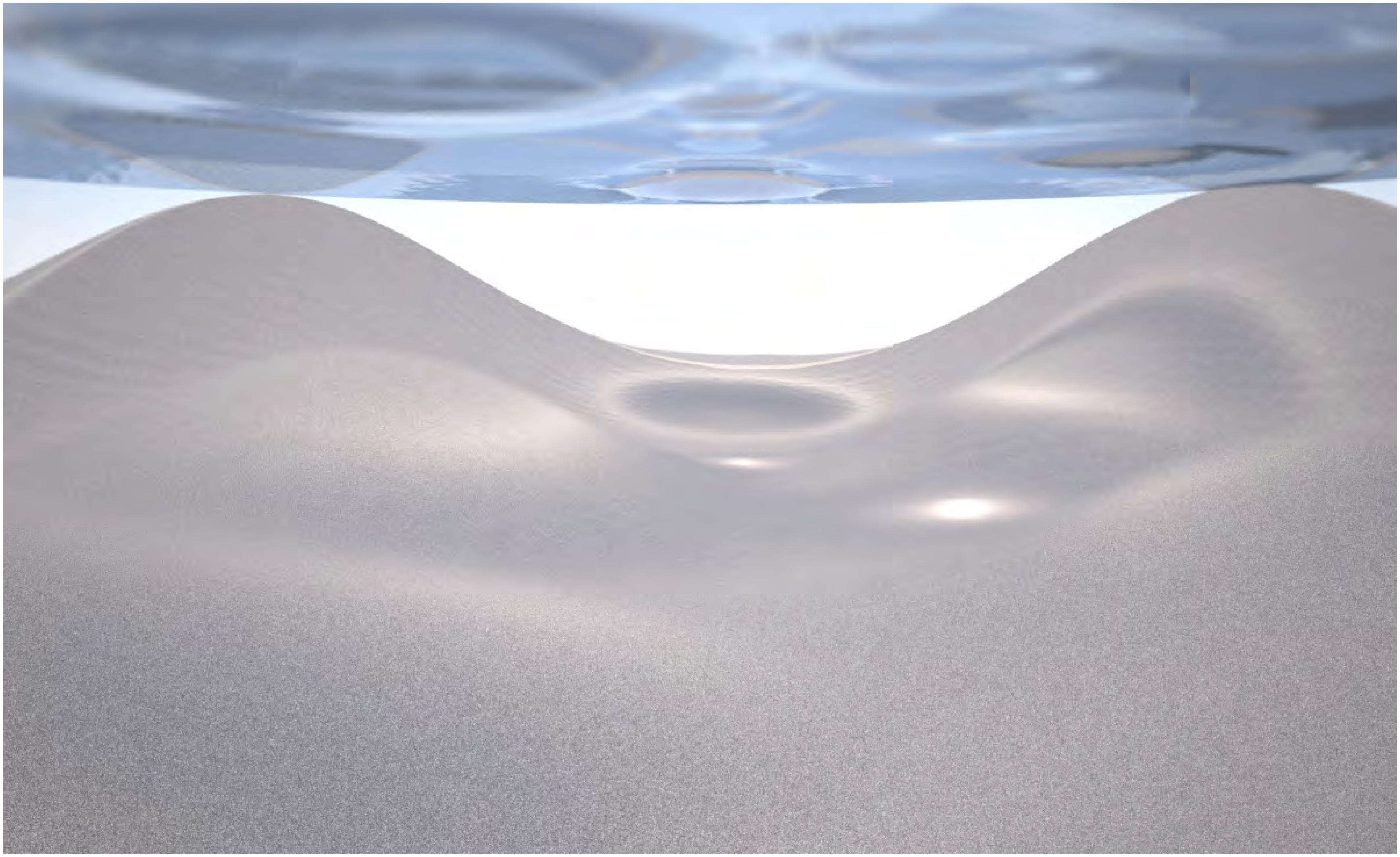
ground

contour



top rendering of the refracted light

sunlight direction perpendicular to the ground



a typical view angle of light dynamics

sunlight direction perpendicular to the ground at noon

photo of the test model

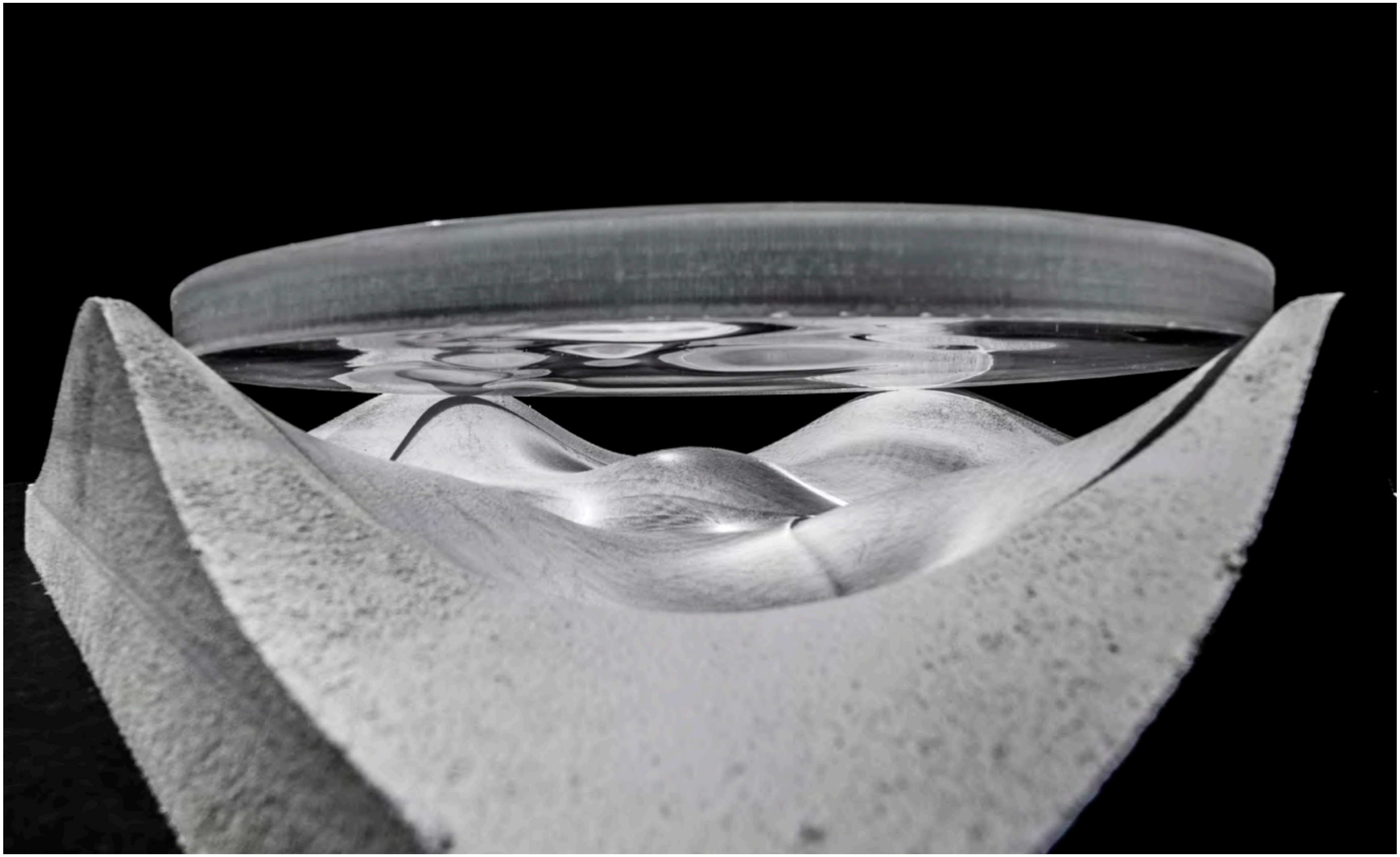
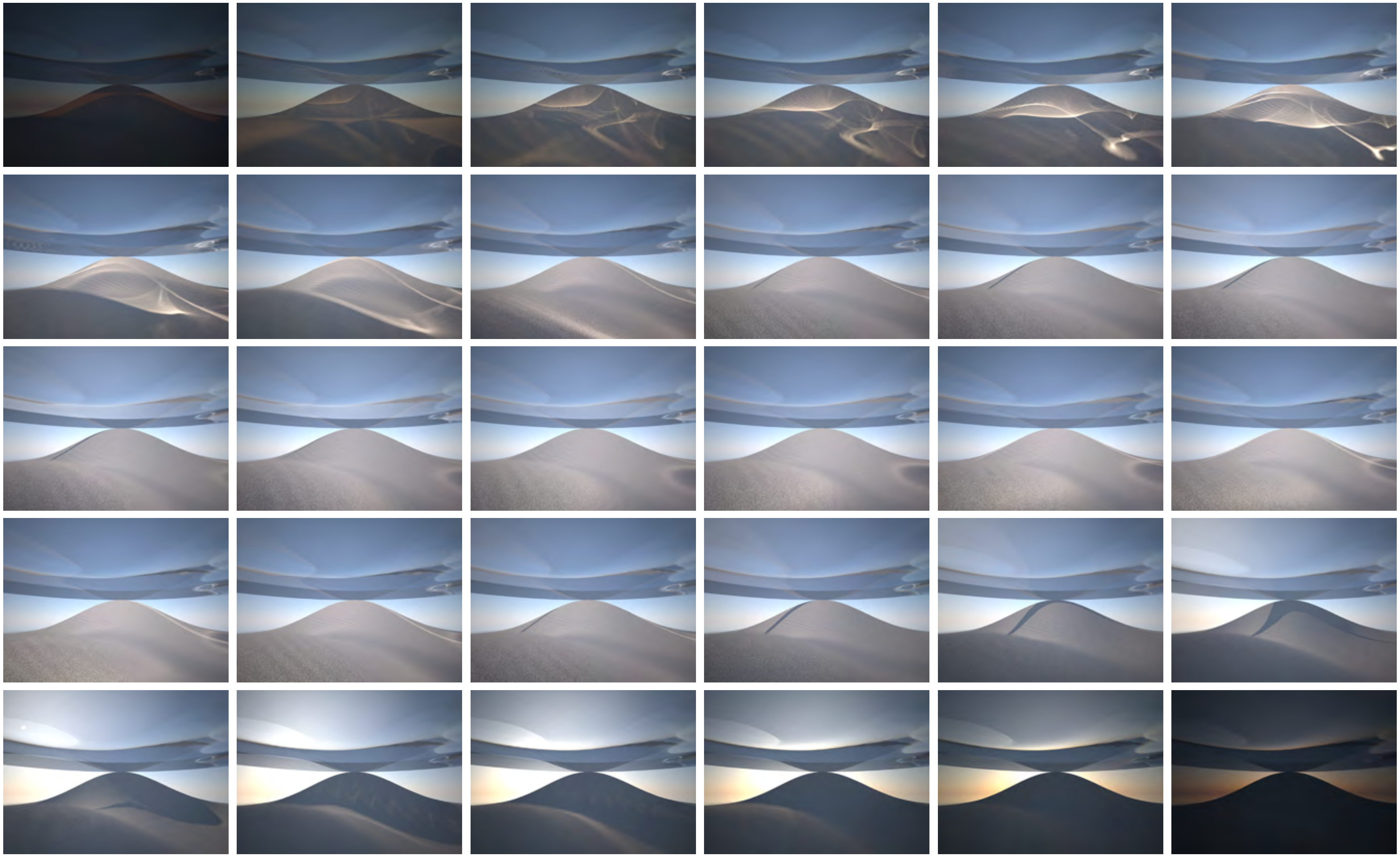


photo test model

contineous framing of light distribution throughout a day

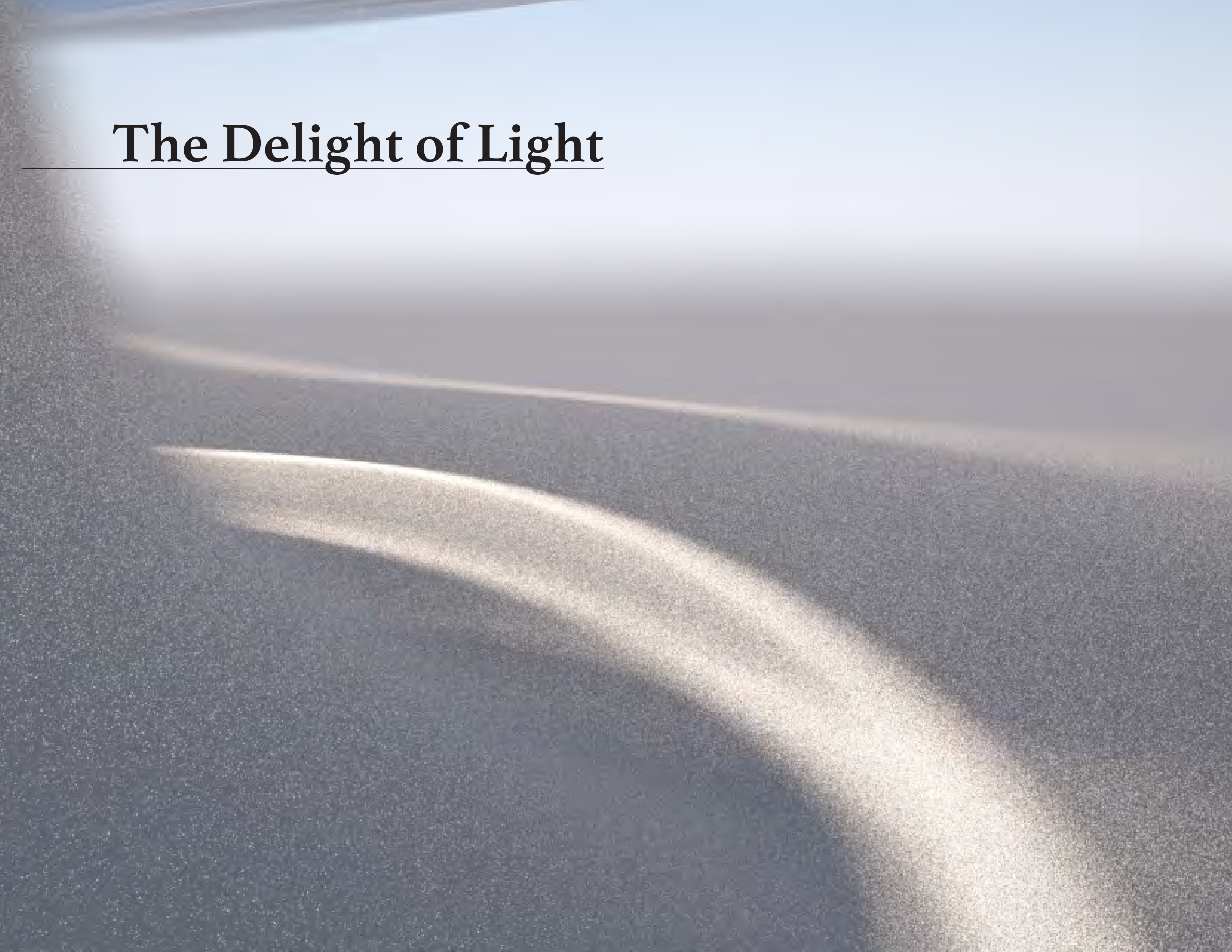
sunlight direction perpendicular to the ground at noon



contineous framing of light distribution throughout a day

sunlight direction perpendicular to the ground at noon

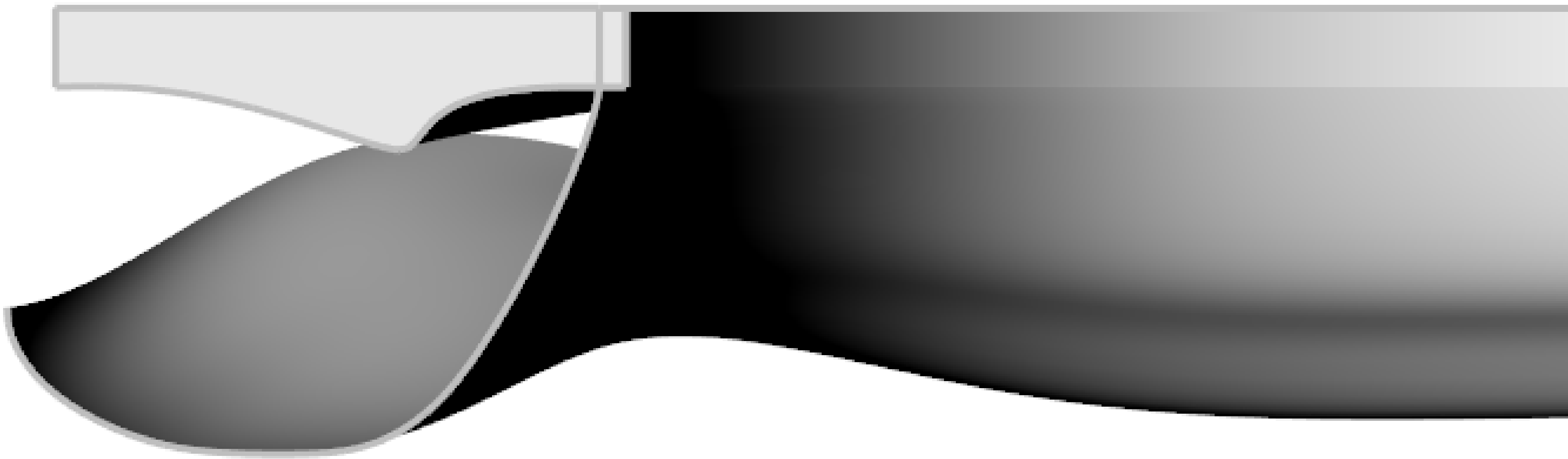
The Delight of Light



Dynamic: flow

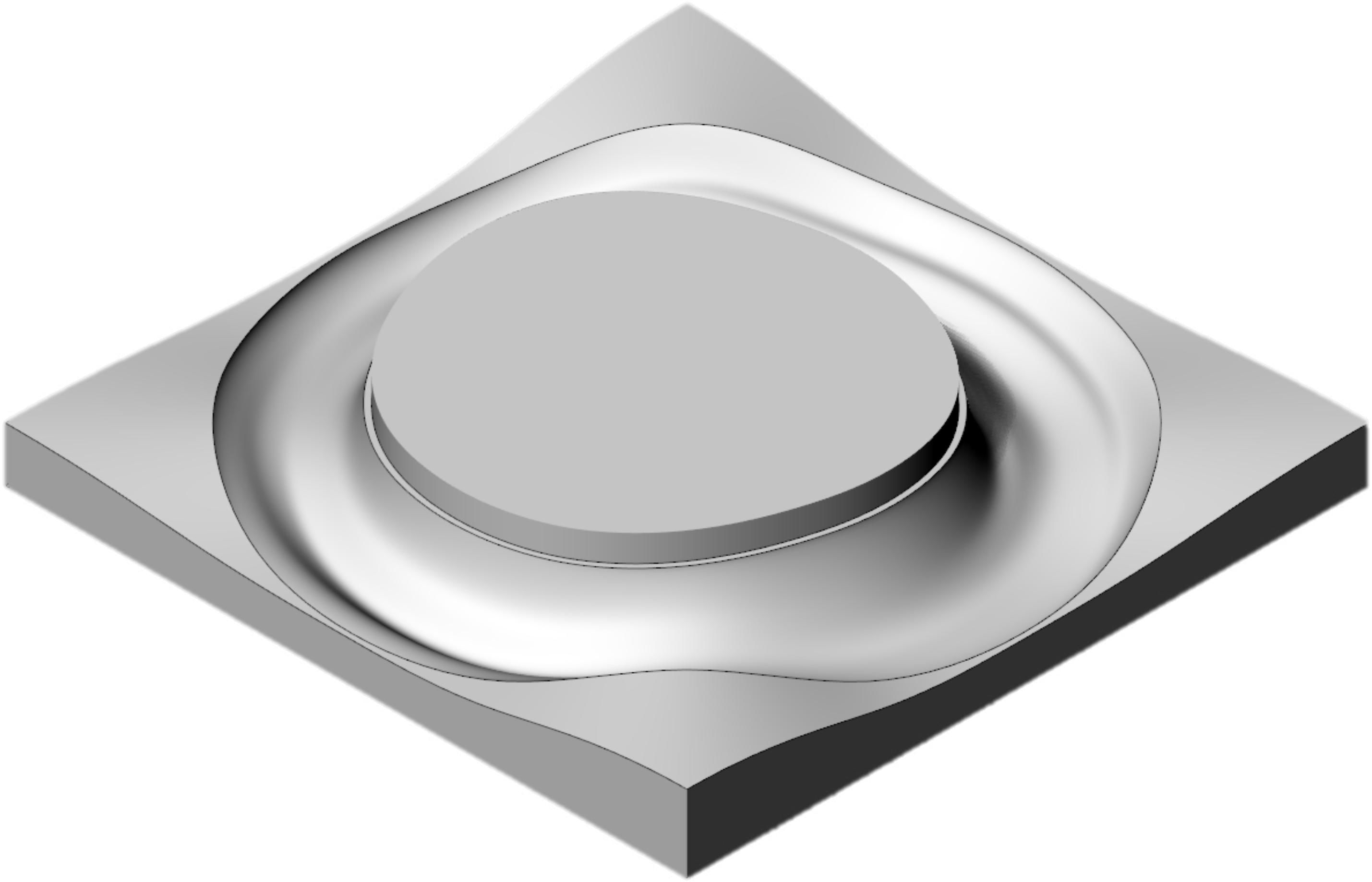
The "Dynamic: flow" aims to zoom at the dynamic property of light flow through the contineous movement in a specifically designed circular space.

The light folds, separates, crosses, and distributes along the the space to create different sensational experience when walking around the space.



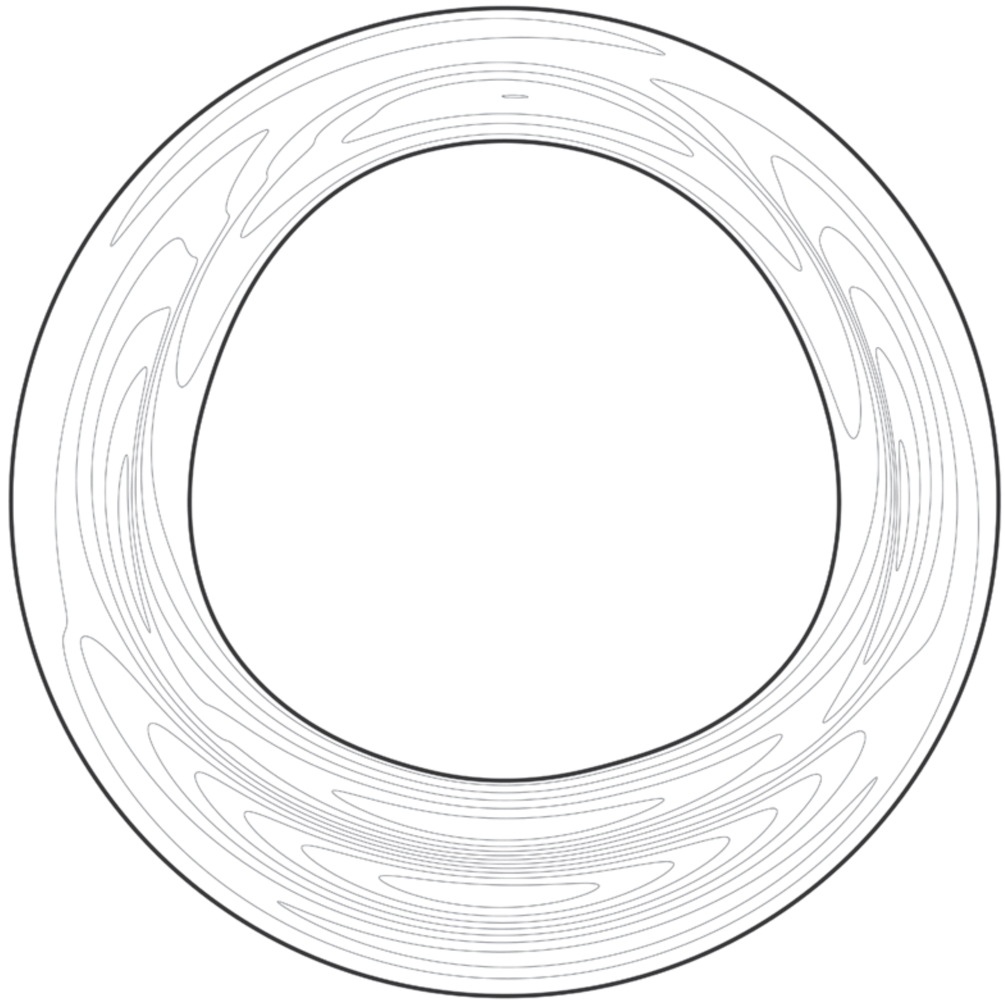
roof

3D mesh model



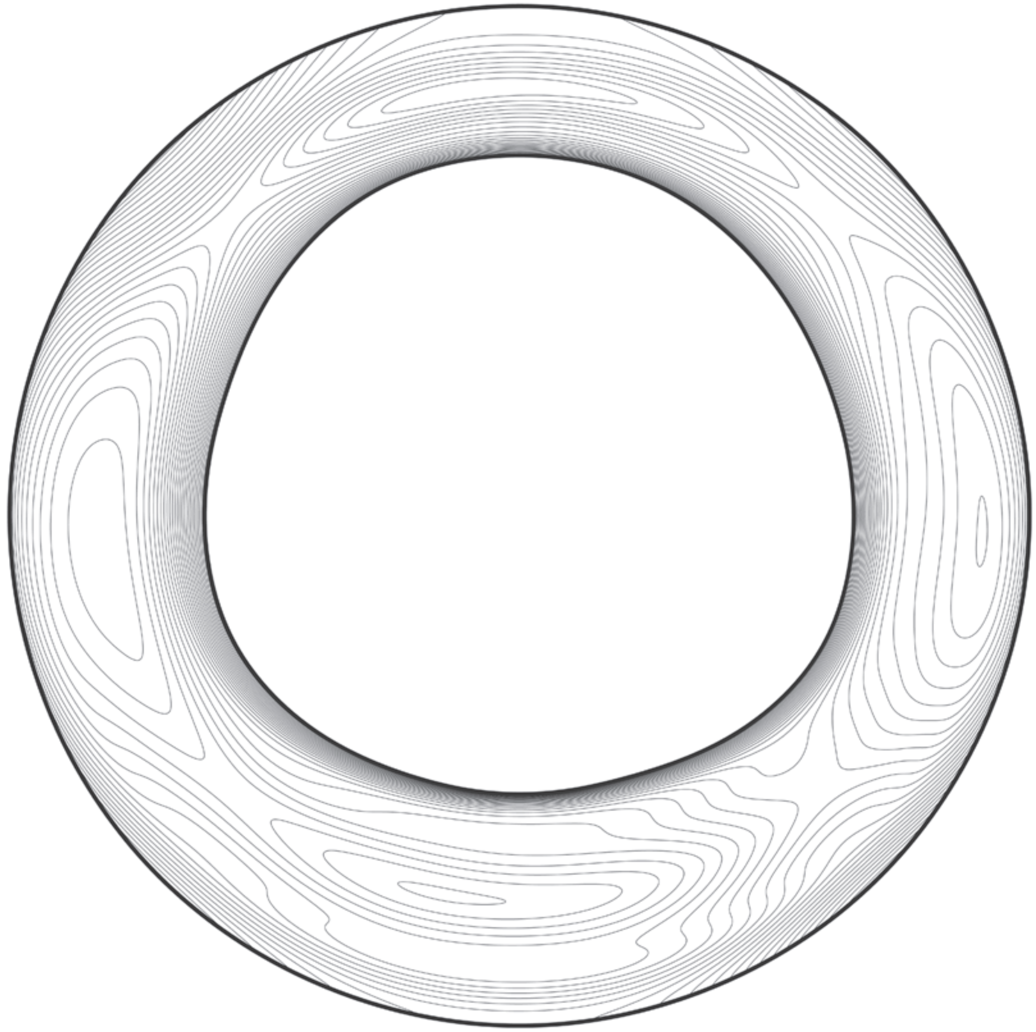
ground

3D mesh model



roof

contour



ground

contour

top rendering of the refracted light

sunlight direction perpendicular to the ground

a typical view angle of light dynamics

sunlight direction perpendicular to the ground at noon

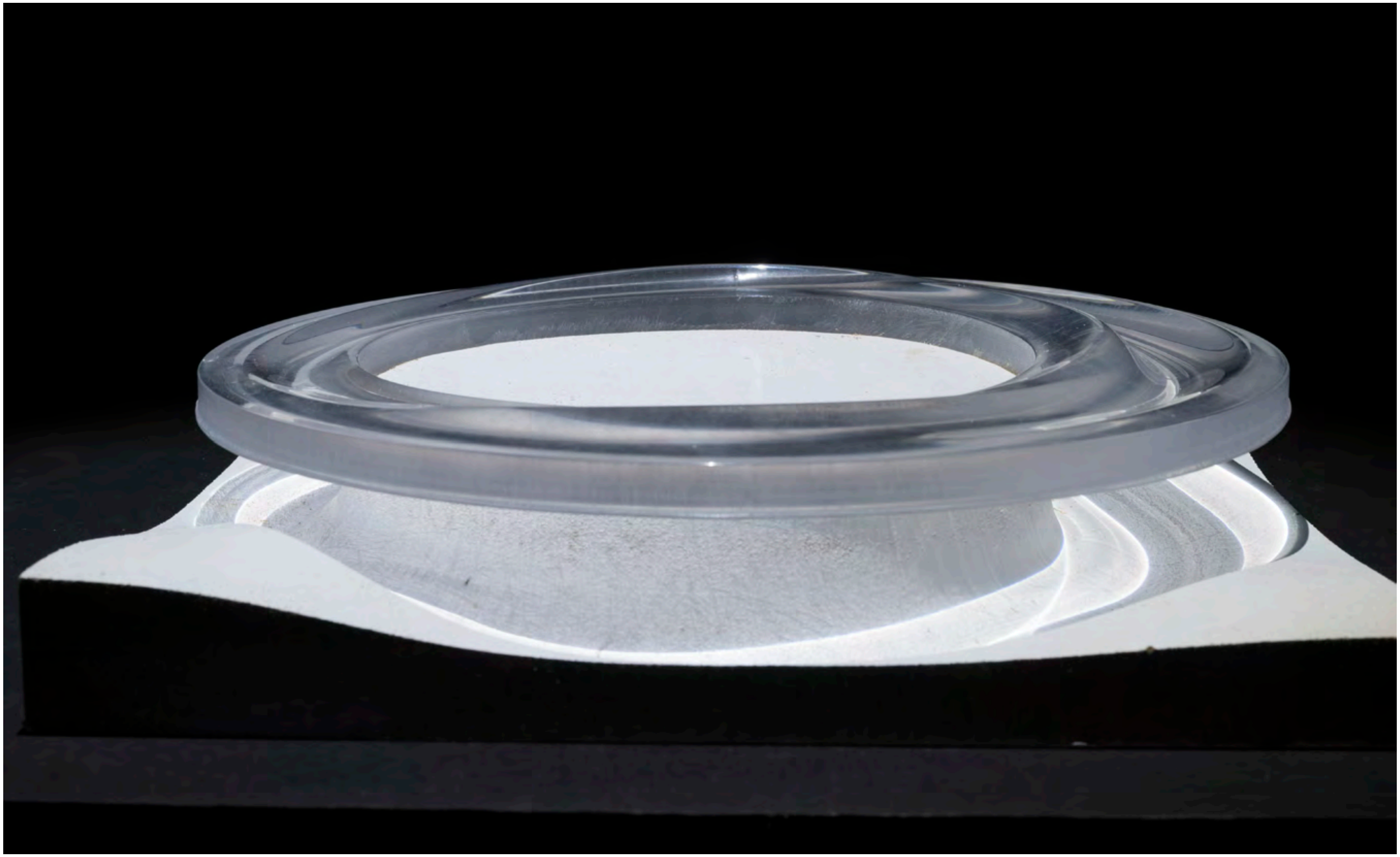
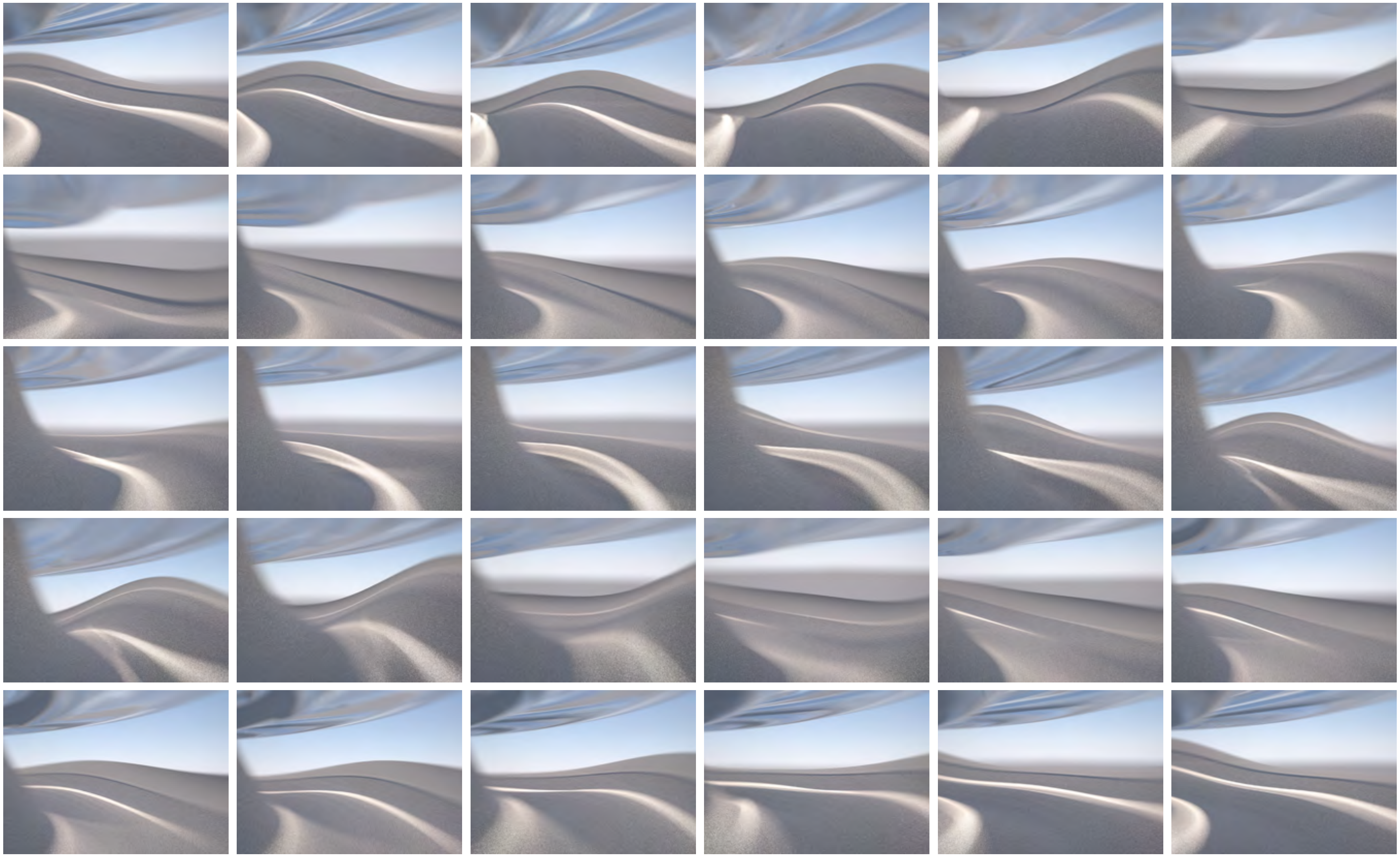


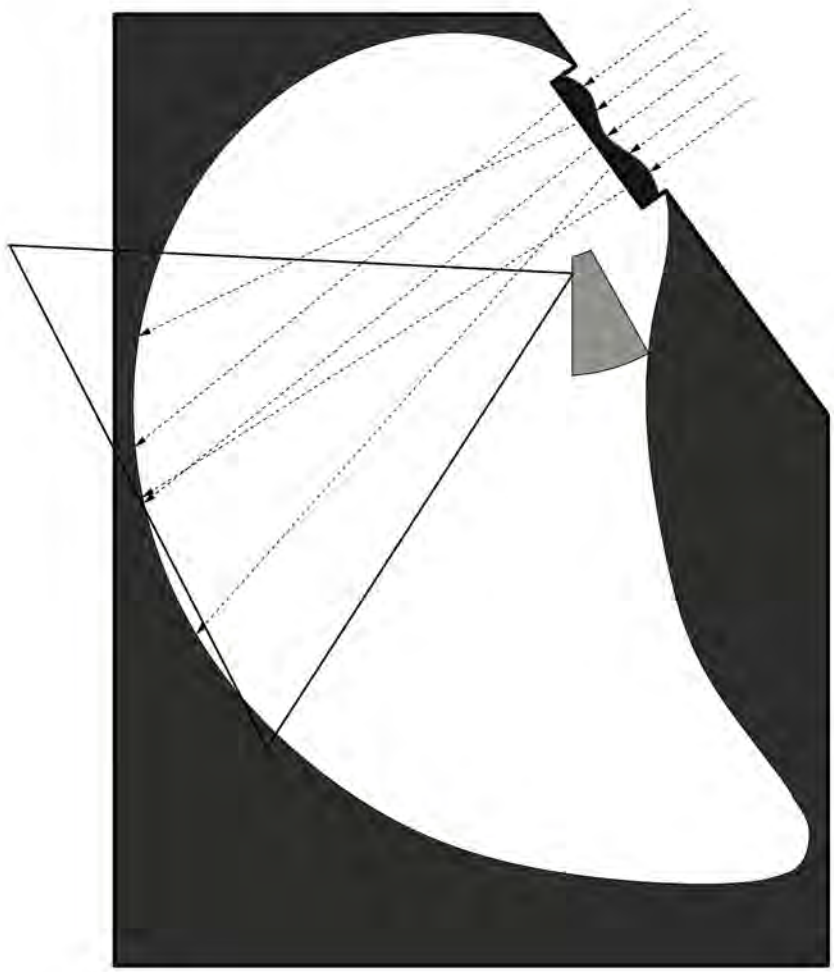
photo of the test model



contineous movement in the circular space

sunlight direction perpendicular to the ground at noon

The Delight of Light

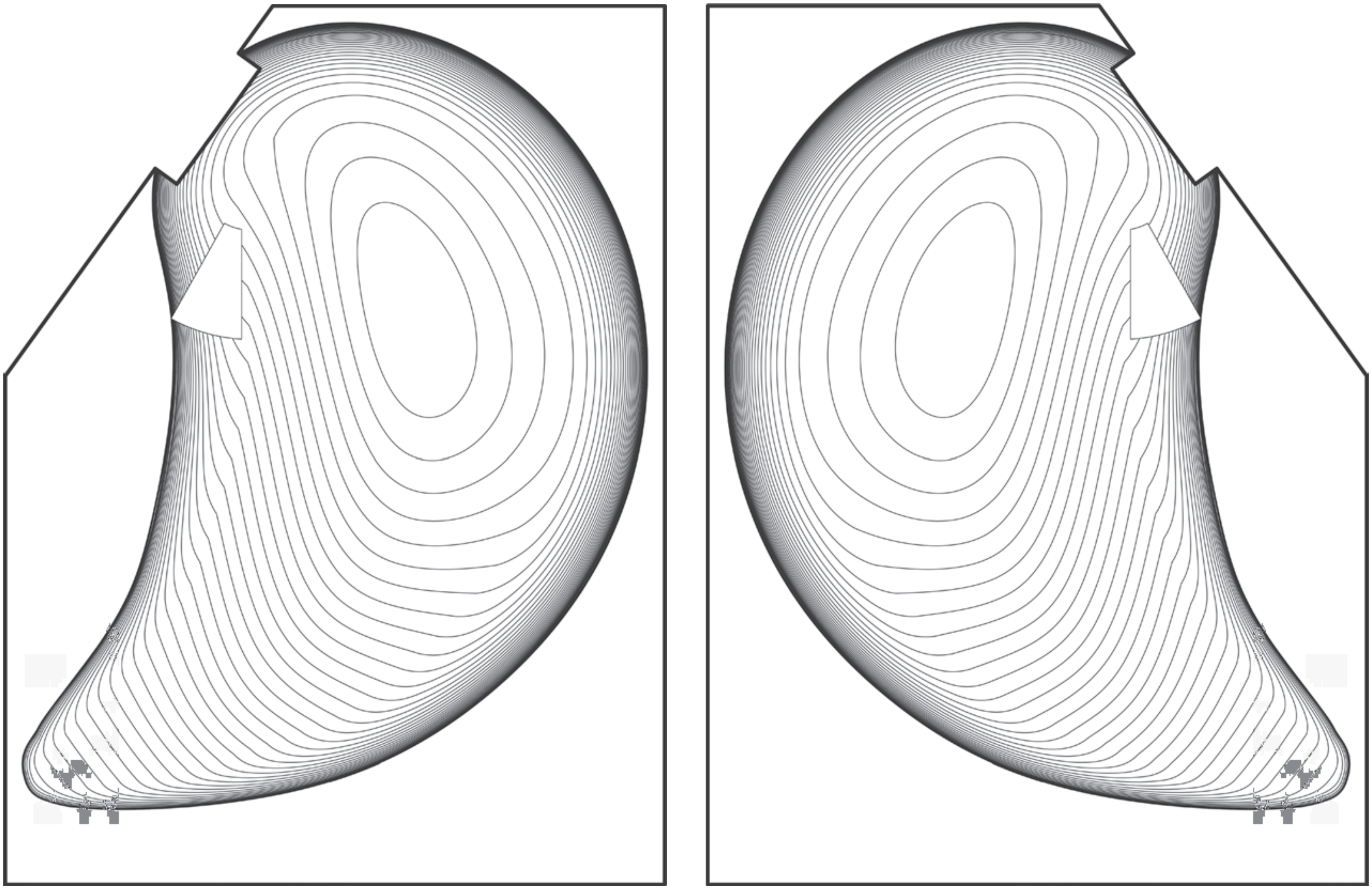


Dynamic: rise

In this project, the space is designed by following the Fibonacci curve to create an constant increasing speed and projection distance. (137.5°)

Various pieces of refraction surface are used to explore the multiple possibilities of light patterns projected on deformed receivers.

These projections reveals the dynamic and artistic aspect of light where precision here has the least importance.



contours of the inner space

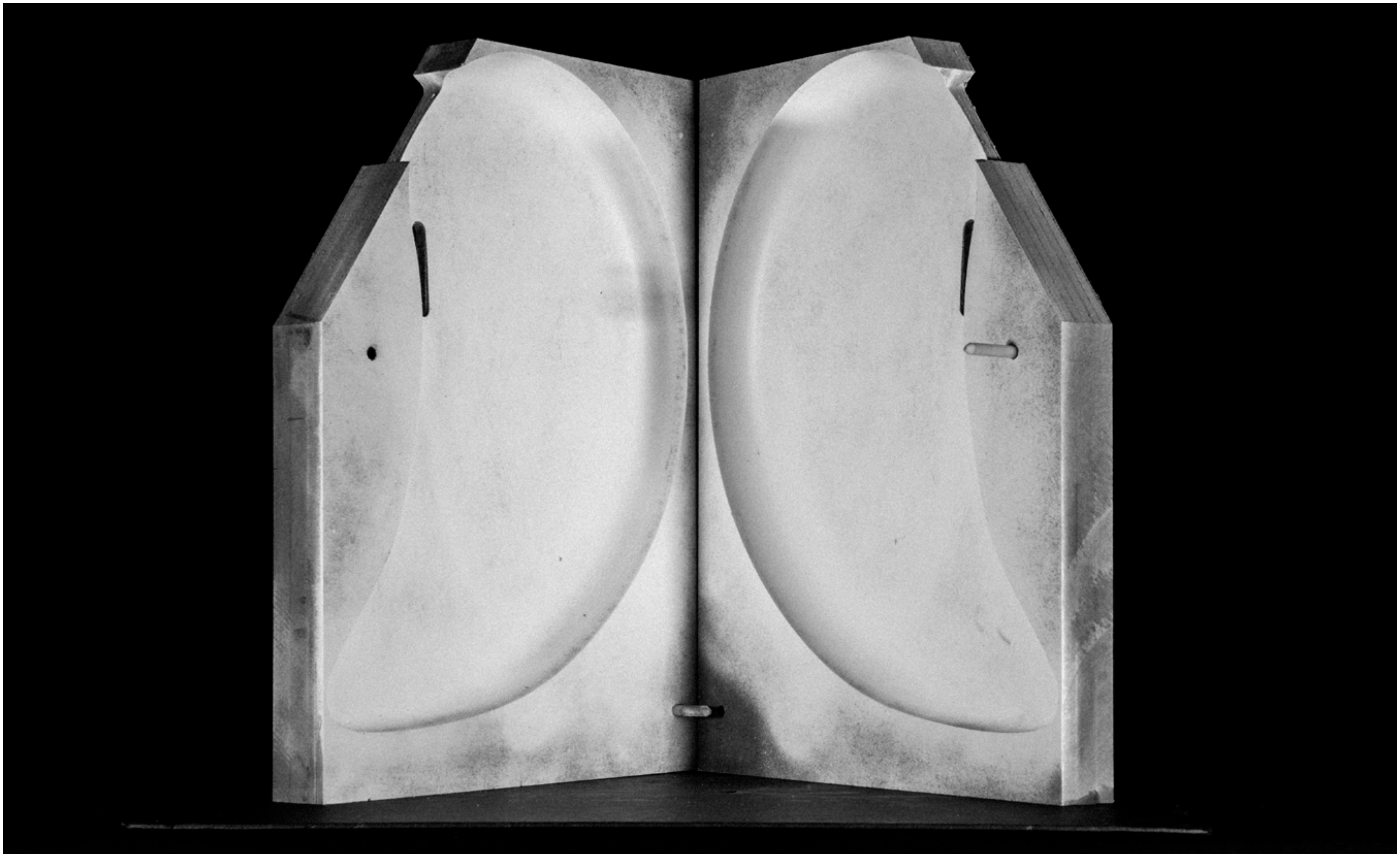
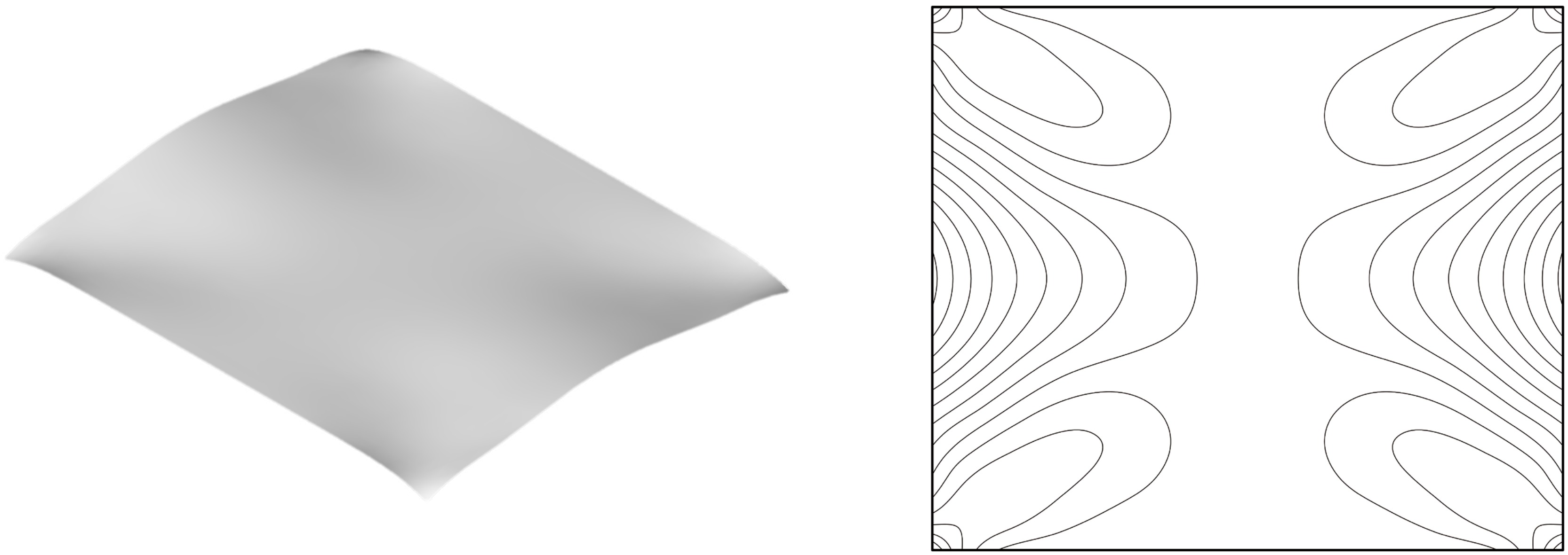
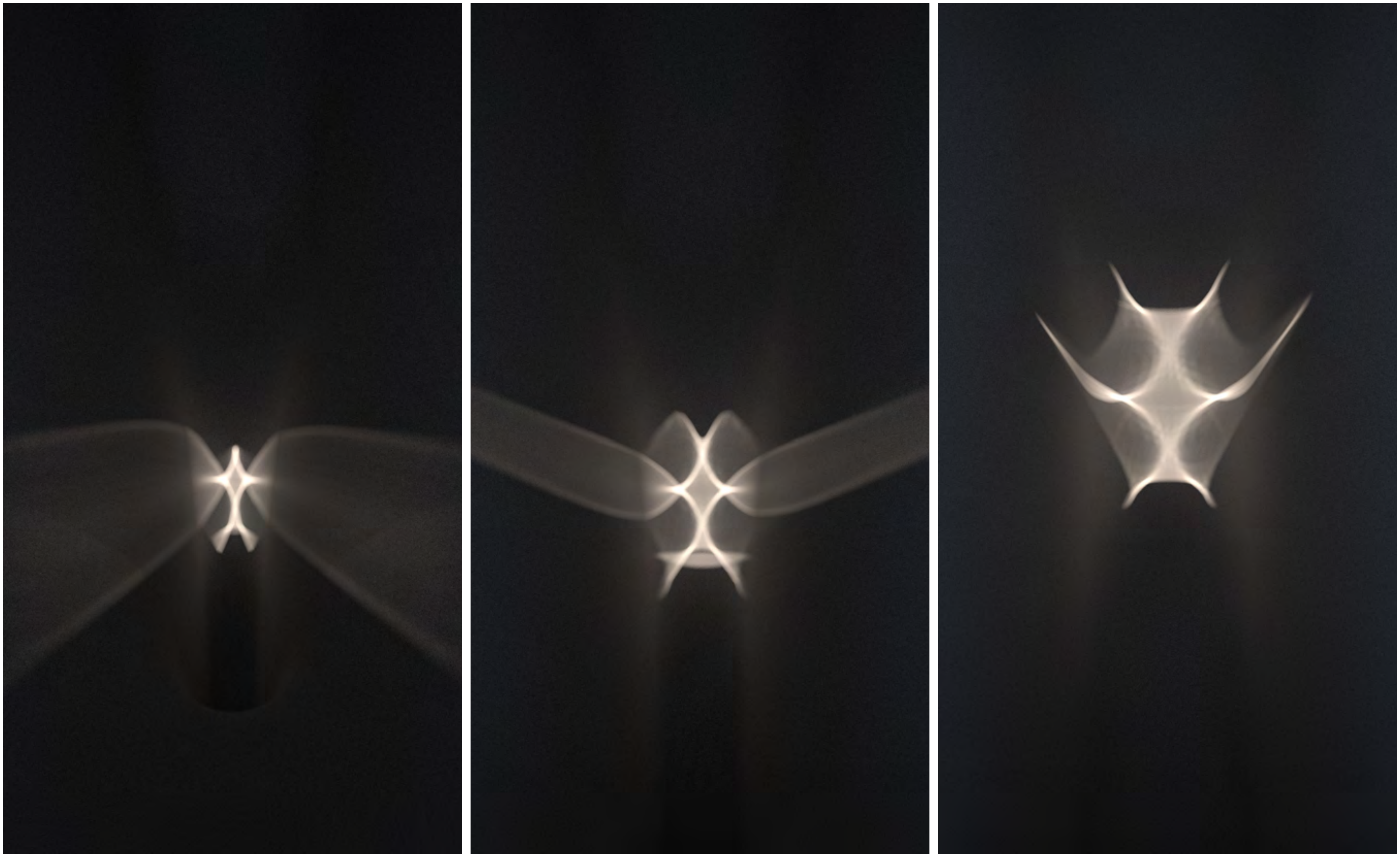


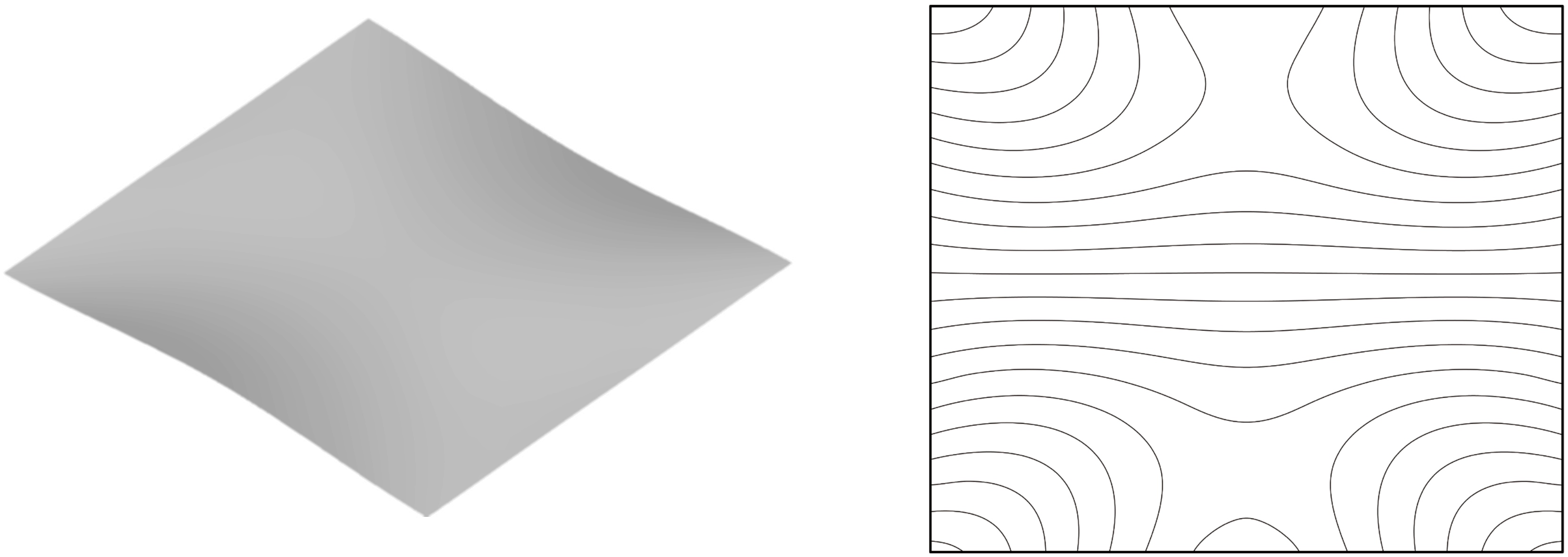
photo of the looking device



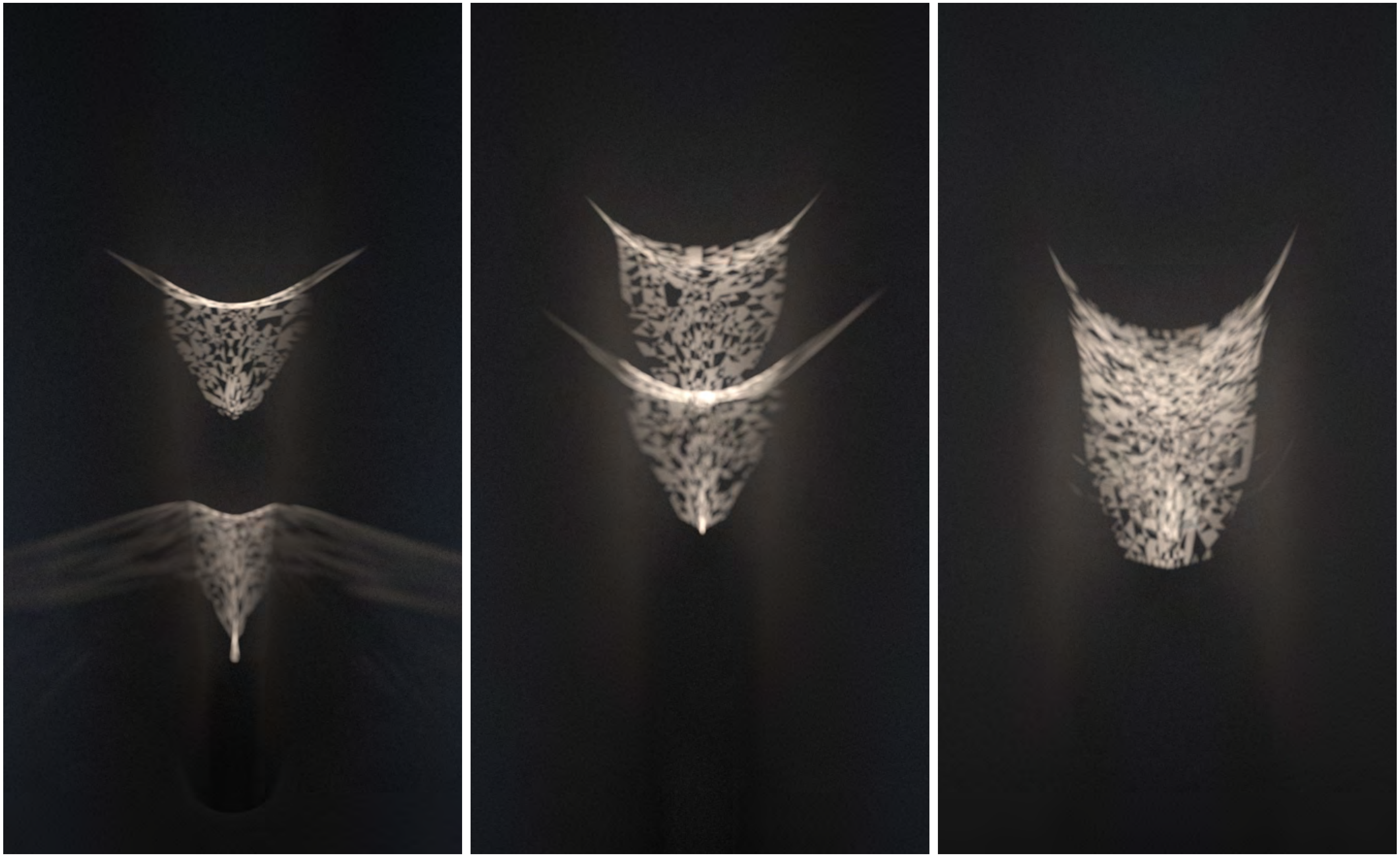
refractive surface and its corresponding contours



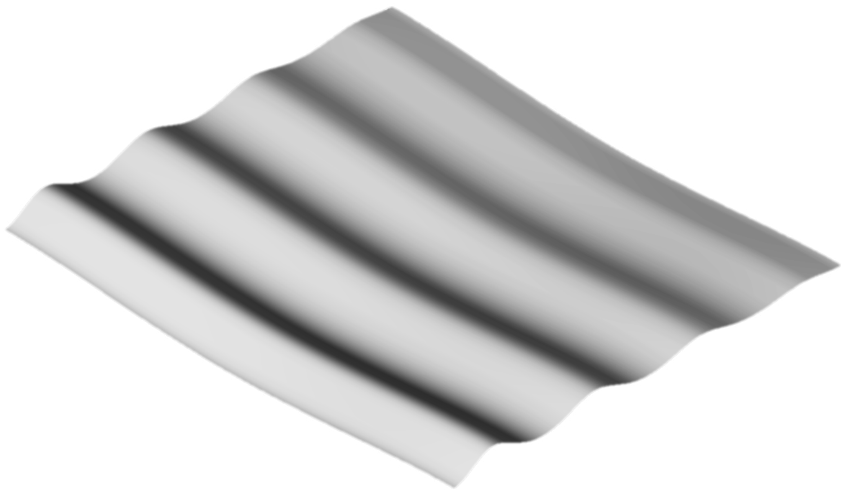
rendering simulation

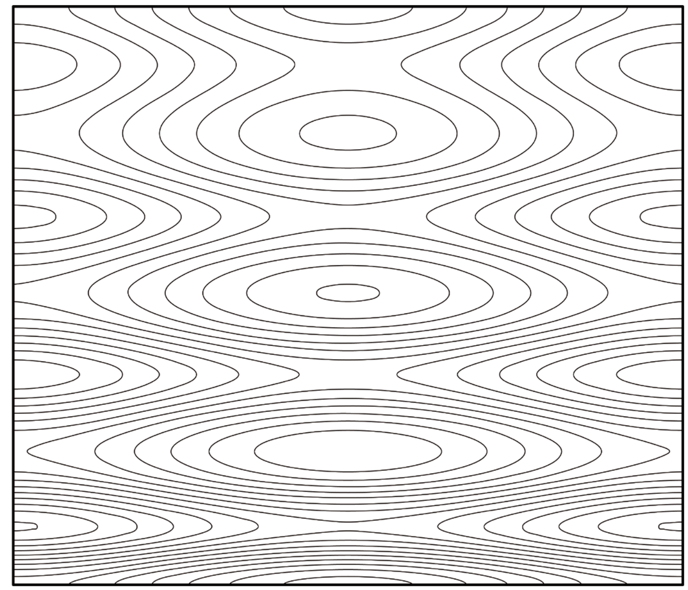


refractive surface and its corresponding contours

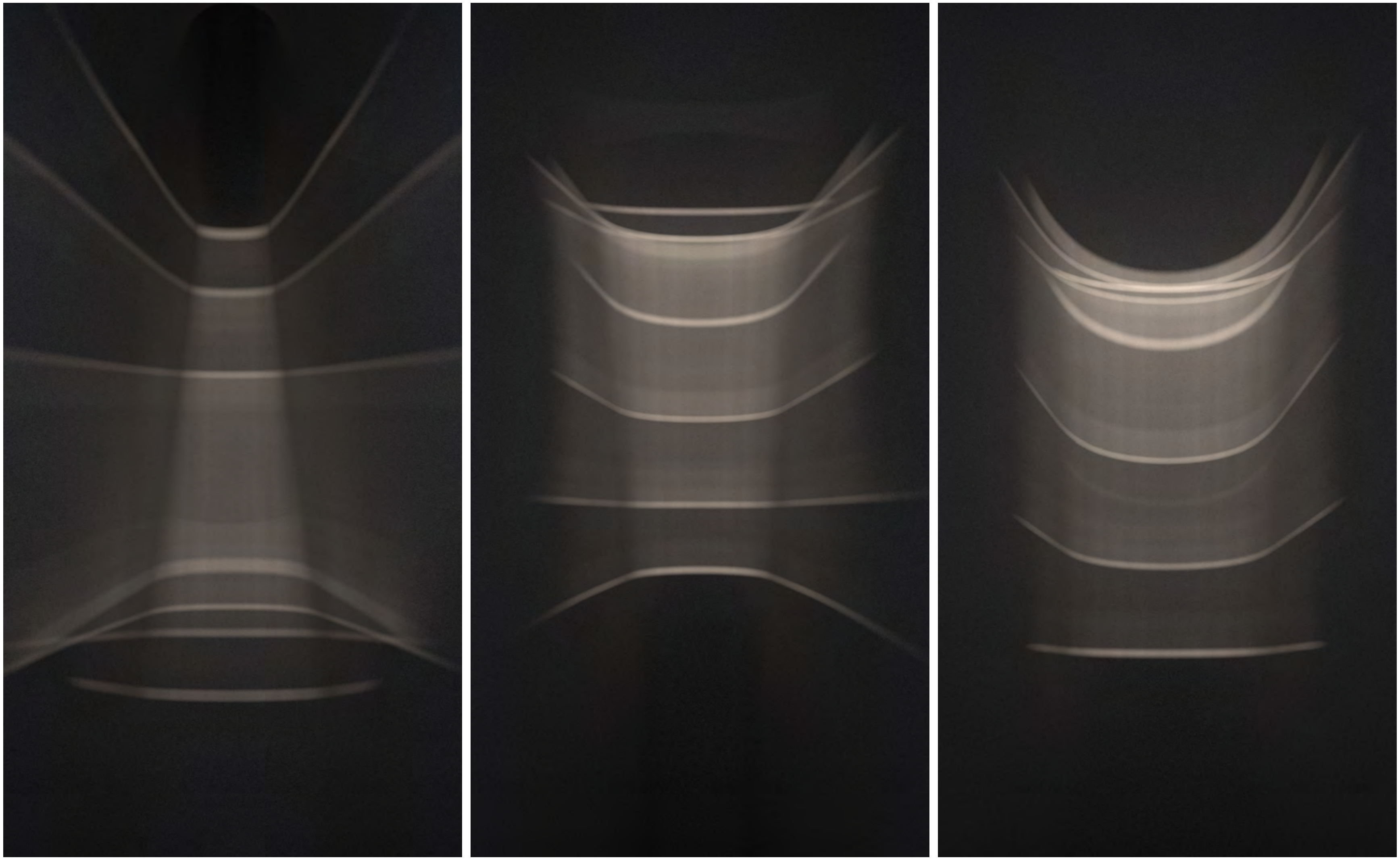


rendering simulation





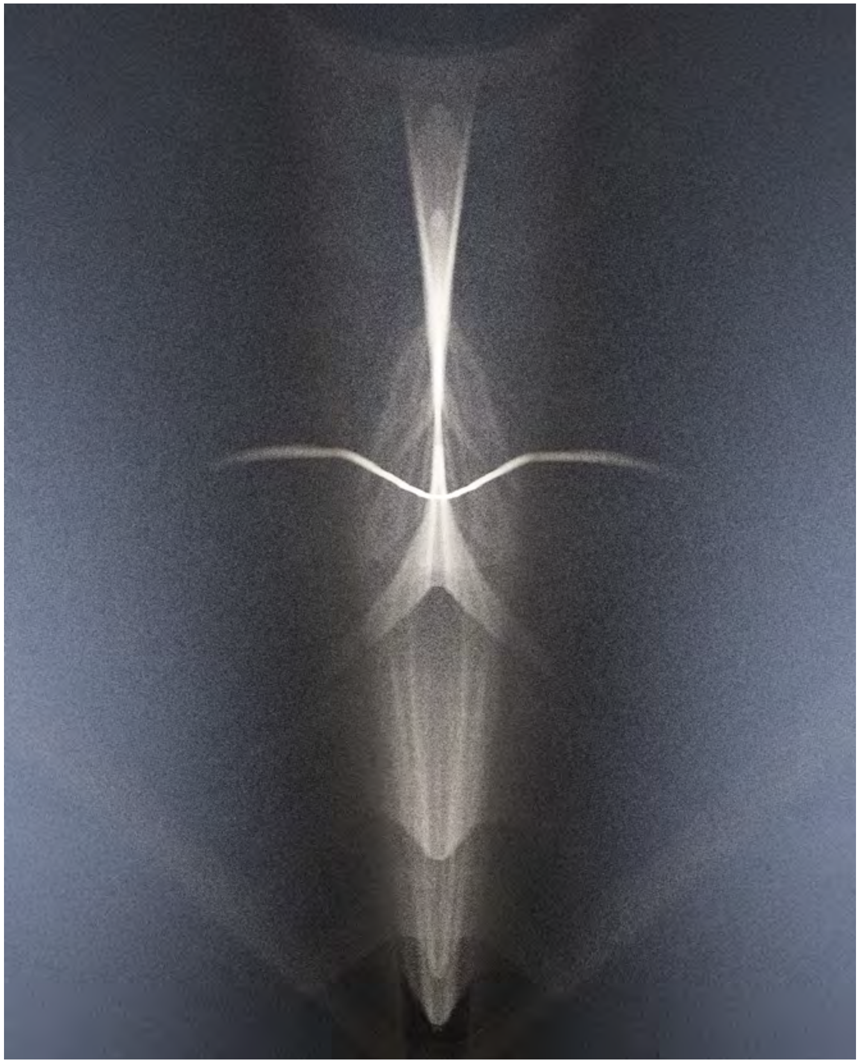
refractive surface



rendering simulation

By furthur developing the possibilities of refractive patterns, we could use multiple refractive pieces overlayed by each other to make even more complex refraction composition.

Some of the selected results is shown here, presenting the artistic and complexity potiential for the system.



rendering simulation

Bibliography

AGARWAL, S., MIERLE, K., AND OTHERS, 2013. Ceres solver. https://code.google.com/p/ceres-solver/.

ALEXANDER GESSLER AND OTHERS 2015, Open Asset Import Library, http://assimp.sourceforge.net/, last retrieved 09-2015

AURENHAMMER, F., HOFFMANN, F., AND ARONOV, B. 1998. Minkowski-type theorems and least-squares clustering. Algorithmica 20, 1, 61–76.

FANG, F., ZHANG, X., WECKENMANN, A., ZHANG, G., AND EVANS, C. 2013. Manufacturing and measurement of freeform optics. fCIRPg Annals - Manufacturing Technology 62, 2.

FINCKH, M., DAMMERTZ, H., AND LENSCH, H. P. 2010. Geometry construction from caustic images. In Computer Vision–ECCV 2010. Springer, 464–477.

LIU, D. C. AND NOCEDAL, J., On the limited memory BFGS method for large scale optimization methods, Mathematical Programming, 45 (1989), pp. 503-528.

MÉRIGOT, Q. 2011. A multiscale approach to optimal transport. In Computer Graphics Forum, vol. 30, Wiley Online Library, 1583-1592.

PAPAS, M., JAROSZ, W., JAKOB, W., RUSINKIEWICZ, S., MATUSIK, W., AND WEYRICH, T. 2011. Goal-based caustics. Computer Graphics Forum 30, 2, 503–511.

ROOSENDAAL, T. AND OTHERS, Blender, http://www.blender.org/, last retrieved 09-2015

SCHWARTZBURG, Y. et al., High-Contrast Computational Caustic Design, ACM Transaction on Graphics (TOG) 33, 4, 74.