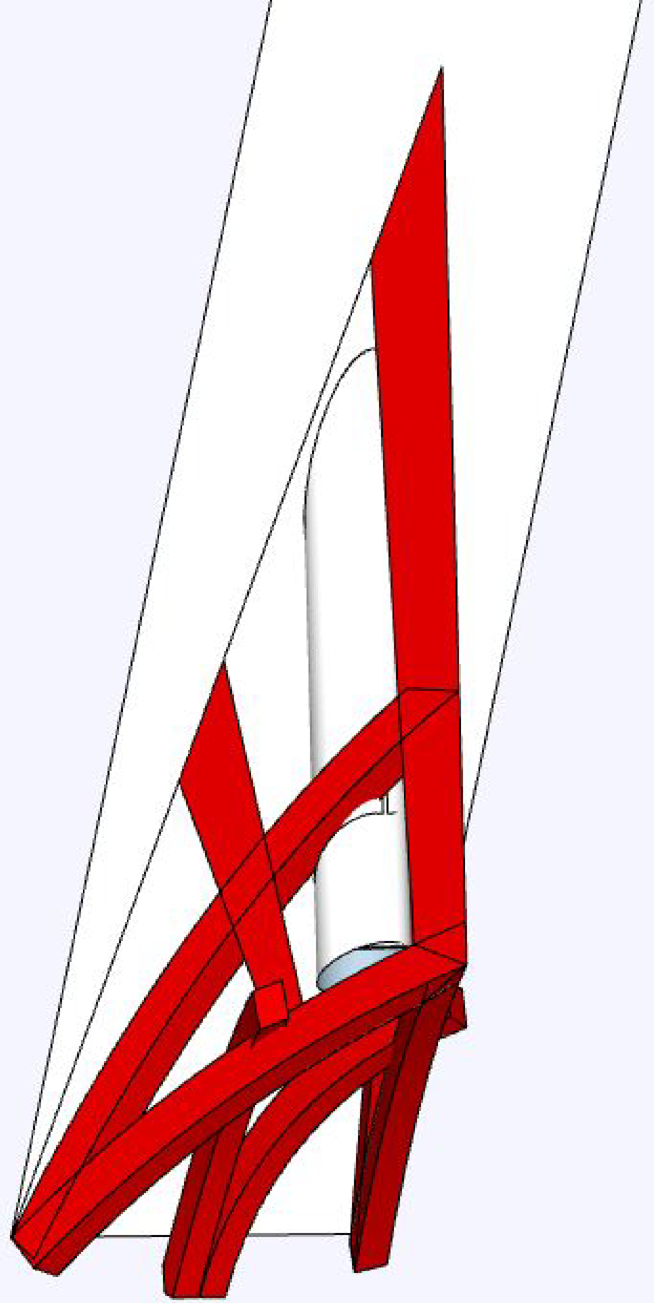
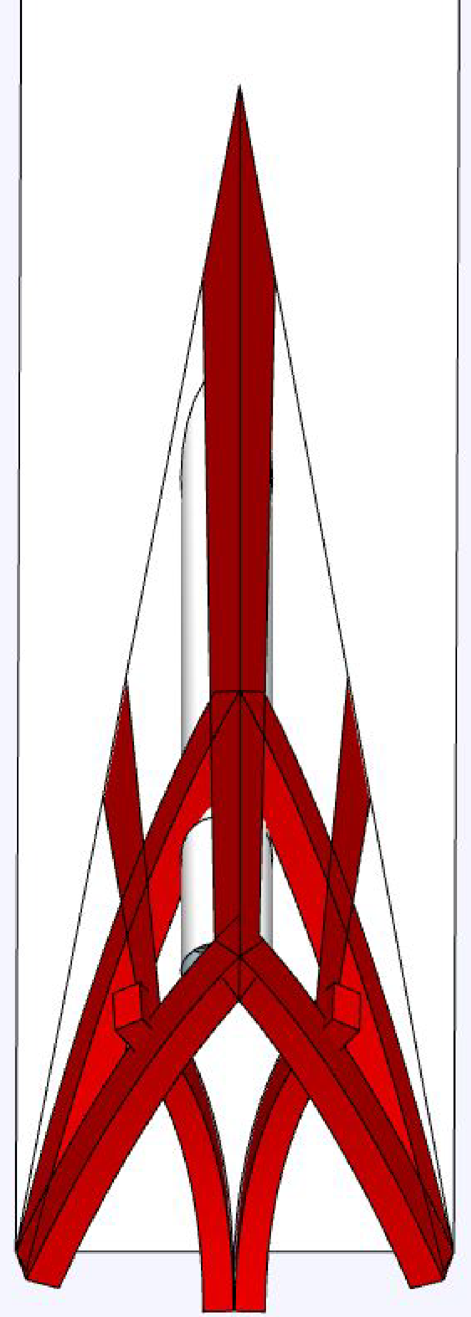
Project 1:

Custom Solar Light Pipe Design for the Ark Museum

Context A lighting solution expanding on the concept of solar light pipes to offer a custom chandelier design for the Ark Foundation Museum, Vadodara.





Design models made in Google Sketchup

Introduction to the new Ark Museum

Envisioned to become a contemporary symbol of the modern arts of Baroda, the Ark Foundation Museum requires evocative lighting designs solutions that complement the modern and aesthetic theme of their architecture.

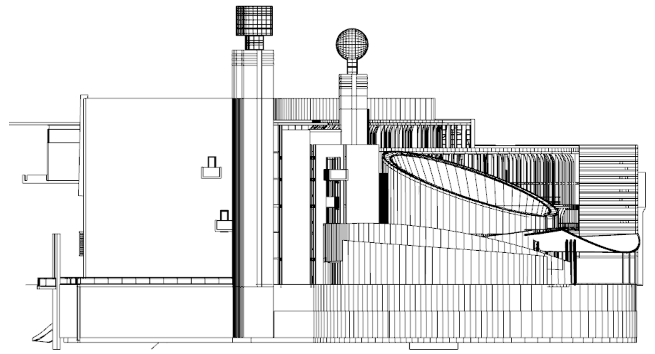
The Vision

The Ark Foundation Museum is an up and coming arts museum in Vadodara, Gujarat. The organisation commissioning the project is known as the Ark Foundation for the arts - an institution dedicated to representing and expanding the scope of the arts and art histories of Baroda. This new museum will accomodate gallery spaces, performance theatres, art conservation and restoration areas and much more. The museum is expected to turn into a public cultural center providing accesibility to the arts and further supporting emerging and contemporary artists in Baroda.

The architecture and the architects

The building is being designed by a notable architecture firm known as 'Prabhakar B. Bhagwat architects'.

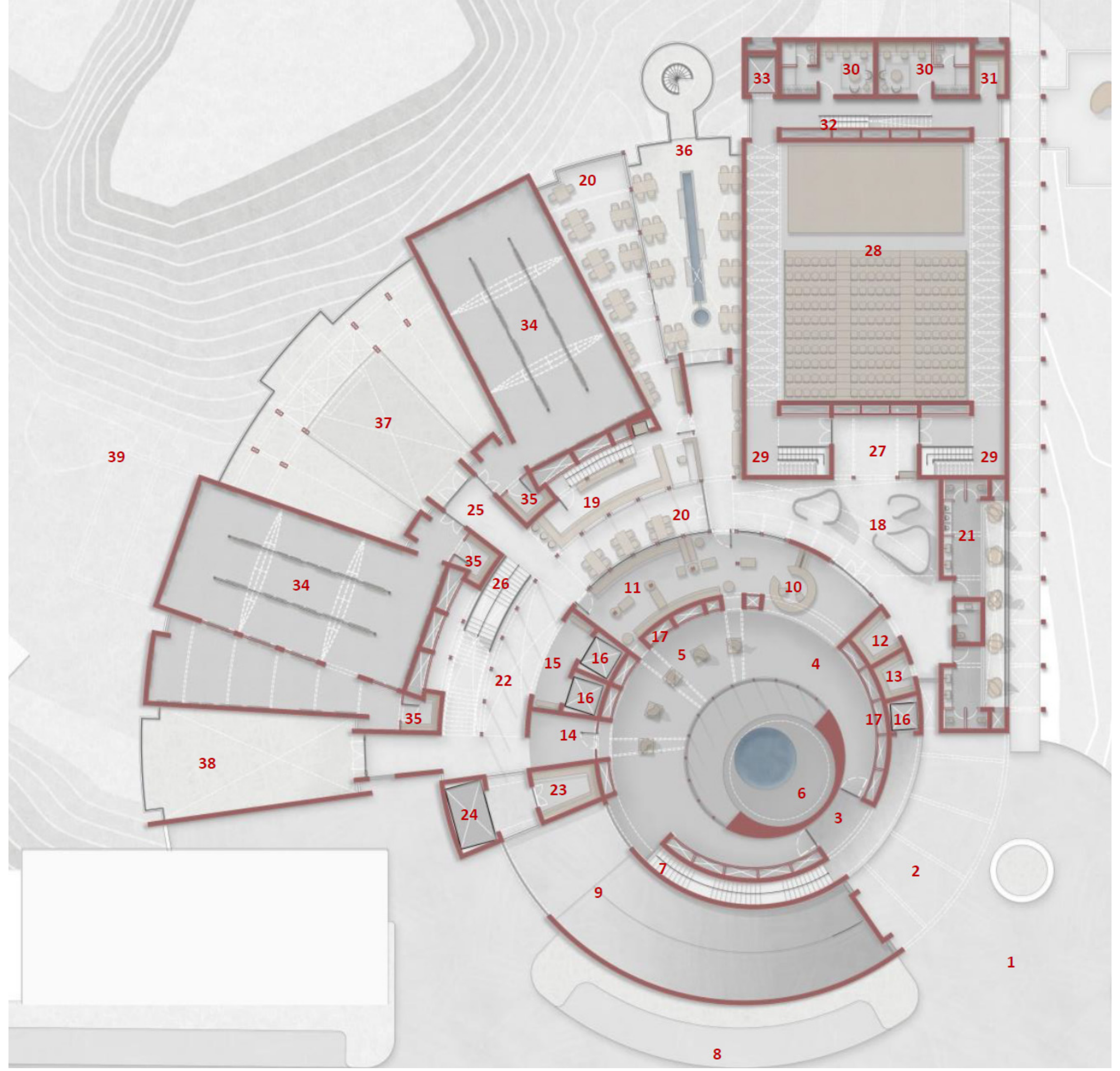
The museum has incorporated an extremely evocative and expressive architectural form intended to complement the organisations' mission - which is to represent the artistic spirit of Baroda.



On the lighting design

Lirio Lopez Lighting Design Consultants, the sponsor for this graduation project has been hired to provide appropriate lighting design solutions for the various spaces within the museum - including the gallery spaces, performance theatre, art storage spaces, parking areas etc.

This document focuses on the students' contribution to the overall project, involving specific areas of the lighting design that the student has worked on.

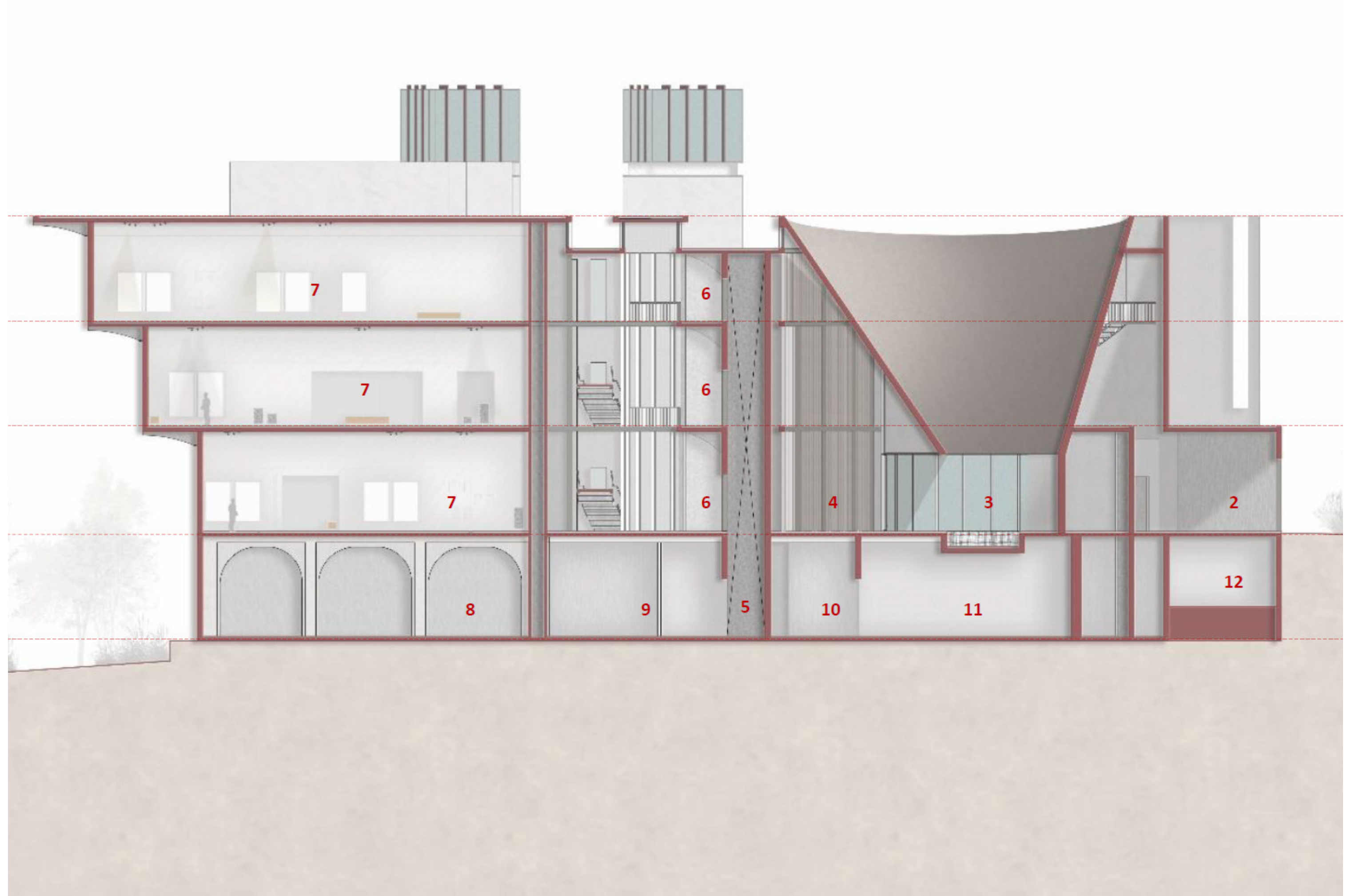


Proposed Museum Plan and Section

The architectural plan contains about 5000 sq mts.. of built space including the following spaces:

Internal Spaces:
Museum Galleries,
Black Box,
Auditorium,
Library & Archives,
Restaurant & Café,
Restoration & Conservation Studios
Art Storages

External Spaces: Lighting design for all external landscaped areas including roads and pathways & selective facades' lighting.

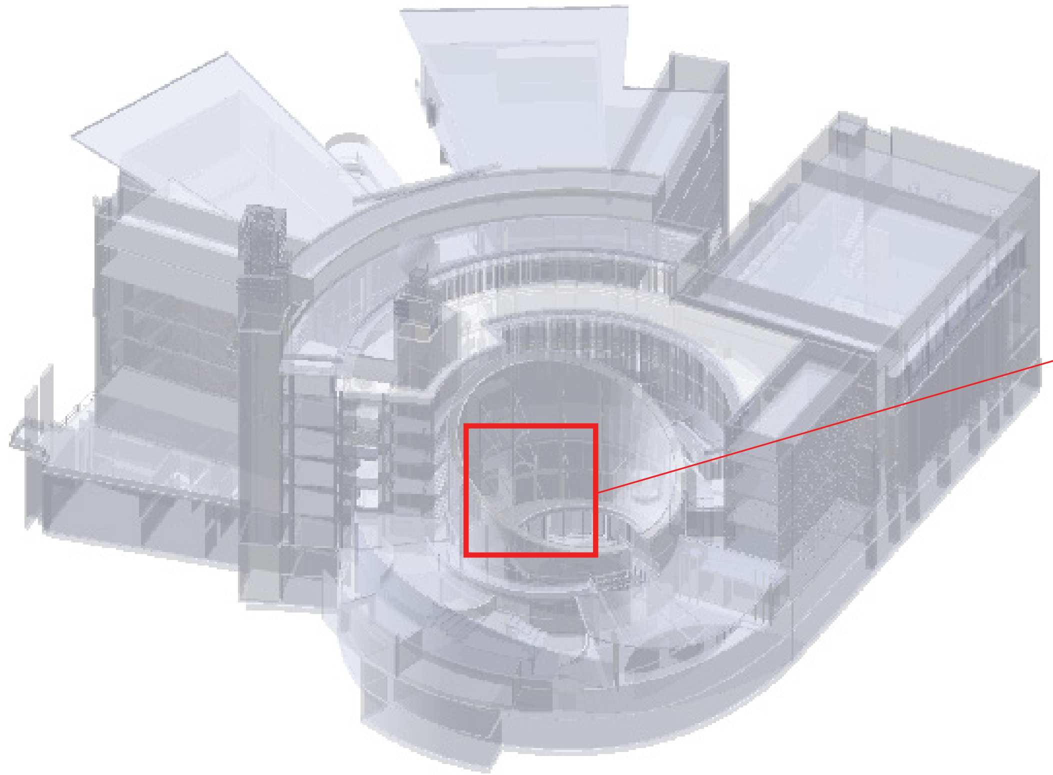


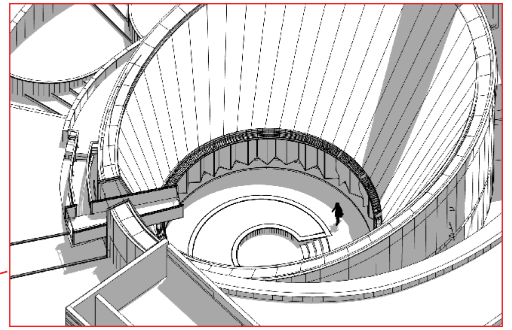
Architectural Renders

These were shared by the architectural firm to communciate the vision for the building. The following renders and architectural drawing layouts provided the tools upon which the lighting design decisions were made by the lighting consultancy.

Design Brief

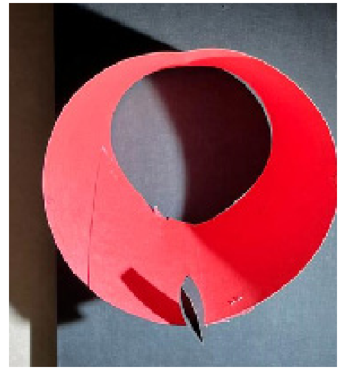
The design brief has been split into two parts. Part A talks about one of the design possibilities that was being considered. And Part B talks about the space itself - which is the design brief as the space is the main constraint for the lighting design.



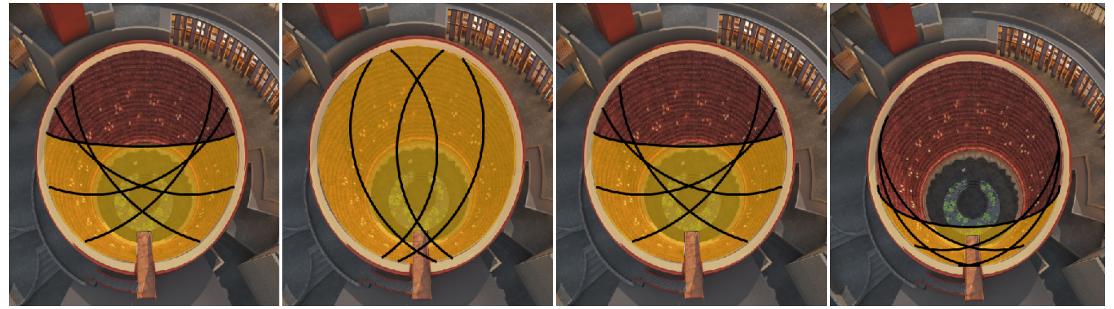


A Sundial Installation

For the **Outer Courtyard,** a interesting idea was being considered. The team had discovered that the cylinder like building had the potential of being used as a sundial - if the shadows were mapped correctly. The viewing deck at the top would act as a “gnomon”, projecting shadows to indicate the time.



Physical model built by the team to test how the shadows will form



Initial analysis of how the shadows were expected to form on the building at different times of the year: Solstices and Equinoxes

Time Markings

If one could place elevations and recessions on the brick surface, then the shadows could also create lines which indicate the time:

The shadows would naturally form on the inner surface of the cone (except when the sun is directly above). Therefore we could mark the hour, and season lines on the surface- so that one could observe the time by comparing the shadow lines with the markings.

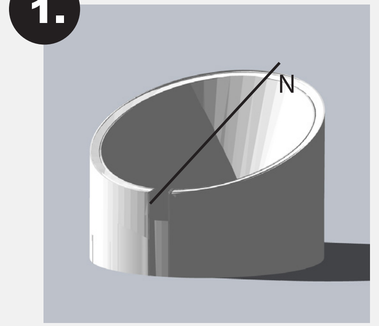
Art by Teja Gavankar

Look: Markings as recessions in the cladding

Reasons why the sundial idea can work

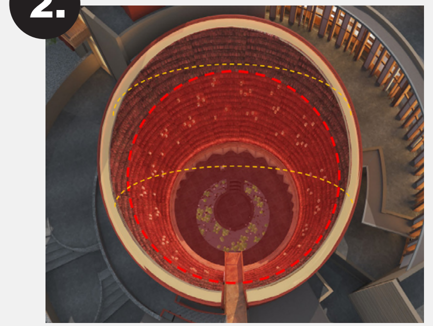
Certain properties of the building make the sundial idea quite viable.

1.



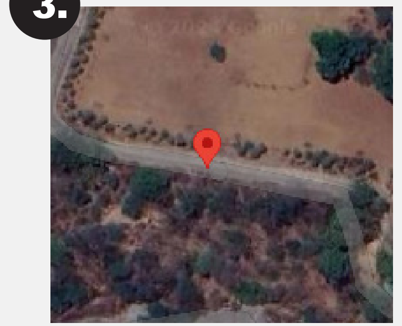
The 'truncation' of the cylinder building is aligned closely to True North. This means that the shadows formed will be symmetrical - just like a well positioned sundial.

2.



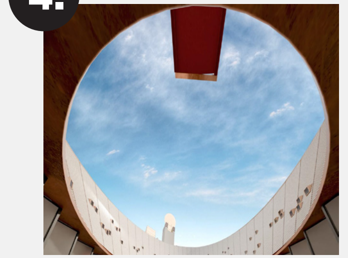
The site is about 6 kms away from the Tropic of Cancer. Which means it gets a lot of sun, but also dynamic light and shadow variations and a particularly high solar angle at noon (almost perpendicular), symbolising 1200 hours.

3.



The site is located in a foresty area without any tall buildings around. This saves the sundial from any collateral shadow interferences.

4.



The remoteness of the site also means that it is less likely to have any light or dust pollution, which should help reduce the refraction of sunlight from the atmosphere (this prevents innaccuracies), and create crisp, sharp shadow lines.

Next steps

The requirement was to now consider the building layout and determine the details of how and what can be designed to make this idea work.

B Lighting Design for the Atrium

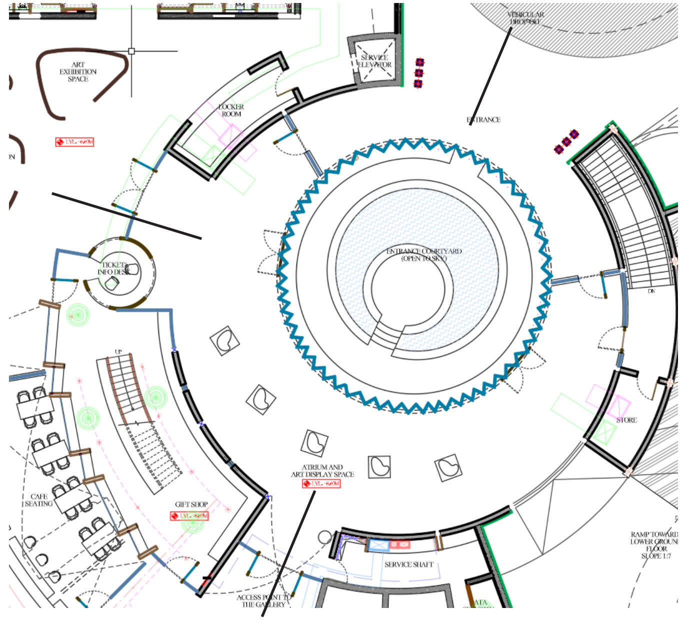
The sundial was thought to be a feature existing outside the cylindrical building. There was another space inside it that needed to be lit - the Atrium. This was one of the main spaces in the museum because it was the first space that people entered. The lighting design choices for it would have to align with the majestic architectural interior that was designed for it:

Fig: Atrium (Interior of the inverted cone): The edifice of high-reaching red arches made it appear like the "rib-like carcass of a beast", captivating the visitor at a first glance

The Atrium was one of the key spaces in the museum - It was the main entrance, and also the nucleus of the whole building.

As visitors entered the space, they were confronted with a large Atrium with a 40 ft high ceiling and large menacing red arches supporting it.

As you go around the corridor you can leave the Atrium through 3 exits all leading to different parts of the museum. This makes it a sort of central meeting point connecting the entire museum. It also has the functional utility of being used as an art display space- if preferred by the foundation - for this there will be tracklight installed around the corridor, providing focus lighting solutions.



The Atrium also lends a solid first impression to the museum. The lighitng design choices for it will need to enhance the existing space not just functionally but also in an expressive, visual way.

The Atrium is spacious - and there is an ambient light source at the very top, which was referred to as a “rim light”. This provides ambient light during the day - but it is expected that this light will not reach the ground (corridor) at most times of the day, and it will be ‘hard light’ unless it filters through a diffuser. Therefore, sufficient lighting is still a requirement especially for the corridor and for night-time. Supposedly, the proposed solution should exhibit that level of functionality, while also being a visually compelling design.

Parts of the Atrium

1. **Rim Light (Ambient Light Window)**
   At the top of the ceiling, a ring of light seeping through
2. **Catenary Arches**
   The tall red arches holding the building in place
3. **Cone Walls**
   The slanted walls where the arches as reaching out from
4. **Corridor**
   The circular path on the ground where the visitors can walk.

Existing Light Sources

1. The rim at the top is the only prominent light source. It creates some ambient light in the Atrium, but likely not a great amount.

Proposed Idea for the Atrium

An initial idea proposed for “lighting” in the Atrium was to embed translucent perforations on the surface of the “funnel walls” This would create a light filtering effect ‘sprinkling’ ambient light in the corridor of the atrium.

While this was a decent direction to go with, the hope was to build something better - and perhaps somehow bring the sundial inside the Atrium, so that a strong conceptual narrative could exist - while also fulfilling the functional requirement of ‘adequate lighting’.

Next steps

To determine the lighting solution for the Atrium, we needed to know how to respond to the space, and design something which would do justice to it.

Scope of work

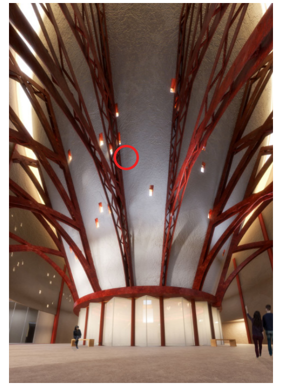
The steps and deliverables of a lighting design consultancy project are as follows:

1. Understanding the space and client needs to come up with a lighting design philosophy/narrative for the design
2. Working with the contractors/architects to determine the feasability of design options
3. Providing mock-ups and visualisations to test the effects of the lighting before approval from the architect/client
4. Creating lighting design layouts
5. Specify the exact lighting fixtures and their placement for a (good for construction) lighting layout.
6. Determine the cost of the lighting solutions for the project
7. Oversee the installation and provide further consultation in case of future problems.

The students’ role in this project is limited to the first 4 stages mentioned above. It will involve mostly coming up with a compelling lighting design layout/ concept that can be further developed by others with practical lighting design and technical experience.

Other possibilities to explore

Light filtering effect



In one of the renders, the atrium shows these small light apertures letting light inside. This was the main inspiration behind the possibility of creating a "light filtering effect".

Light refracting blocks in the Atrium

Glass bricks have the property of total internal reflection, so the light never leaks out of it, and bounces inside the glass, coming out of the other end. This is also observed in optical fibres. It was imagined that this would allow us to redirect light intentionally by changing the thickness/ length of the brick.

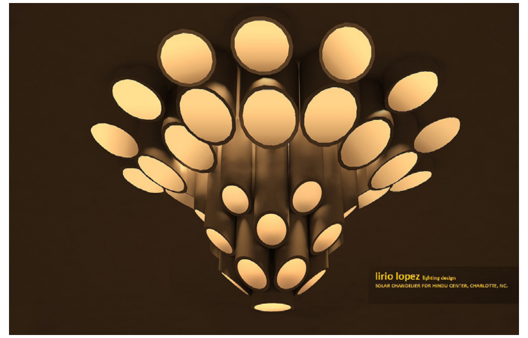
Instead of glass, it was considered that PMMA/Acrylic could serve as a substitute. This idea was possible to take forward, if preferred by the architects.

Foreseen Challenges

However, although it is an applicable concept. There are a couple of difficulties in implementing this idea.

- Accounting for heat expansion of the two different materials
- Water leaking through the building as a result of gaps forming between the bricks and the concrete
- Total Internal Reflection can fail if the outside material is denser than the translucent brick.

Solar Chandeliers



Previous Chandeliers by Lirio Lopez for the Hindu Temple

Lirio Lopez has produced for many of their previous projects, a light fitting known as a "Solar Chandelier". This has been installed in projects such as the Hindu Temple and Lopez Design, New Delhi.

The Solar Chandelier is a daylight capturing device that collects, transmits and emits natural light from an external collection point to an interior space. This is done through refractive or reflective apparatuses like an aluminum tube or a TIR light pipe/fibers.

Pros

- The Solar Chandelier is a tried and tested solution. Lirio Lopez has worked on it many times before.
- It can take on any shape and look visually impactful

Challenges

- Requires an open access in the building to channel sunlight into the interior
- Does not work at night
- Cannot provide focused lighting solutions, only ambient and aesthetic

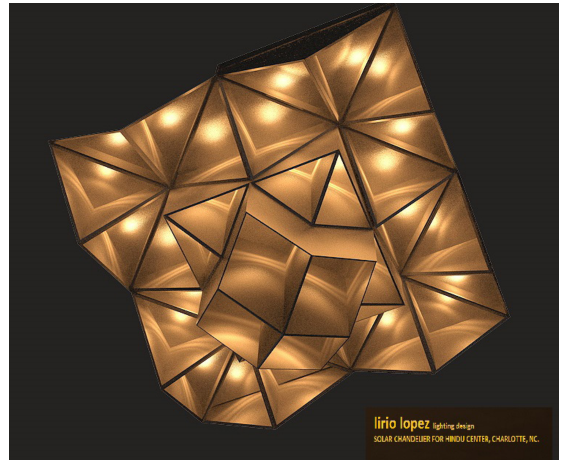
Placement of "Solar Chandeliers"

Various places were in contention as to where we could place the Solar Chandeliers. The main ones were predominantly around the Funnel since the requirement was that they be located close to a source of sunlight and the Funnel was one of the most open areas there was, these areas were:

1. The Cone Walls

2. The "Rim" at the ceiling of the Atrium

3. Under the Central Courtyard, in one of the Basement Conference Rooms

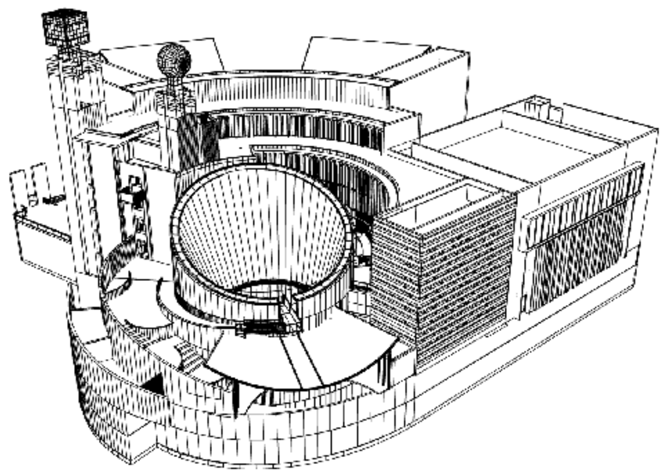


Methodology

In order to determine the right lighting solutions for these areas, we needed to gain some key information about the building and how it functions - so that we could design accordingly.

The first thing we required was a solar path analysis, which maps the shadows that form throughout the day. This would help us determine what form the sundial concept could take, whether we can utilise more daylight into our lighting choices and whether it is even possible to make our ideas work.

There are tools that facilitate this: known as solar path analyses - done frequently for architectural projects.



Next Steps

1. Conduct a solar path analysis (shadow mapping) for the building

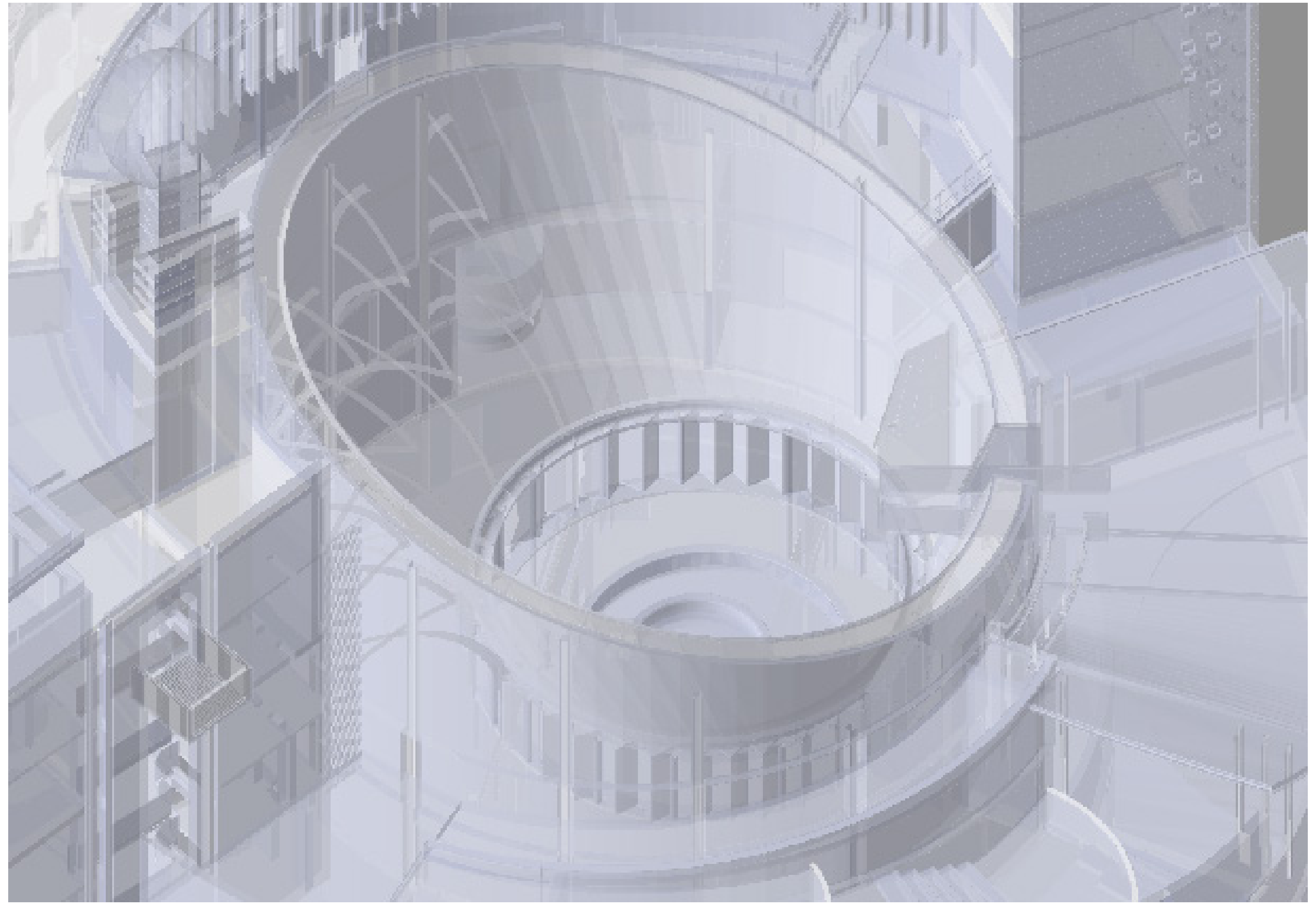
2. Based on the data found, propose lighting design possibilities which satisfy the requirements of the space, both functionally and aesthetically

3. Feedback and redesigning.

4. Present visualisations/solutions to the architecture team for approval and construction.

Final Deliverable

The goal was to present the ideas to the architects, who will determine whether they thought it was a compelling lighting solution and whether it was feasible. To that end, the final product involves visualisation renders and technical drawings of the functioning of the lighting fixtures and how it would work.



Museum model in Google Sketchup

Features of the space

Purpose of the Space

1. Central pivot point for the museum: Large corridors where people can exit to different parts of the museum
2. Art Display Area: Potential space for installations and art

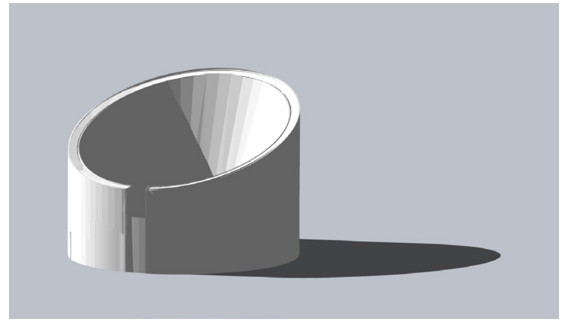
Desired Effect

Central space in the museum - feeling of monumentality, scale and centricity - as pronounced by the architecture

Architectural Center of Interest

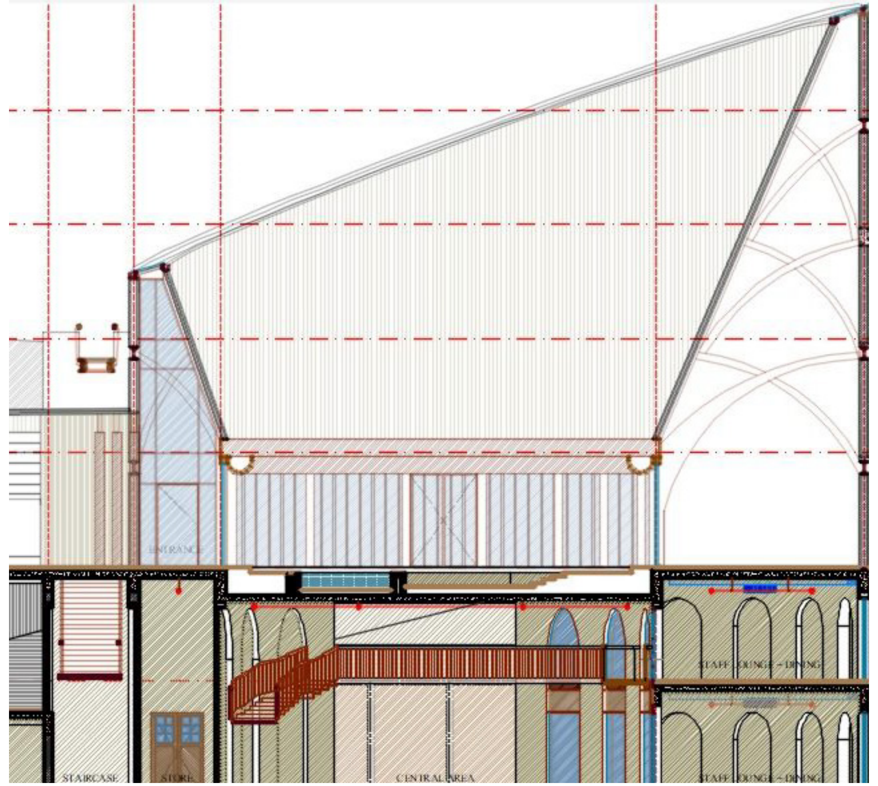
This building is the central structure in the entire museum, the other buildings appear to be "rippling outwards" from it.

Open to light, dust, rain etc, like a receptacle that invites these natural elements and holds them within itself.



Walking Pathway

Imperfect Geometry

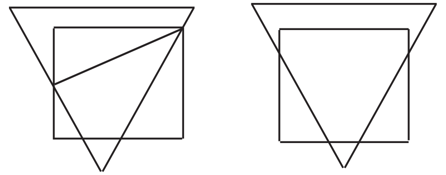


The building is shaped as a "truncated cylinder", but tapered and hollow on the inside. It is best described as a complex drama of basic shapes such as cones, cylinders and parabolas. Most of these are not even particularly centered, yet they convey a visual harmony regardless of this.

It is an odd and interesting shape for many reasons.

The corridors are wider from the front and narrow from the back, this is because the inside cone is not centered to the cylinder

Offset at the top of the cylinder (allows sunlight to come inside)



1. Height: 16.5 metres is the maximum height of the Atrium.

Many other measurements were considered from the CAD drawings like wall thickness, Corridor Length, Distance from beam to beam etc.

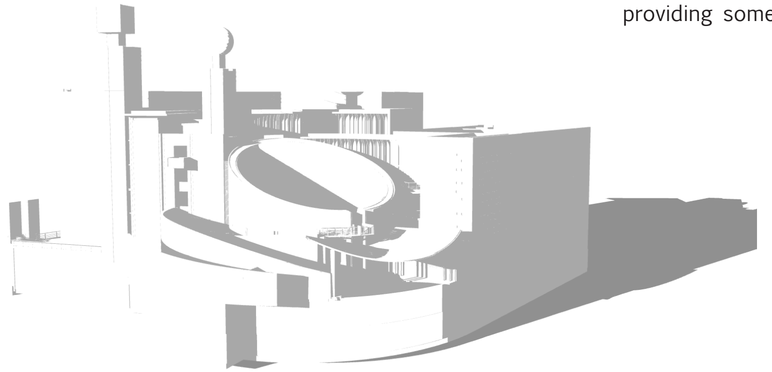
About the Design Philosophy

Summary

So the objective was to create an effective lighting design strategy for the Atrium - and one of the more interesting ideas was to use the concept of a sundial - which would be an interesting lighting concept to follow while designing.

The outer courtyard doesn't need lighting (except perhaps at night) - depending on its' need, but the main space to consider here was still the Atrium, which was the central space in the museum. People walked in and the first thing they would see is this large concentric room - that makes it quite important. The hope was that perhaps the sundial concept - which was completely envisioned in the outer courtyard could seep into the Atrium, providing some functional utility. And that was the initial design challenge. Also to create something which complemented and was as formally/visually compelling as the magnanimous architectural form of the space. The lighting design had to be exciting.

As the lighting designers, there was an opportunity to make the most of the sunlight in that open natural location, wherever possible. Of course, different spaces have different lighting requirements. Daylight can be detrimental to artworks. But atleast in the Atrium there was an opportunity to make the most of it. Especially if it also aligns with some lighting concept such as the sundial.

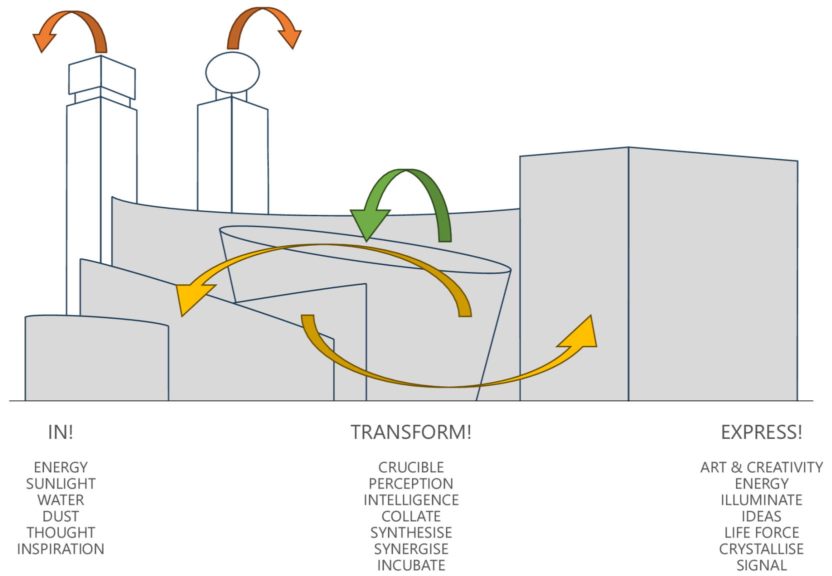


Lighting Philosophy

At this point, it makes some sense to talk about the lighting design philosophy that was being adopted by the team. This would implicitly guide much of the design styles for the lighting.

When the architectural layouts were shared with the lighting team, the lead architect provided the lighting team with a sense of design liberty. The architectural form was to be treated as a canvas - and the lighting designers were free to interpret the architectural form in any way they like - and to design something that they felt matched their personal vision. As such, Lyle, the team lead at 'Lirio Lopez Lighting' concocted the following narrative response to the architectural form of the Ark Museum:

IN, PROCESS, OUT



A living organism, or any natural physiological or physical process can be summarised with a basic framework, input, process and output. We observe this basic principle everywhere around us. Machines, flora, fauna all operate on this basic principle.

The building was imagined to be a large abstraction of this idea, or a natural phenomenon, like a volcano. Metaphorically, light, energy, sound and activity enter the building through it's openings or apertures. Notably, the funnel in the center, which represents this 'harvest' of energy and matter. The whole building has a very permeating architecture with large windows, small openings and open ended structures composing a larger geometric form, therefore, its design was generally imagined to integrate rather than isolate itself from it's environment, allowing a natural osmosis with its surrounding.

Inside the building, as visitors, ideas, artworks and natural elements such as light, sound and color enter the building, it results in internal activity and inspiration.

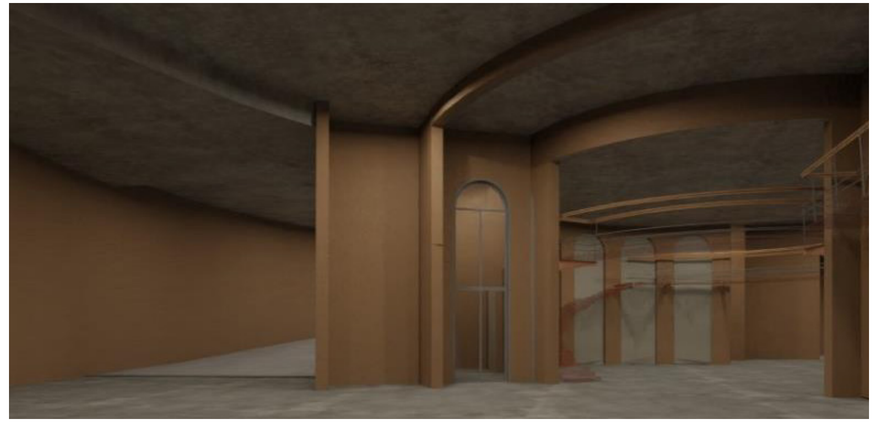
This result, then is output in the same way, through the permeating spaces of the building and the people and materials that make it, light and energy leaks out of the building naturally, through the large tower-like structures and the windows and spaces between the architecture.

It's interesting to note that the building contained very permeable spaces - forms that allowed natural light to seep in through the whole building. There were spacious windows that accomodated ambient light during daytime, with a requirement for greater lighting needs at night, or for focused lighting.

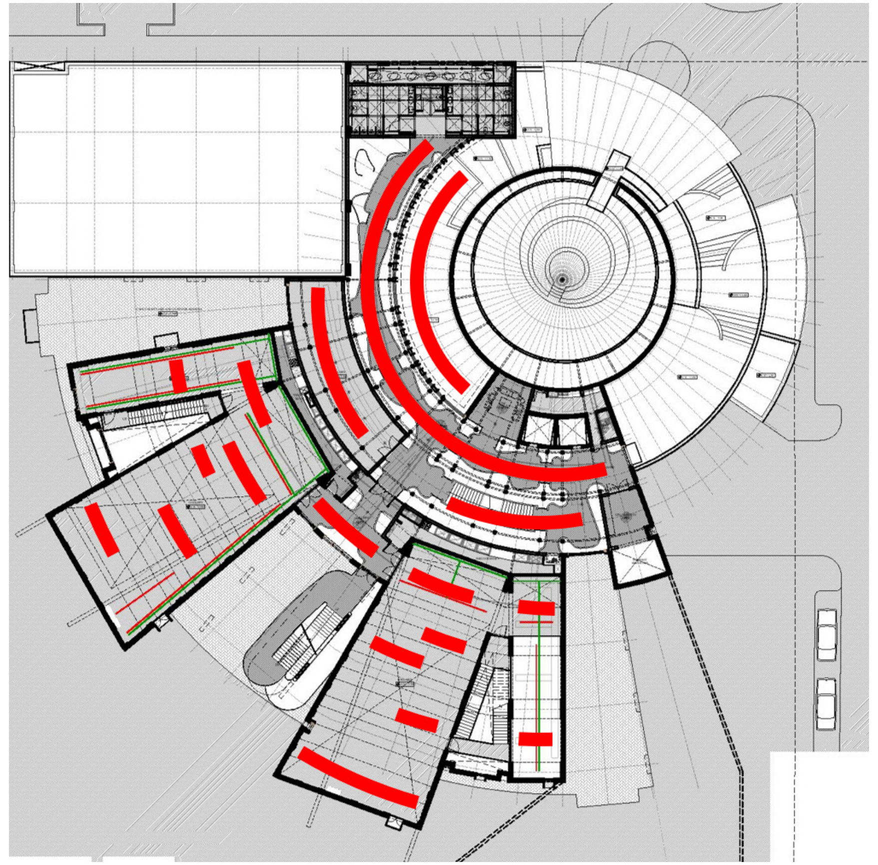
Concentricity of the Architecture

One of the most gratifying features of the architectural design layout of the museum is that the design follows a concentric pattern, as if rippling outwards from the central courtyard (Cone). The entire walls, corridors and gallery spaces, all follow this grid. This has the effect of revealing to a visitor, how far they are from the center of the museum, facilitating a natural and intuitive movement through the musuem and inviting the visitor to gradually make their way towards the center of the building.

The initial lighting design approach taken by the team was built around this attribute. The lights were designed to enhance/reflect the existing form of the interior/building, This design approach was also utilised for the final lighting design for the atrium.



Basement featuring concentric corridors



Plan view of the concentric layouting

Parking sustaining the concentricity using 'rippling' lights

Researching Sun Paths

Secondary Research

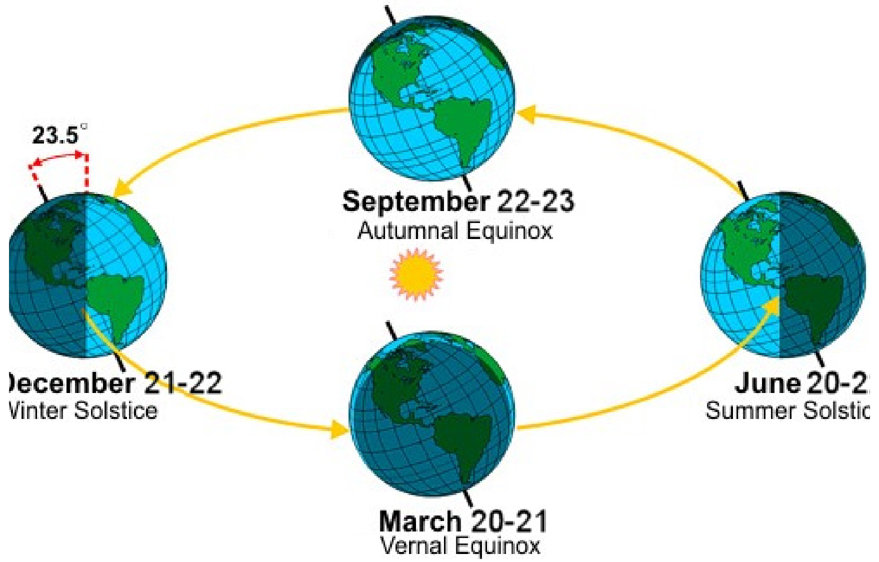


Fig 1

It is common knowledge that the Earth rotates around the sun in an orbit once every year. While orbiting, it also spins on it's own axis; one revolution completes one day, and night. This axis is not perpendicular to the orbit, it is 22.5 degrees tilted. And this tilt is the main reason why we see a variance of climate (season) throughout the year- as it causes the amount of sunlight each place gets, to vary.

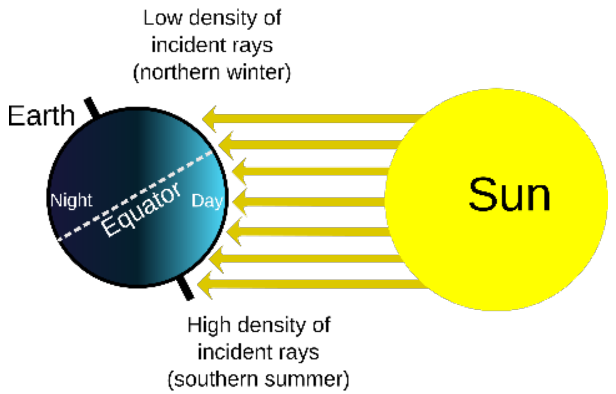
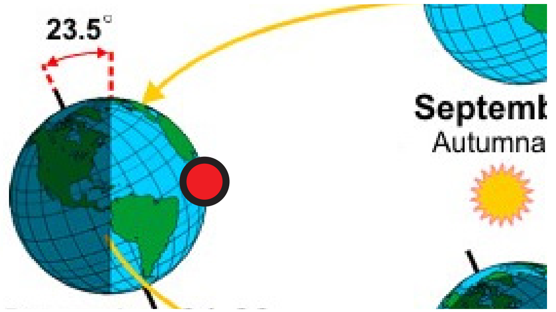


Fig 2

Land perpendicular to the sunrays is much hotter than land which is at an angle. This is why the poles, which recieve light at a very shallow angle, are generally colder.

So how can we connect the macro movement of the Earth around the sun to the micro movement of how the sun moves across the sky (from east to west) when we look at it from our balcony?



It should be easy to notice, if you imagine yourself at the equator on Earth, how the sun will appear to rise from the east and set in the west, since the Earth is rotating anti-clockwise. Now, thanks to the Earths' axial tilt, this path in the sky will also shift slightly throughout the year. It would have been the same if the earth were not tilted, but since it's not, it shifts, making the sun take slightly different paths, as the year progresses.

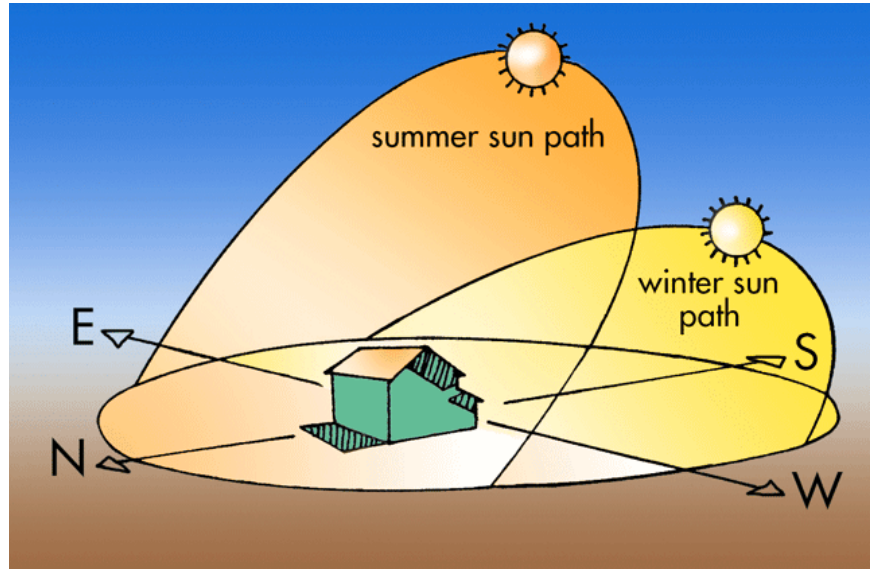
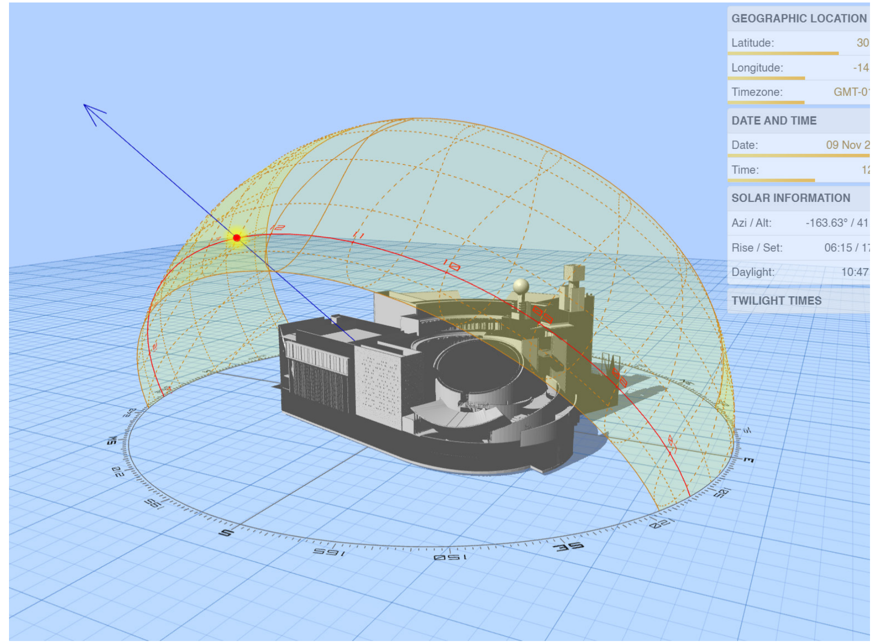


Fig 3

The sun's path is usually higher in the sky during summer and lower in winters. The angle of the suns height from the ground is known as the solar altitude. Comparatively, the azimuth is the angle/direction at which the sun is positioned when measured from north. These two values allow us to locate the exact direction of sunlight in the sky.

Solar Analysis of the site



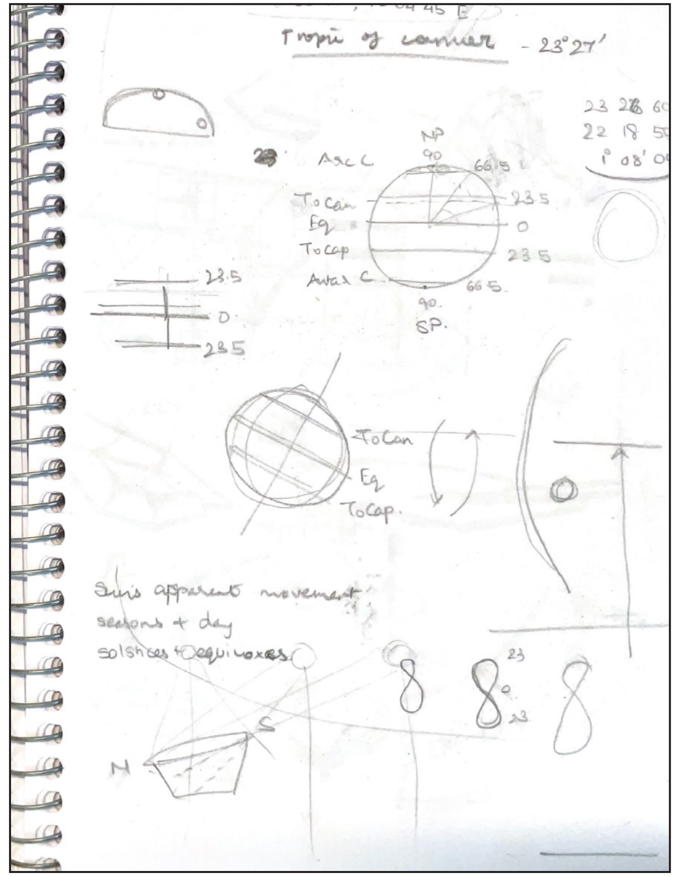
A 3d model of the building analysed using a Solar analysis tool.Each intersection of these lines represents an hour in the day (lateral lines) and day in the year (medial lines). The red dot represents the current sun's position, which is 1230 hours on 9th November 2025

Why does the sun move like that?

If we boil the design problem to its' core- it's the idea of how can we translate the movement of the sun into something embedded within the museum architecture that also tells the time in some indicative way.

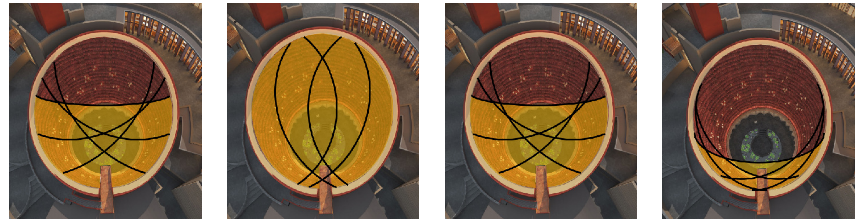
Understanding how the sun moves around the Earth is the first step to tackle such a problem. This would give us a deep understanding of how daylight will behave in Vadodara over time and whether we can create some kind of mechanism or pattern that translates the sun's movement in an interesting way.

Previous Research

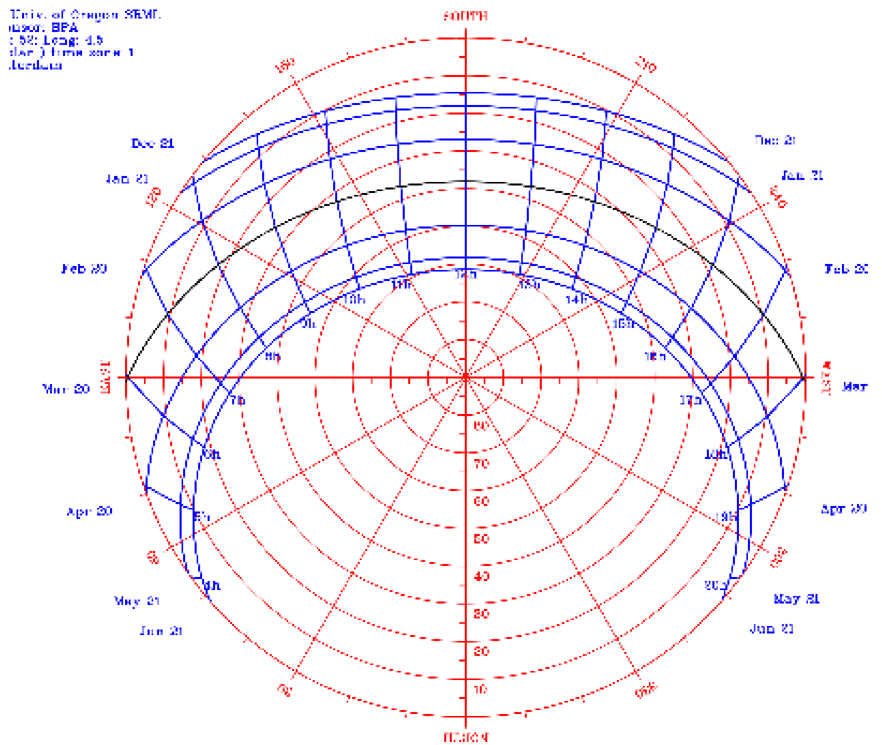


Notes: Trying to understand how the sun moves in the sky - by considering various positions on earth.

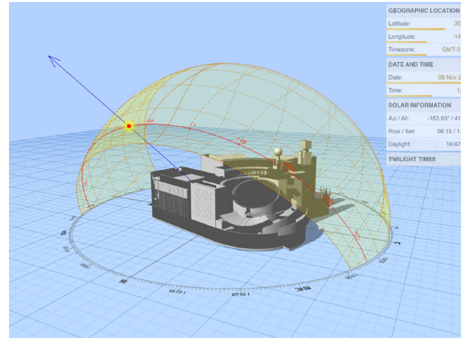
Paper model experiments mapping the shadows on the face of the building

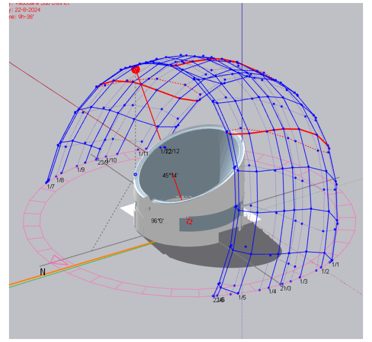


Solar Chart



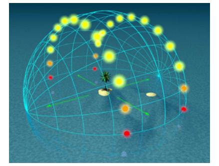
Polar sun path chart program, University of Oregon

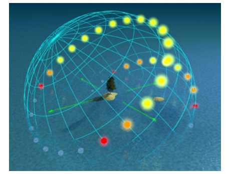


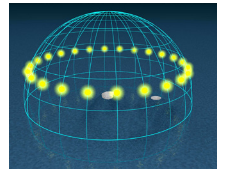


This is a solar chart, it's a tool that helps us understand, or map the movement of the sun throughout the year by visualising it's location in the sky. It creates an arched grid by dividing the suns movement by days (curved horizontal lines) and hours, (curved vertical lines). All in all, it is just a just a simple way to map out all the "possible" locations of the sun for a given place on Earth.

The chart obviously is different for different locations on Earth. For example, places near the north pole have a lower arch.







https://en.wikipedia.org/wiki/Sun_path

Longitude and Latitude

If you imagine the earth sliced up like a cake, both vertically, and horizontally, you end up with something like a grid for a sphere. This is the coordinate system that helps us locate places on Earth.

22°N, 73°E

It is written in this format. The first part denotes how up north or south and location is, the second part is for how east or west it is. Other values such as "minutes" and "seconds" help us point out places with greater fidelity:

22°18'55.0"N 73°04'45.0"E

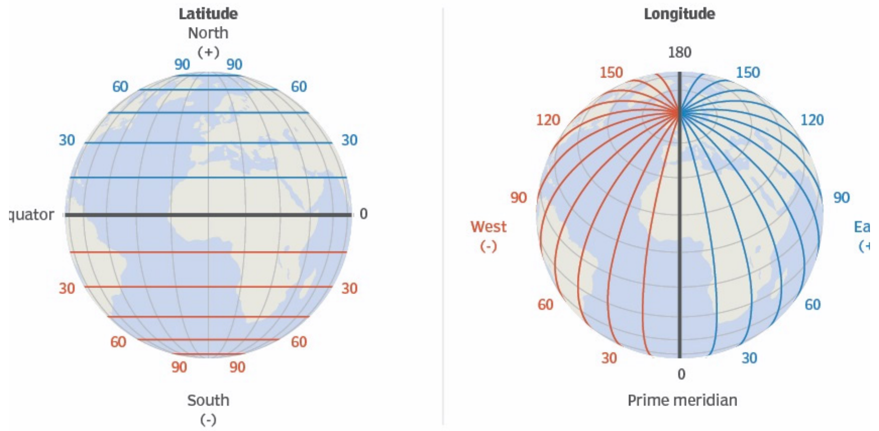


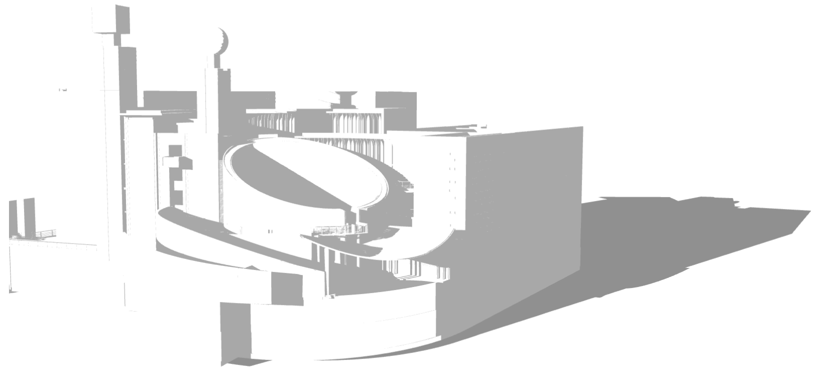
Fig 4

Conducting a Solar Path Simulation

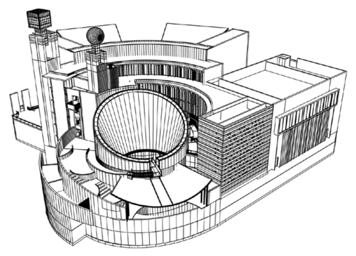
Solar Path Simulation

Since the physical shadow mock-up was rather crude. There was inevitably a need for higher accuracy analysis - the two most viable options were to use a miniature model on site or to use a digital simulation. For our needs, a computer simulation was just fine.

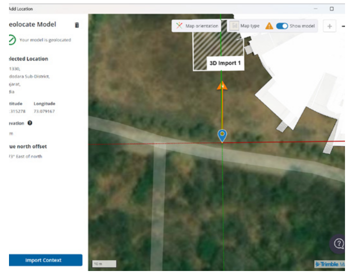
I suggested the inbuilt shadow mapping tool in Sketchup for this. I imported a 3d model of the proposed building and took screenshots for various dates and times of the year.



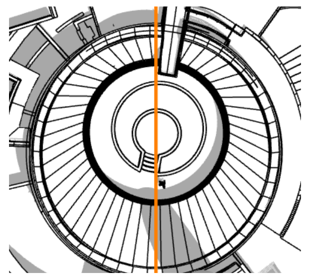
Setup



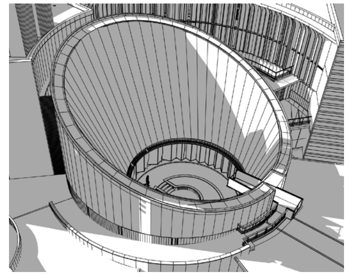
A model of the building was imported to Sketchup



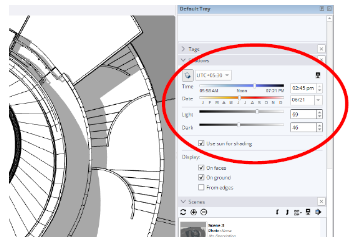
The location of the model was set to 22°18'55.0"N 73°04'45.0"E (Vadodara, Gujarat)



The building was then oriented to True North so that the shadows are accurately recorded



Lastly, the model "style" was adjusted to ensure that the shadows were clear and visible



The date and time sliders were adjusted to give an accurate representation of what the shadows on the building will look like at different times of the year.

Strategy

The sun has a rotation (day) and movement along the orbit (year). How can we capture the trend of the suns movement throughout the year without capturing it on every single day:

We selected 4 equidistant days in the year - the solstice and equinoxes. And for each of them, we selected five times (hours) in the day. The same for all the days. We suspect this would be like a low fidelity mapping of the solar path, enough to see if we could design any lighting solutions around this informaiton.

The solstice and equinox days were chosen for the site: 20th March, 21st June, 22nd September, 21st December, which are spaced out evenly over the year.

We are interested in the shadow lines that form on the building. Therefore, we chose to take 5 captures for 5 different times of the day: 7:30, 9:45, 12:00, 2:45 and 5:30. These were selected on the basis that we only wanted screenshots that had shadow lines in them, so we chose the latest sunrise and the earliest sunset so that we see shadow lines in all the snaps. The times increase by 2 hours 15 minutes for each snap, and these were taken for all 4 days.

	7:30 AM	9:45 AM	12:00 PM	2:45 PM	5:30 PM
20th March (Vernal Equinox)					
21st June (Summer Solstice)					
22nd September (Autumnal Equinox)					
21st December (Winter Solstice)					

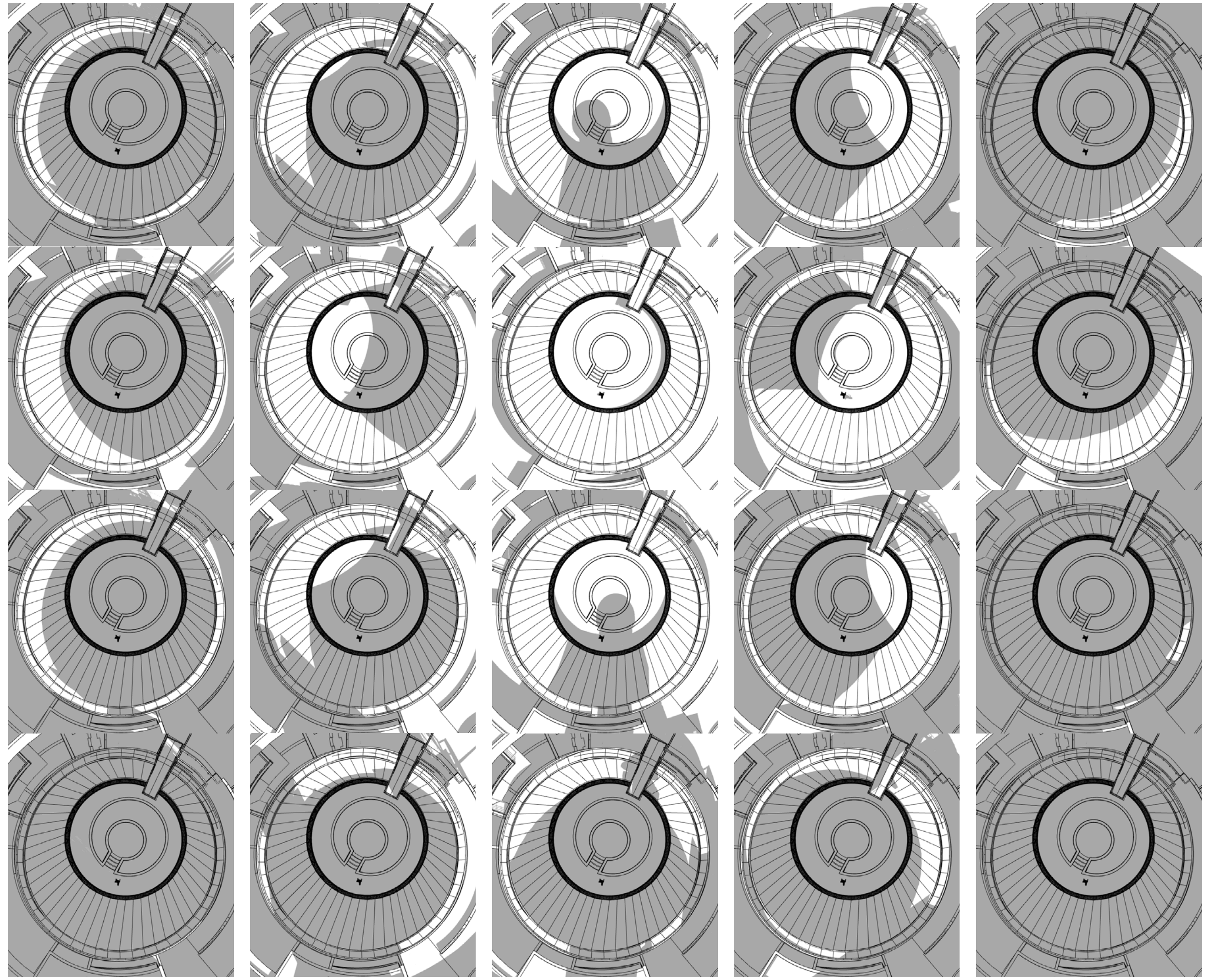
7:30 9:45 12:00 2:45 5:30

Vernal Equinox

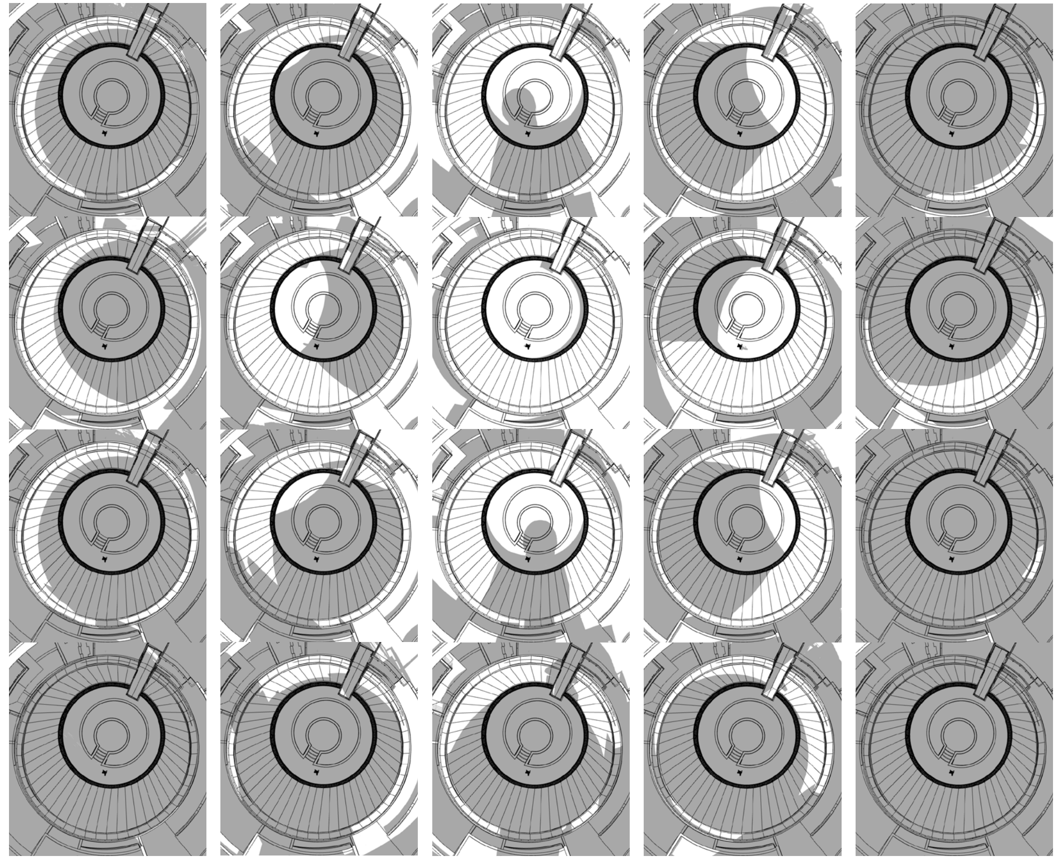
Summer Solstice

Autumnal Equinox

Winter Solstice



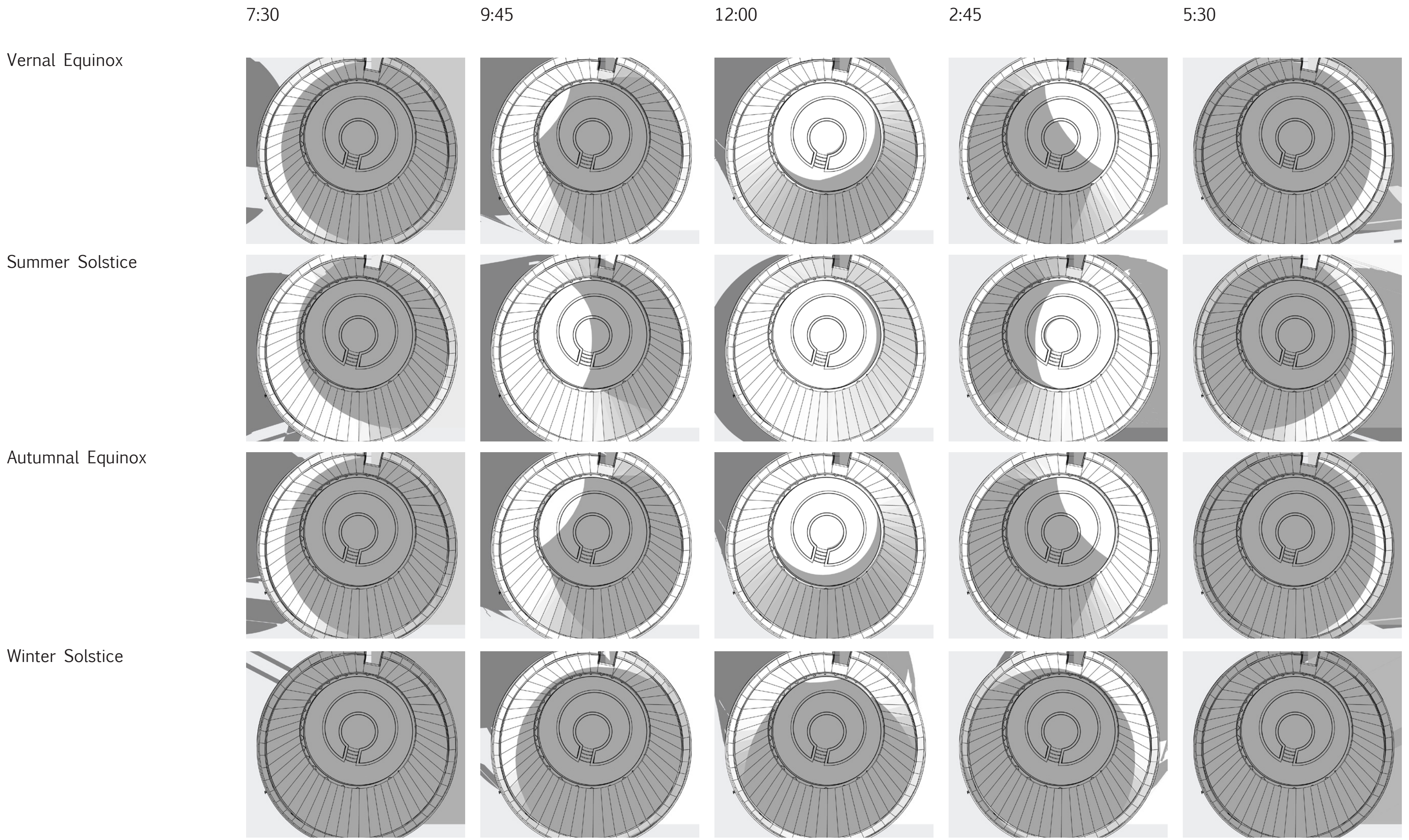
These results were shared with the project sustainability consultant for confirmation in the form of a report. It paved the way for more detailed discussions on how we could utilise daylight for more complex lighting solutions



Findings

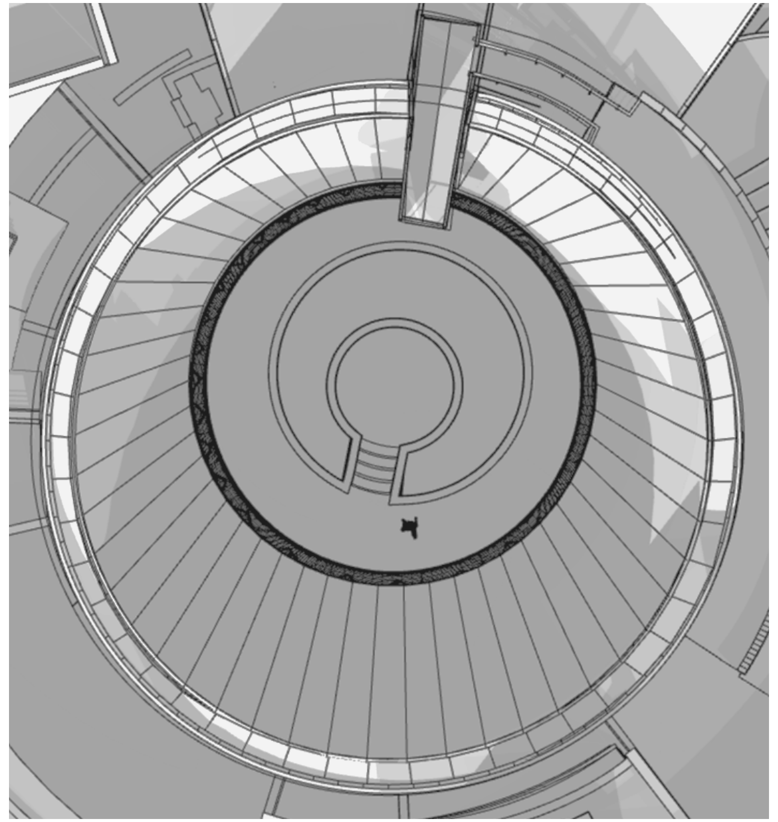
1. The biggest thing we couldn't consider was that the shadows of the buildings around the cone would disrupt the symmetry of these ordered shadow patterns. So a clear way to make marking was going to be more challenging now
2. There is definitely lesser light on the south side of the building. It appears that it's usually dark except at noon on most days.
3. We see that the patterns of light formed on Vernal and Autumnal equinox are identical. So technically there are only 6 months that are unique, after that the sun cycle just goes in reverse.
4. There is definitely more light higher up in the building. Light only reaches on the courtyard or low walls near noon.
5. The shadows projected by the viewing deck isn't that significant, or clean. It would be unideal to utilise it as a gnomon.
6. The shadows will most likely be hard shadows. But the site is probably going to be so bright that even areas which don't see to get light will get ample ambient light. But of course, the areas with direct sunlight will be very bright.

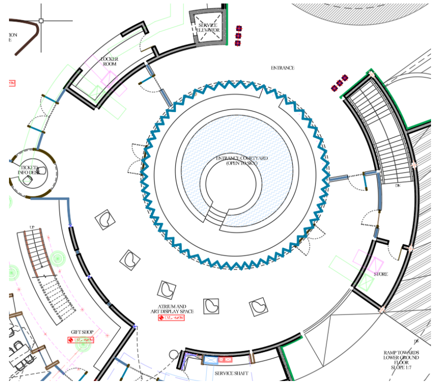
Second Shadow Mapping Analysis (Without the collateral shadows)

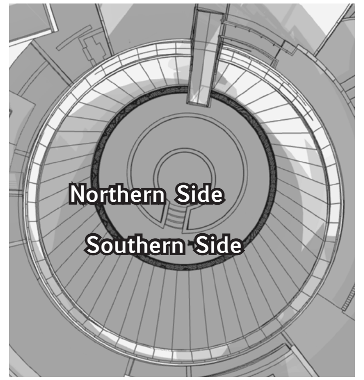


The first set of screenshots had a lot of noise from the neighbouring interferences, and it was hard to discern exactly what the patterns were. I took another set of screenshots without those buildings just for clarity and seeing the exact shadow lines that formed as a result of the cone itself. These are the patterns that would form if the colaltéral shadows didn't interfere.

Shadow Overlay Analysis Insights







Using the 1st analysis, I tried an overlay of the shadows to see if any clear patterns were visible. All the shadows were transposed on top of one another. The overlay wasn't very clear, but it shows how the northern side gets more light compared to the south. Because the site is towards the Tropic of Cancer (north) on the world map

What do these insights imply for our design?

The original vision, of using recessed markings on the outside of the inverted cone to symbolise various dates wasn't gonna work, primarily because of the collateral shadows from outside buildings.

I tried to figure out whether there were parts that were unaffected by the shadow intereferences and it was difficult. You almost always had shadows from the tower at noon, when the sun was high up. Some dates could be represented cleanly, but not most of of the important ones.

At this point, after discussing with Lyle and the team, we decided to utilise the Solar Chandelier concept within the atrium - but I simultaneously looked for ways to salvage the sundial idea. Maybe through another form, or design.

Exercise: Calculating the Solar Brightness in Vadodara, Gujarat

The value of precise thinking and "measurement"

Till now, the designs and decisions that have been made have been rather vague "what if" possibilities. I wasn't sure if this was because of my lack of ownership for the design and execution. But it felt a lot as if I were designing for someone without really caring much about the actual construction of the product. During the discussions, Lyle emphasized the idea of using specificity and measurements to communicate. Talking in "good enough", "lot" and "less" provides no certainty or clarity. As a design exercise, I was asked to apply this to the light brightness of the solar chandelier, can we measure "exactly" how bright this light is going to be in the space?

I discovered that through mathematics and physics, it is possible to calculate this even without stepping out of the office or visiting the site or making the light fitting.

Reasoning:

Direct sunlight consists a range of electromagnetic waves. When this light directly hits the surface of the earth, it bounces around until it converts into heat energy as it is absorbed by various materials.

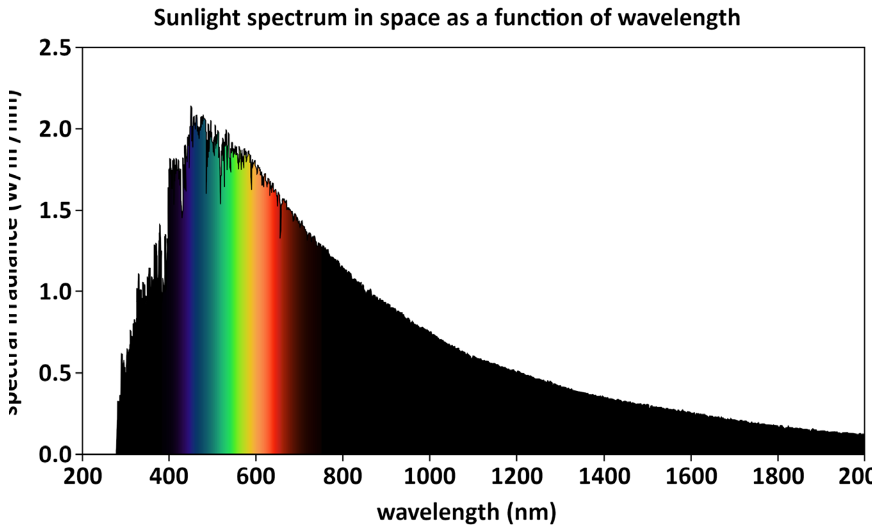


Fig 5

Let's say that you have a material which perfectly absorbs the entire wavelength of sunlight, a blackbody. The degree to which this material would heat up would be its' "solar irradiance". There are instruments that allow us to measure this such as a pyranometer.

However, not all sunlight is "visible light". We want to know specifically the "brightness" of the light, therefore we need to account only for the visible, electromagnetic portion of sunlight out of the total solar irradiation value. This can be done by knowing sunlight's "luminous efficacy" value, which measures how well sunlight produces "visible light". Sunlight produces about 93 lumens per watt of solar irradiance.

Therefore,

*93 (luminous efficacy) * 1000 (solar irradiation) = 93000 (lumens) per sq. mtr*

So sunlight creates 93000 lumens per square meter when directly perpendicular to the Earth's surface. This is theoretically the hottest the sun can be at any point in time, anywhere on Earth.

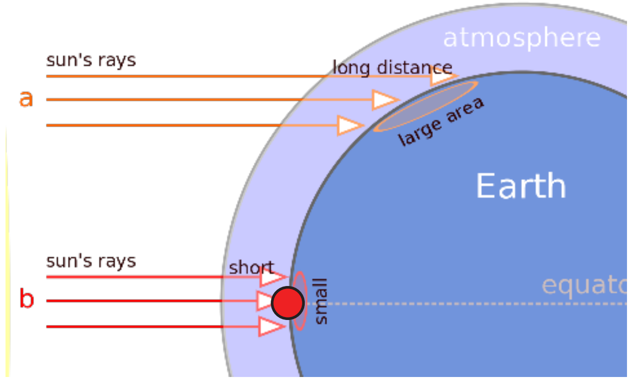


Fig 6

On a perpendicular sun at clear skies, solar irradiation on the Earth's surface is about 1000 watts per square meter. (source)

Extrapolating the values from maximum to minimum

Great, my first hypothesis was that if we consider that the sun produces around 93000 lumens of visible light when it is perpendicularly high in the sky (optimal brightness), and let's say it produces 0 lumens of light when it is below the horizon (minimum brightness)

We can simply fill in the intermediate values, by saying that the brightness of the sun is directly related to the sun's "solar altitude", which refers to how high up in the sky it is, expressed as an angle.

Theoretical table of lux values

Solar Altitude (Degrees)	**90**	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**	**0**
Brightness (Lux)	93000	82667	72333	62000	51667	41333	31000	20667	10333	0

All of these values assume that there are clear skies with no atmospheric interference.

The next step was to simply input these values for the site. The Curic Sun plugin in SketchUp gives the angle at which the sun is positioned in the sky throughout the year. The intensity of sunlight depends on the solar altitude of the sun, the azimuth is of little consequence. In Vadodara, Gujarat, the "solar altitude" usually ranges between 43° to 93°. These angles can simply be input into the lux values found earlier.

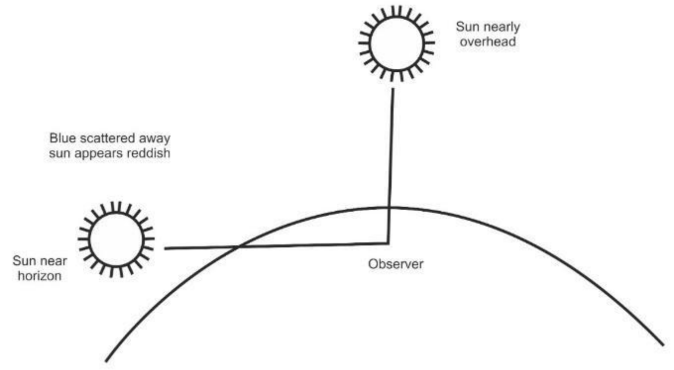
Using this data, one can imagine that if the sun is directly overhead, it is at its maximum brightness. When the "solar altitude" drops lower and lower until it is below the horizon (sunset), it is at its lowest brightness (night-time). If we assume that night-time is pitch black, which it usually is if we ignore the scattering of light in the atmosphere soon after sunset, the refraction (bending) of light as it enters the atmosphere, and the presence of artificial light sources, we will know how bright it will be at each time of the day if we just fill in the values in between.

Correction

When I showed these calculations to Lyle, explaining my reasoning, it was clear that the only way to confirm my calculations woul dbe by actually measuring these things and confirming them with the numbers. I was sure I was bound to be off, but it would be interesting to know, by how much.

Lyle pointed out that my method wasn't exactly right. There were many factors I had failed to consider, and some were outright wrong.

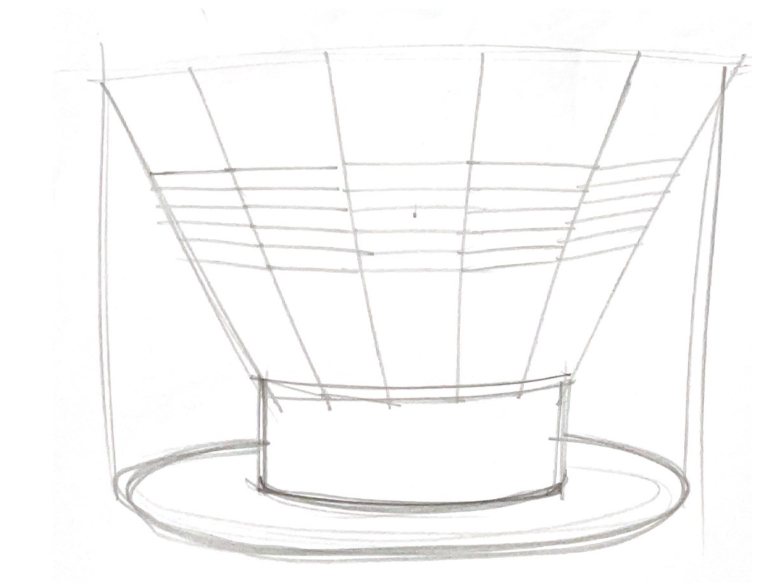
He said that the Earth's atmosphere acts like a denser medium compared to the vacuum of outer space. Therefore, when light enters the atmosphere at a 90 degree angle, almost the entire wavelength of sunlight is able to go through, however, as the angle get's steeper, the density of the atmosphere causes the sunlight to "refract", spreading it out, until at a critical angle, most of the blue light isn't able to enter the atmosphere at all as it simply "bounces away". The following diagram explains this phenomena to some degree. This is why the sky appears orange during the evening, as the blue light isn't even making it through the atmosphere. My calculations assumed that the environment had no effect on the solar brightness. Furthermore the simple extrapolation that I had made turned out wrong. Because as the sun drops lower, it hits the ground at an angle, which makes the values non linear. This is known as te cosine effect.



Reflection

Most likely my calculations were very off, therefore, this was simply a learning experience, and the first time I've actually applied mathematics to try to solve a real application problem to try to find the solar intensity of a place so far away from me, just using information and known values.

Design Alternatives

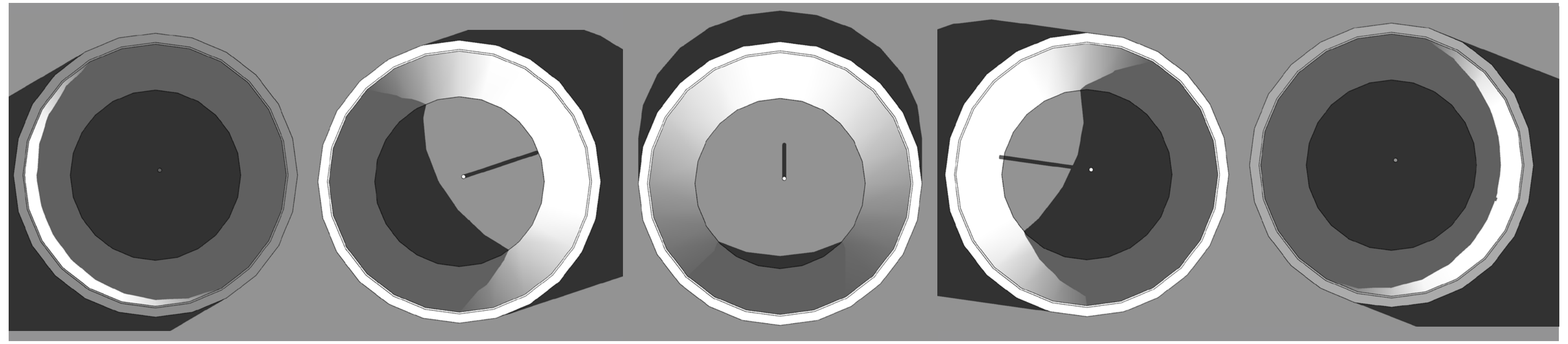


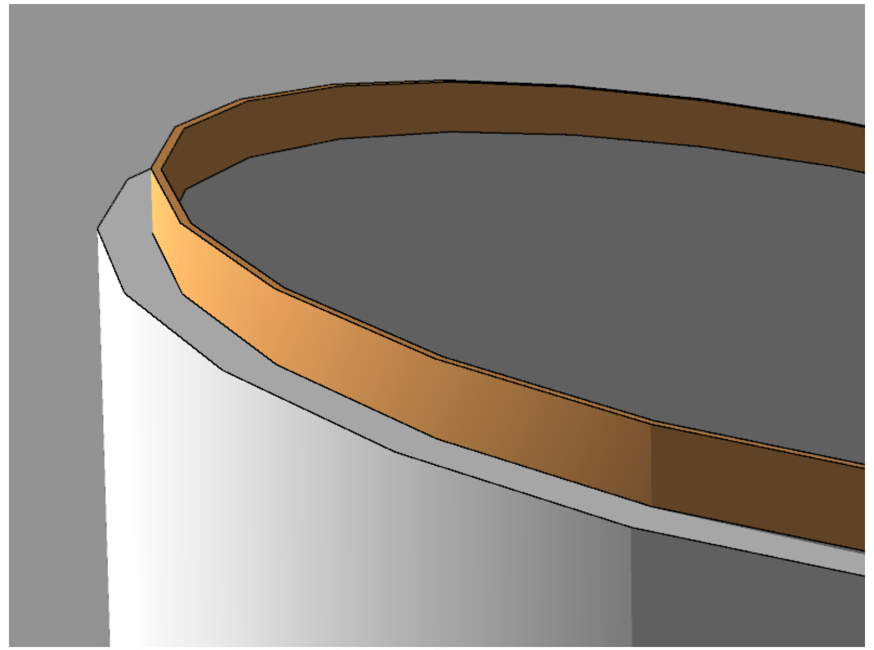
Perhaps the Sundial Idea could still work-

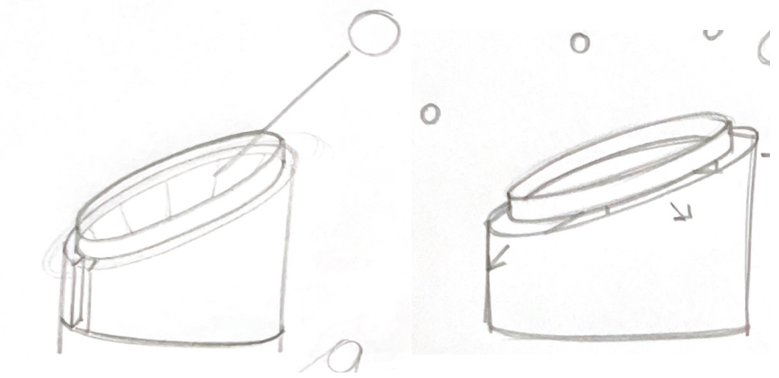
The following pages highlight some other design alternatives which could act as a sundial. They involve various forms and strategies that can be arranged in clever ways to reflect time.

1. A Pole in the middle of the Courtyard?

An early simple idea was adding a pole to the courtyard to act as a gnomon. This functions similar to an actual sundial. Yet a long pole in the courtyard was an obvious aesthetic deterrent to the openness of the space.



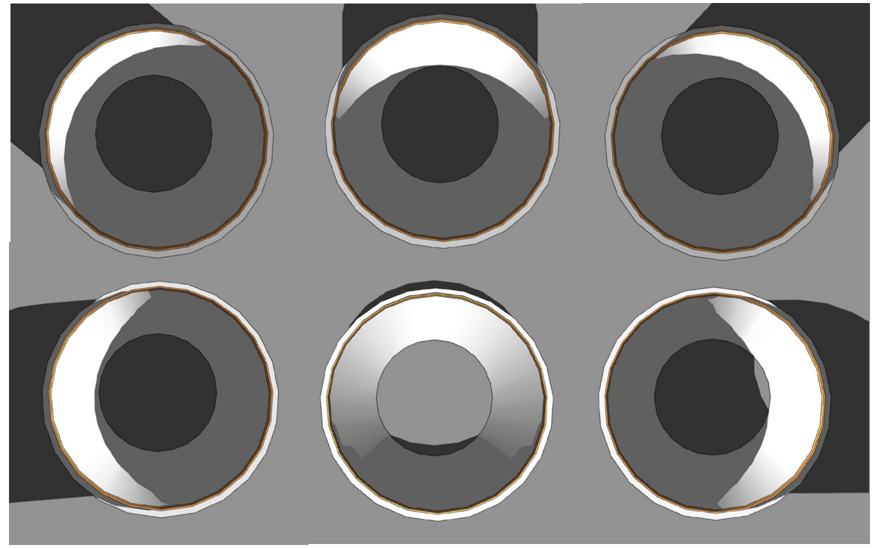




2. A ledge blocks the ambient light in specific places depending on the sun's position

The outer rim is the only place where light enters the building. A simple addition (If approved by the architect), an extrusion along the "rim" will block sunlight from entering inside depending on where the sun is.

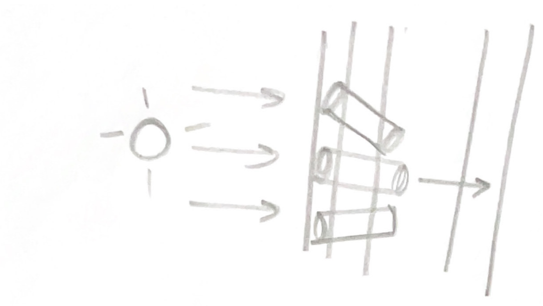
As demonstrated by the images below, the shadow from the extrusion reveals the position of the sun.

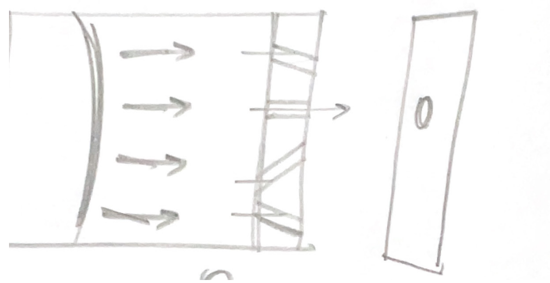


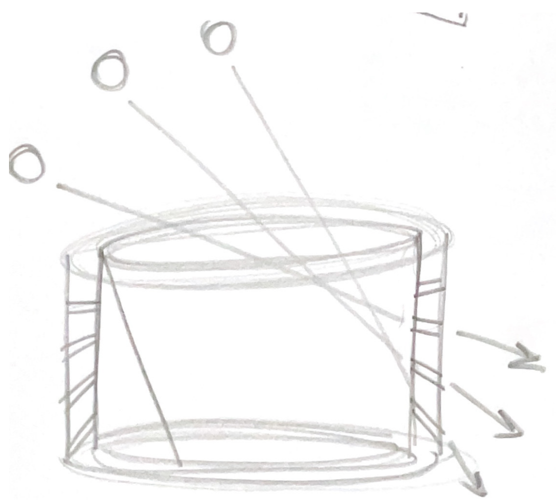
The rim doesn't get as many interfering shadows - because it's higher up and facing the sky.

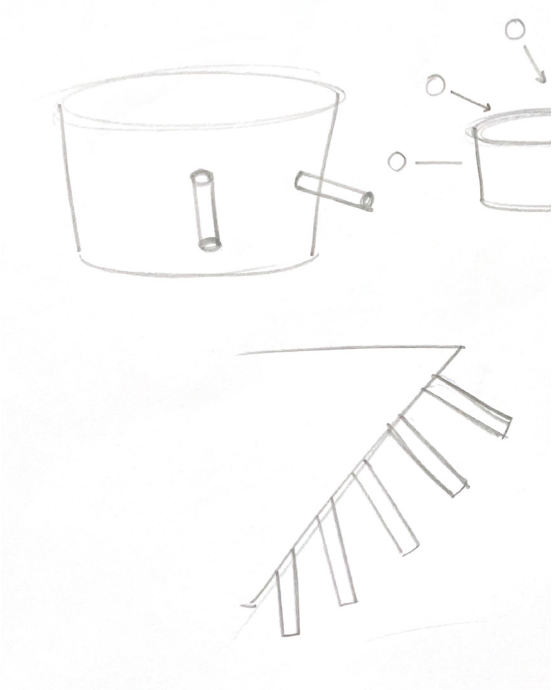
However, the ledge will block ambient light in a particular area inside the funnel, depending on the time of day

3. Angled perforations of light

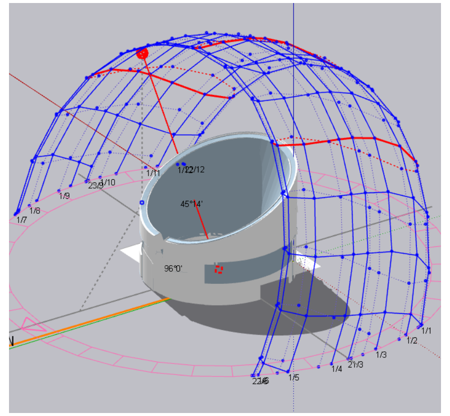


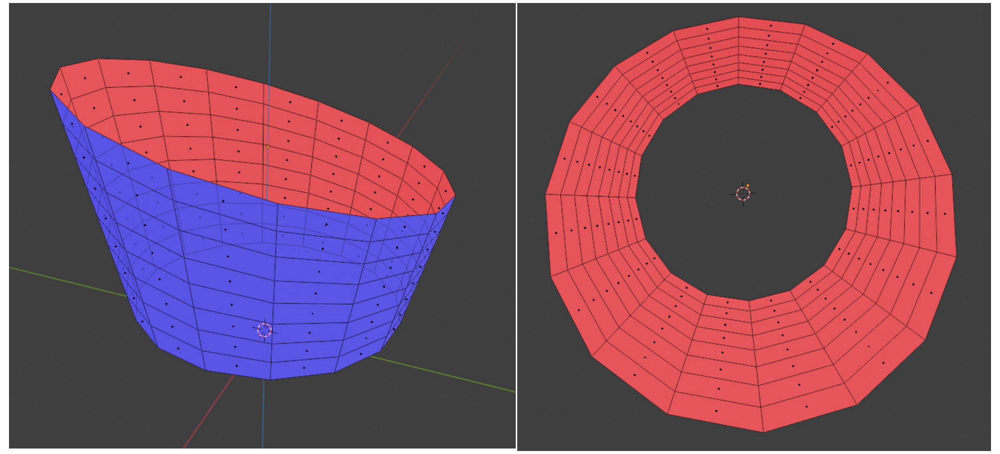






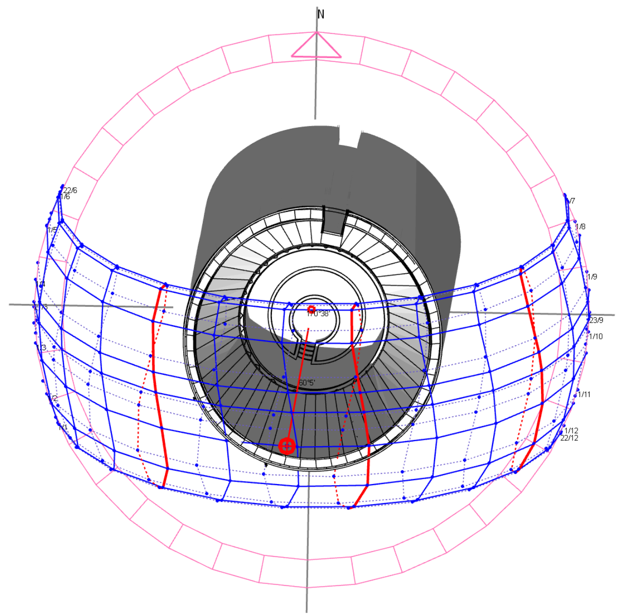
It was here that the idea for using pipes to funnel the light inside was introduced. Depeding on the position of the sun, the light would enter the pipes only if it were precisely aligned with the direction of the pipe. This would mean it would slowly light up one by one depending on its' arrangement. It's not a perfect idea however, The number of pipes would be limited because we can't make one for every hour of every day of the year. And calculating and installing the right angles will be a bit challenging. Not so much but a bit.

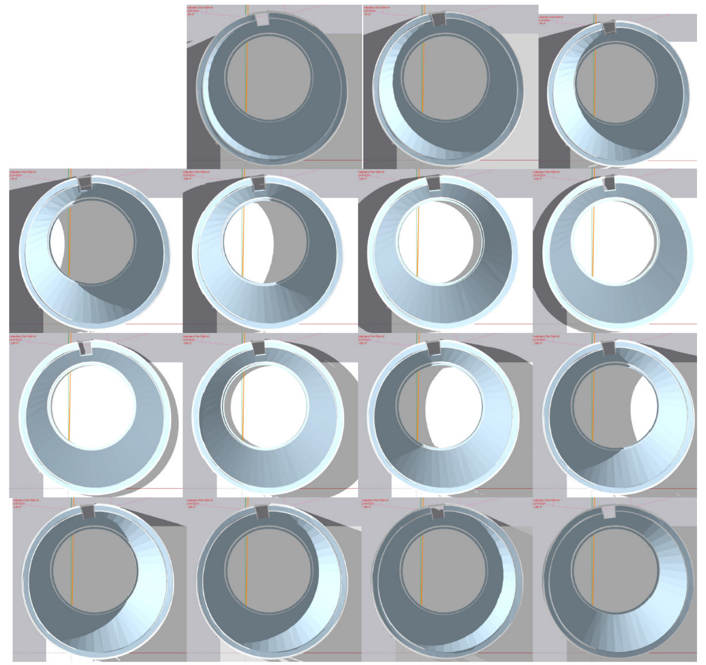




4. Grid with perforations

A simple idea is to simply make evenly spaced holes on the whole wall. This way, while the exact time is not represented, the sun participates much more in the Atrium, and depending on the time of day, more or less perforations will allow light inside. This creates a natural, but fuzzy expression of time. At noon, all holes will probably let light in. While at sunset, perhaps only the top few.





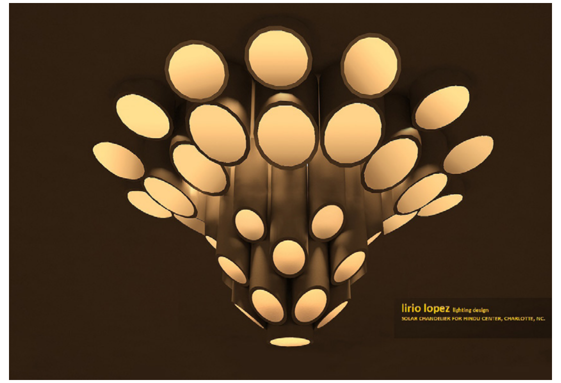
Chosen Design Direction

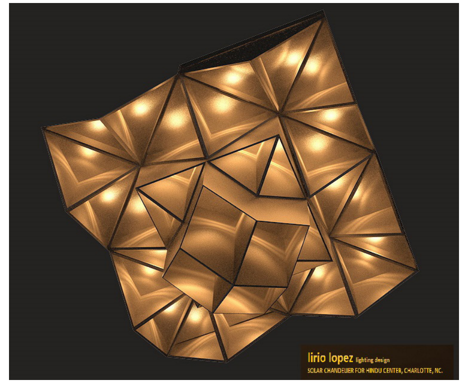
Design direction

After much discussion and consideration with the team lead Lyle. A simple solution was taken forward. The ambitious ideas posed risk, and proposing them to the architects - especially the ones which involves construction, could be challenging. A simpler direction was more fruitful.

It was decided that we would design a Solar Chandelier for the Atrium

Lirio Lopez has before produced lighting fixtures known as "solar chandeliers". These work by funneling light from the outside to interior spaces, bringing it to life. The mechanism behind it works using something known as a solar light pipe, which involves using a highly reflective aluminum coated pipe.. These were tried and tested, and could be replicated for the Ark Museum.

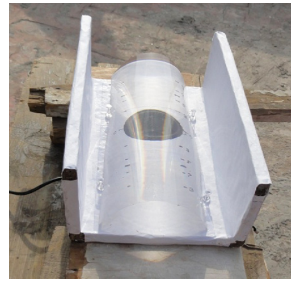




Previous Solar Chandeliers

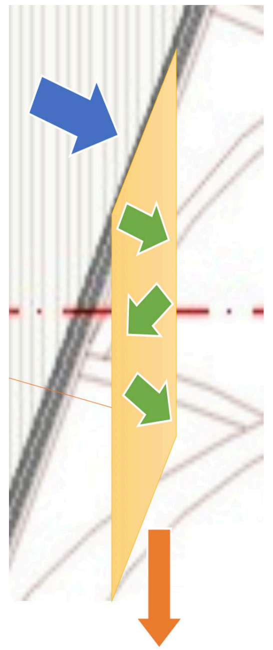
About Solar Chandeliers

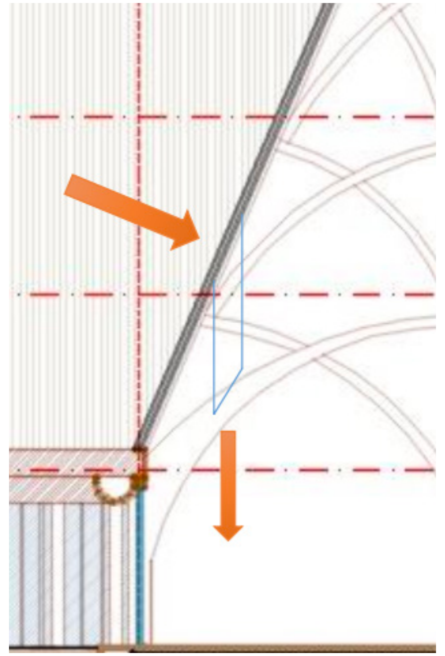
1. Collecting:
A special lens is used to collect the maximum amount of light



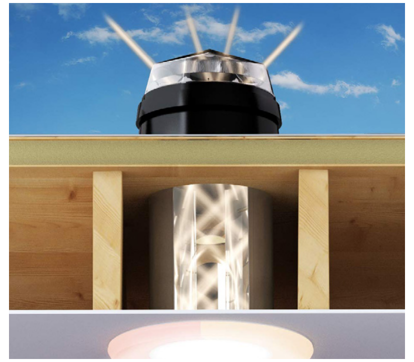
This lens was specificaly designed for the Chandelier, it lowers the light ingress when the sun is at a high altitude and increase it when it's low. This provides more even lighting throughout the day. At noon, the sun can be surprisingly bright. Producing more than 100000 lux!

2. Transmitting:
The pipe has a shiny aluminum finish which allows light to be reflected through





3. Emitting:
At the end is a diffusive material like frosted acrylic which creates a glowing effect



Designing the Solar Chandelier

Placement of the Solar Tube

Referring to the Solar Analysis, we placed the position for these tubes (initially), only towards the north side of the funnel, this was the area which recieved the least unwanted shadows and had ample sunlight. It was also the main entrance so the visitor would see it first.

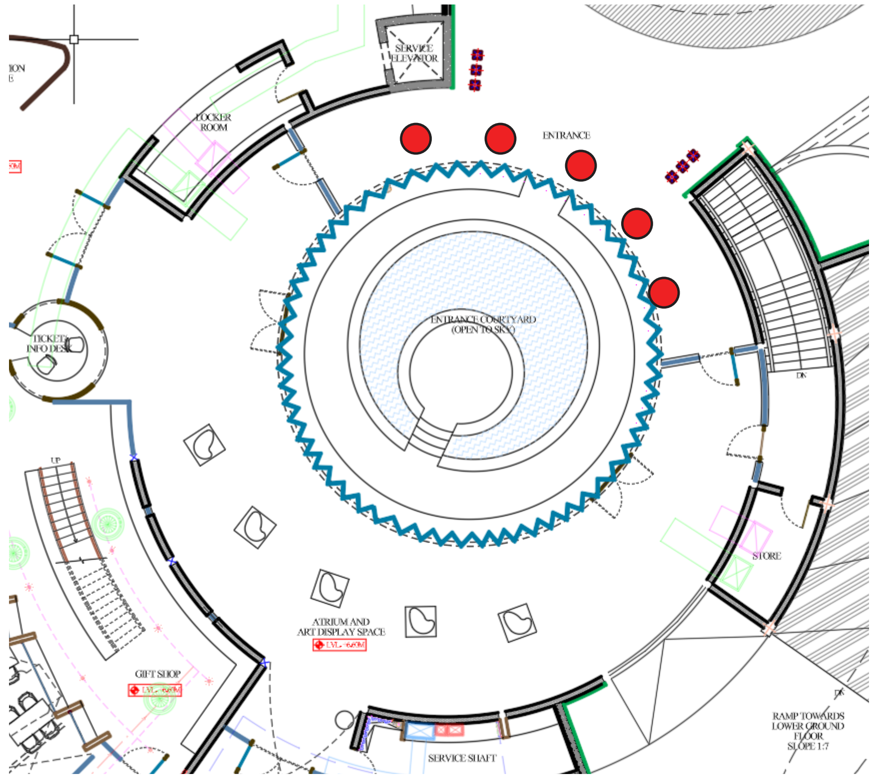
The red markings show the areas where these lights would be placed.

Height of the pipe placement

The height of the pipe placement was crucial as this would determine the falloff distance for the fititng. Light Intensity drops exponentially. The higher up we go, the more ambient the light becomes. In this case we probably want the pipe to come pretty close to the corridor. Therefore, its' placement would be low, and the pipe would be long, so that it can catch light from higher up and funnel it lower.

<u>Light Intensity</u>

100%	25%	6%	1.5%
1m	2m	4m	8m

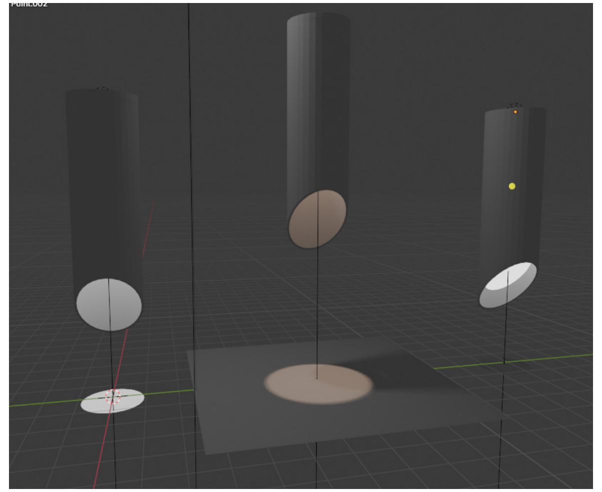


Light Pipe Diameter.

For the design, we had the option of a 30/60 cm dia. pipe to serve as the base of the solar chandelier. There would be an outer facade which would enhance the look and aestheitc of the overall fitting.

Tube selection (30 cm dia)

We decided to choose the 30 cm dia pipe (it was a safe and large size). This would also determine the light ingress for the fitting. Our design would be built around this measurement.



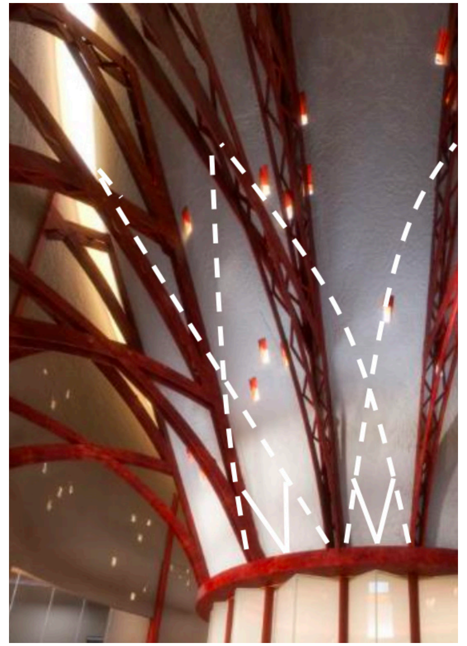
Outer Exterior for the Solar Light Pipe

The next thing was to design an exterior facade for this pipe. It could also be left simply as a tube but we wanted it to be impactful and interesting, therefore an outer form which complements the interior architecture would be much more compelling.

Initial exploration sketches

Designing the fitting exterior

Now it was about focusing really on the “design” of the chandelier and how it looks/ how it channels light through it to lead to some kind of contemporary expression that stands out in the Atrium.

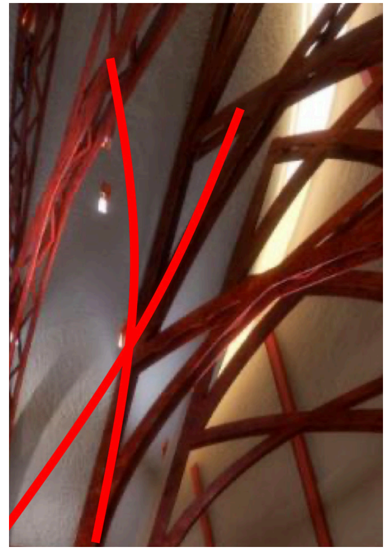


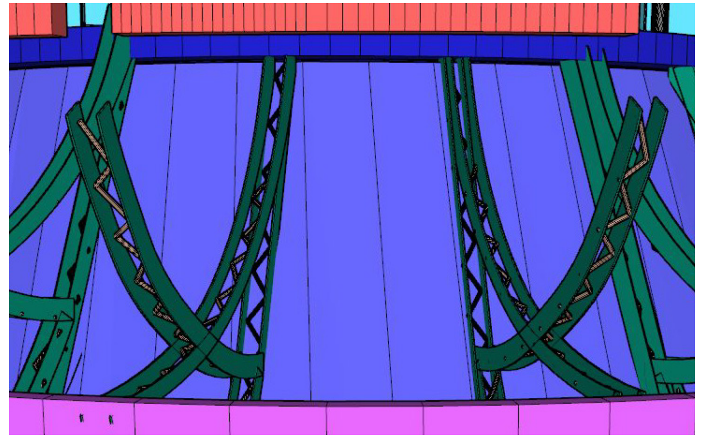
Guiding lines can suggest inpiring visuals form the form of the light fitting.

Aesthetic:

The intention was to create something that would complement the grand and imposing nature of the catenary arches - they were the most prominent forms in the space. The goal was to create lights which work with the existing architecture, or are invisible and enhance them further.

We used the structural members of the catenary arches as a formal inspiration to design the exterior fitting.

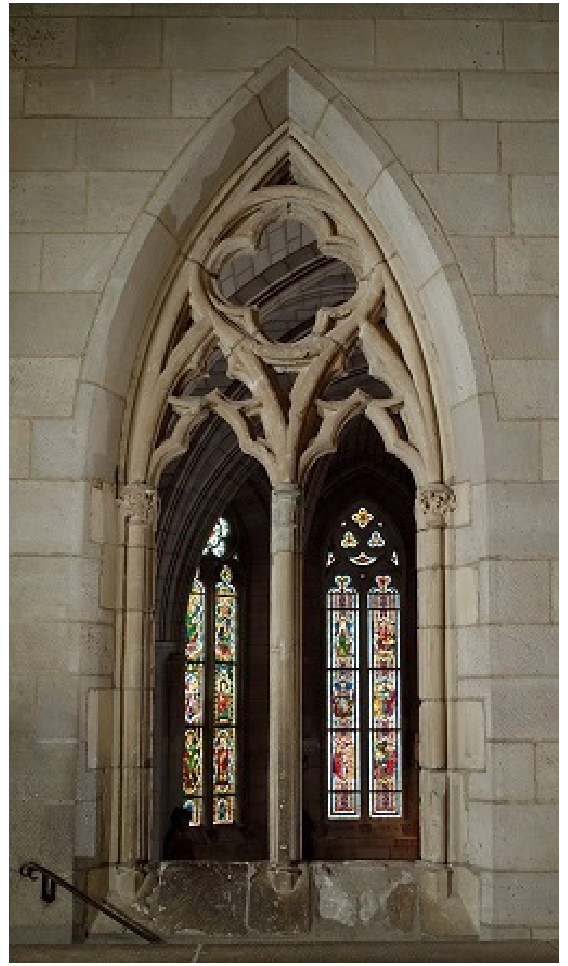




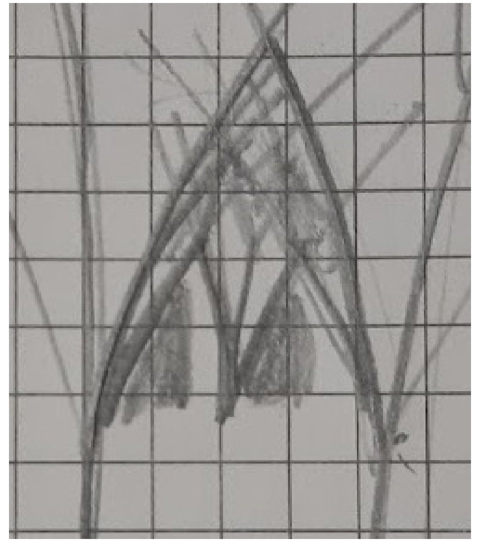
Upside down arches

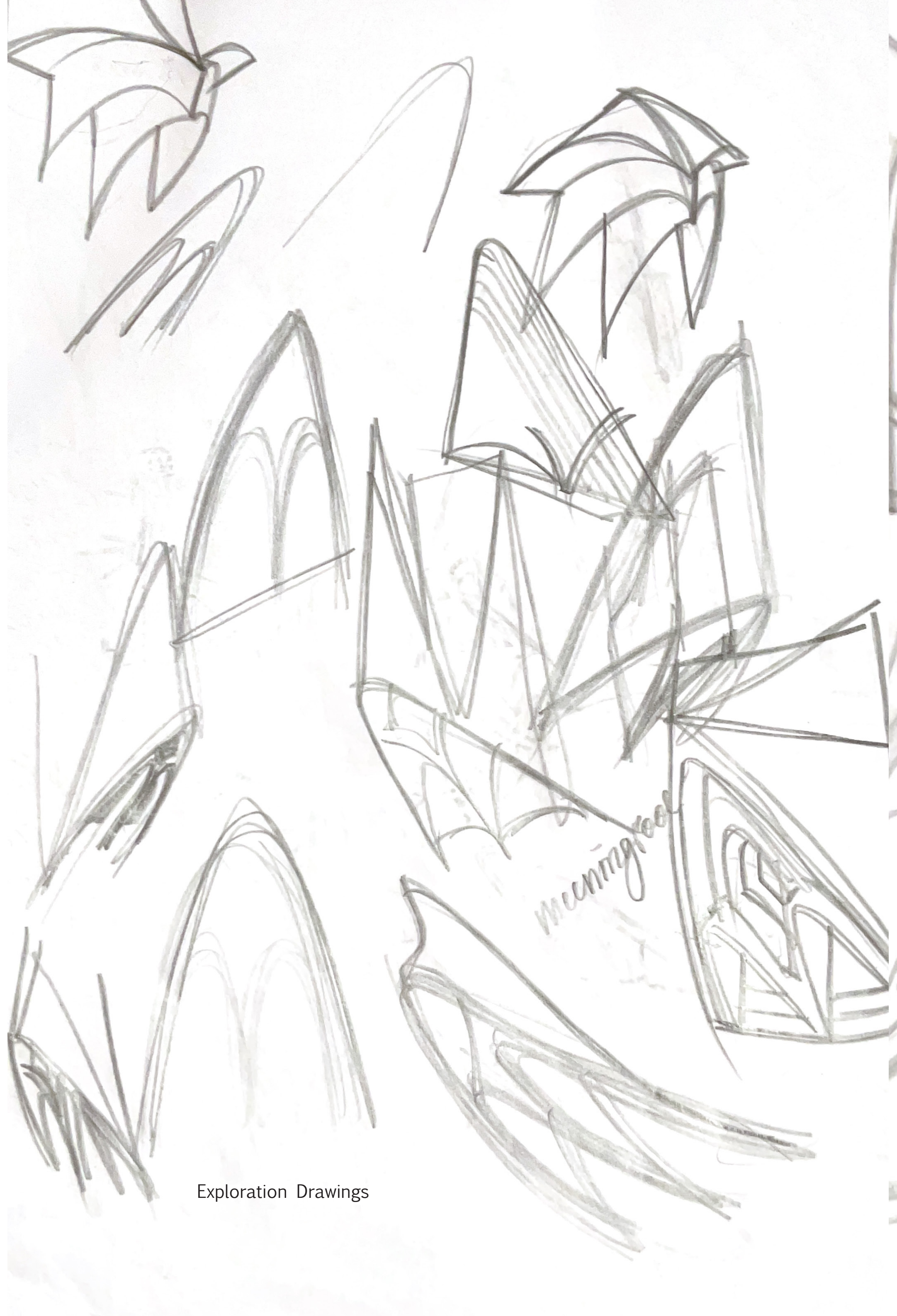
Form Inspiration

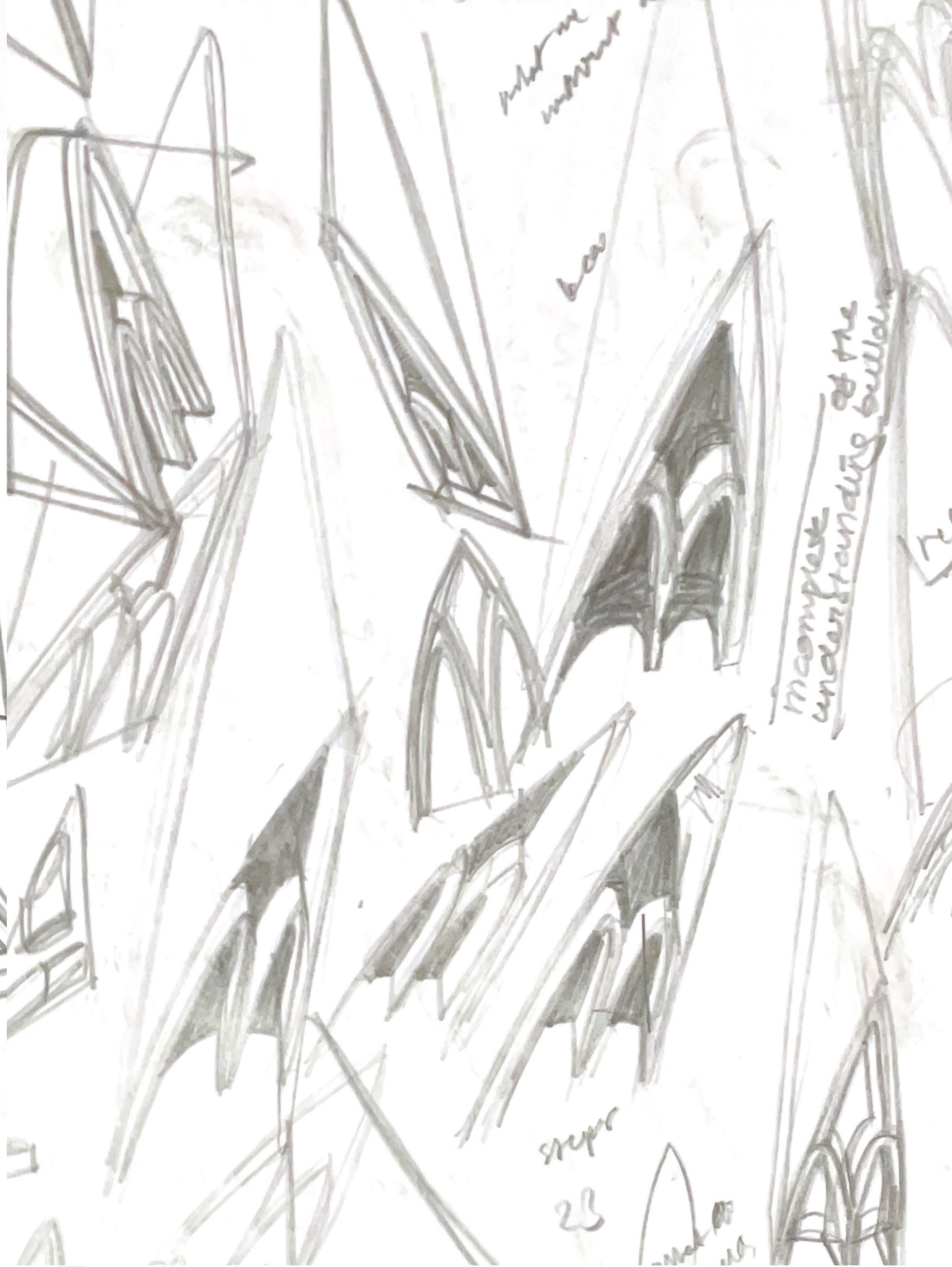
Lyle had a particular shape in mind for the Solar Chandelier. The best representation of his vision was a small drawing he created, which alluded to a "lancet window" found in gothic church architecture.



https://study.com/academy/lesson/what-is-a-lancet-window-definition-architecture.html



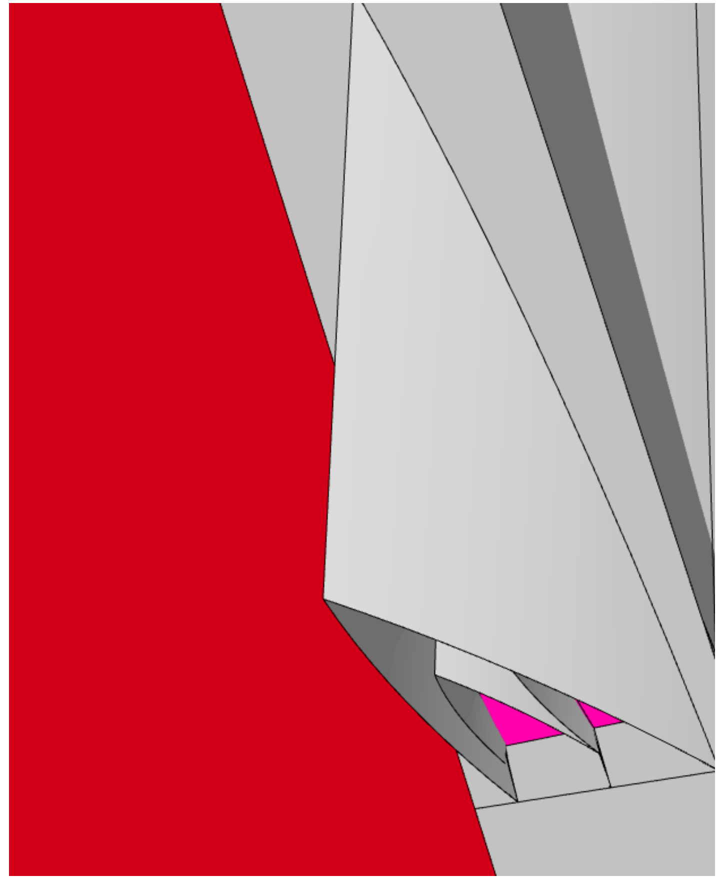


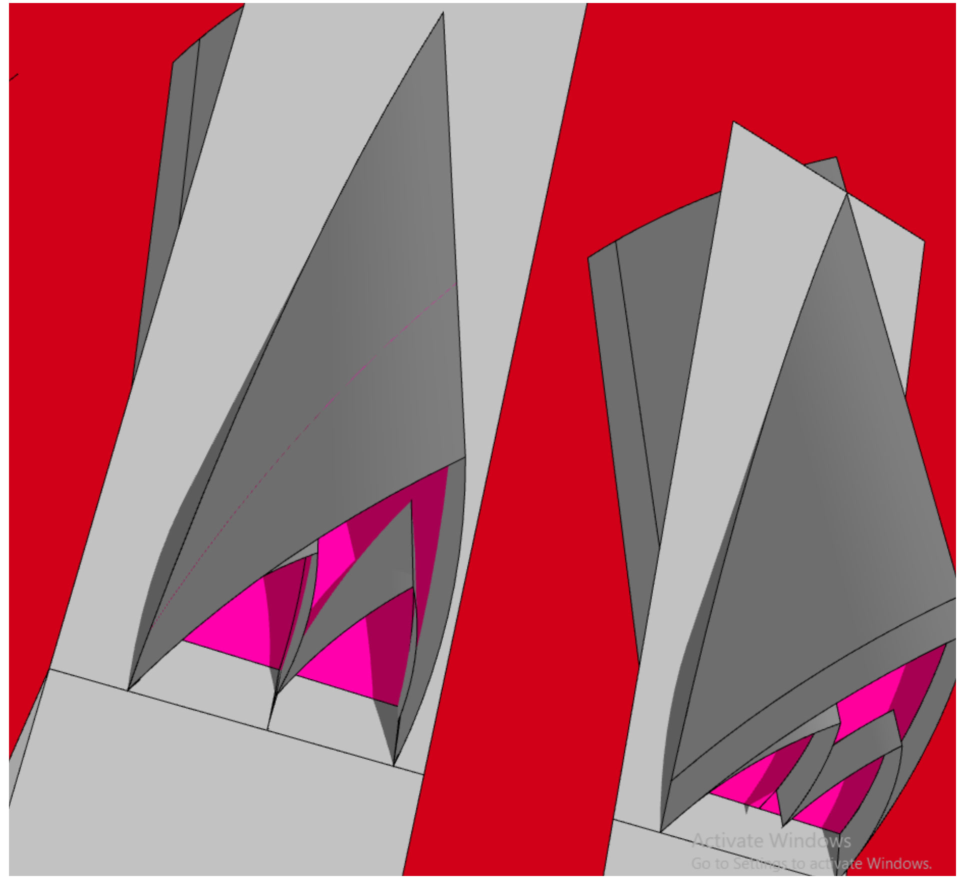


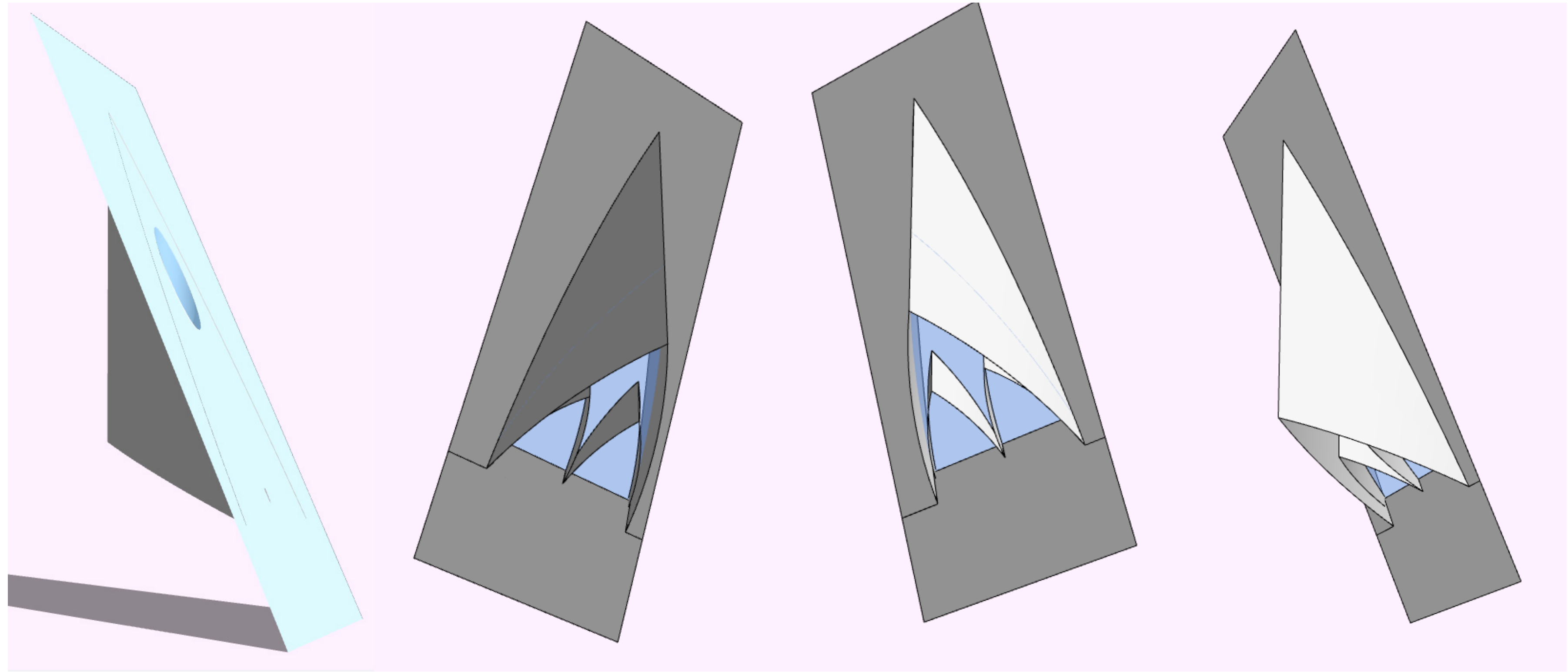
Exploration Drawings

First Iteration

After the initial sketches, I tried to build the fitting as closely as possible to the sketch. This was the result, modelled on Google Sketchup





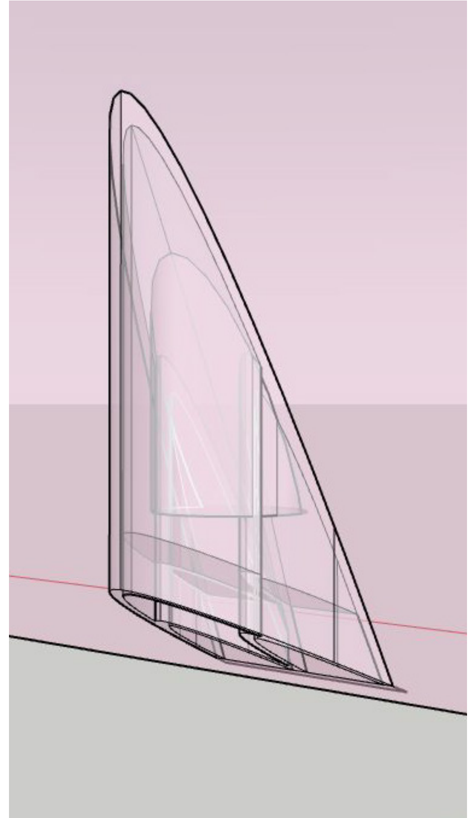


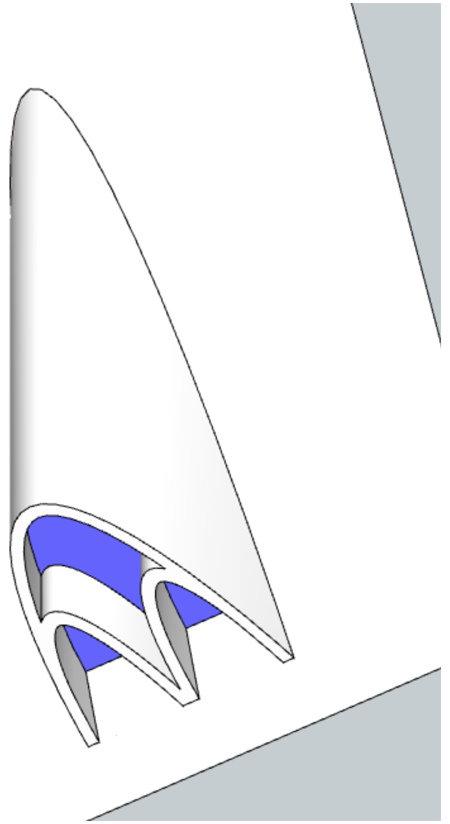
Idea 1

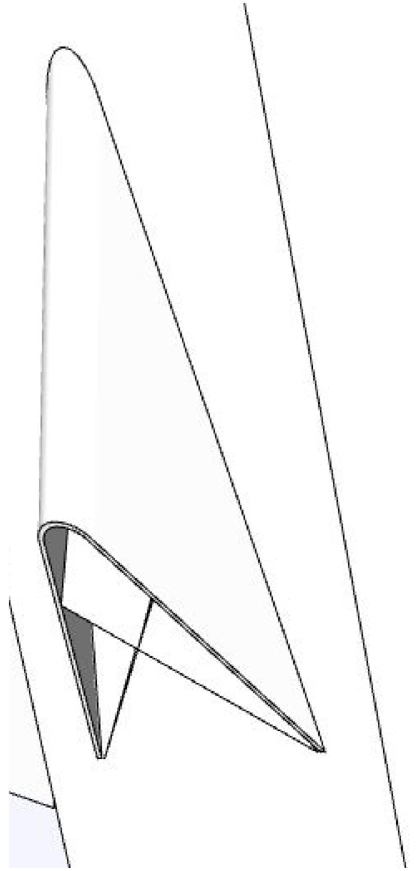
This encloses the light pipe, and allows the light to come from underneath, like a window emitting a glorious light

Design Alternatives

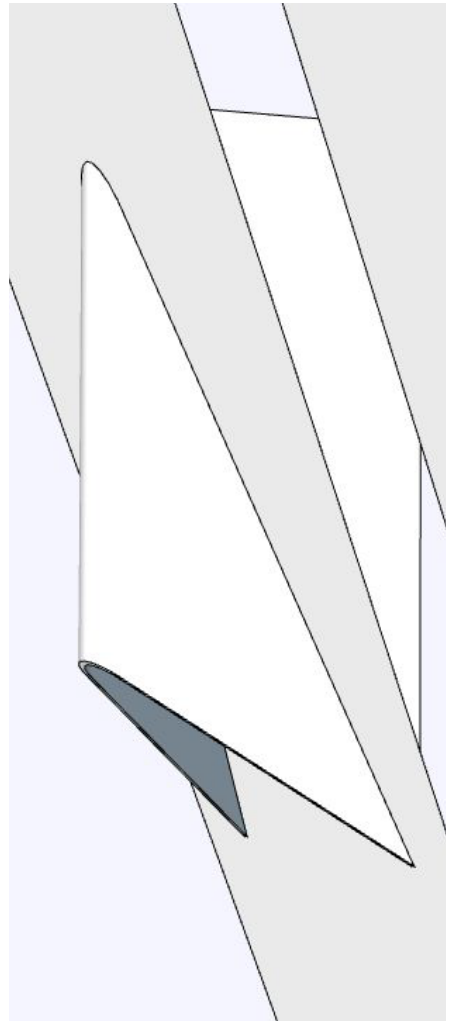
Though it did give off a “windowy” look, I thought the form could be much more refined or interesting here. I proposed a few different variations of the same base idea. These had slight adjustments that added a different personality to the fitting.

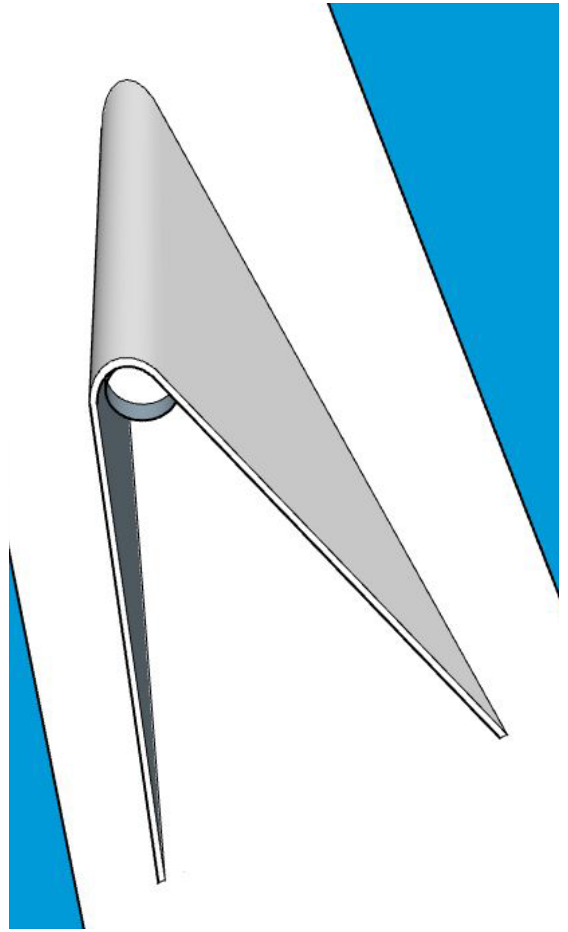






1. Minimal Design



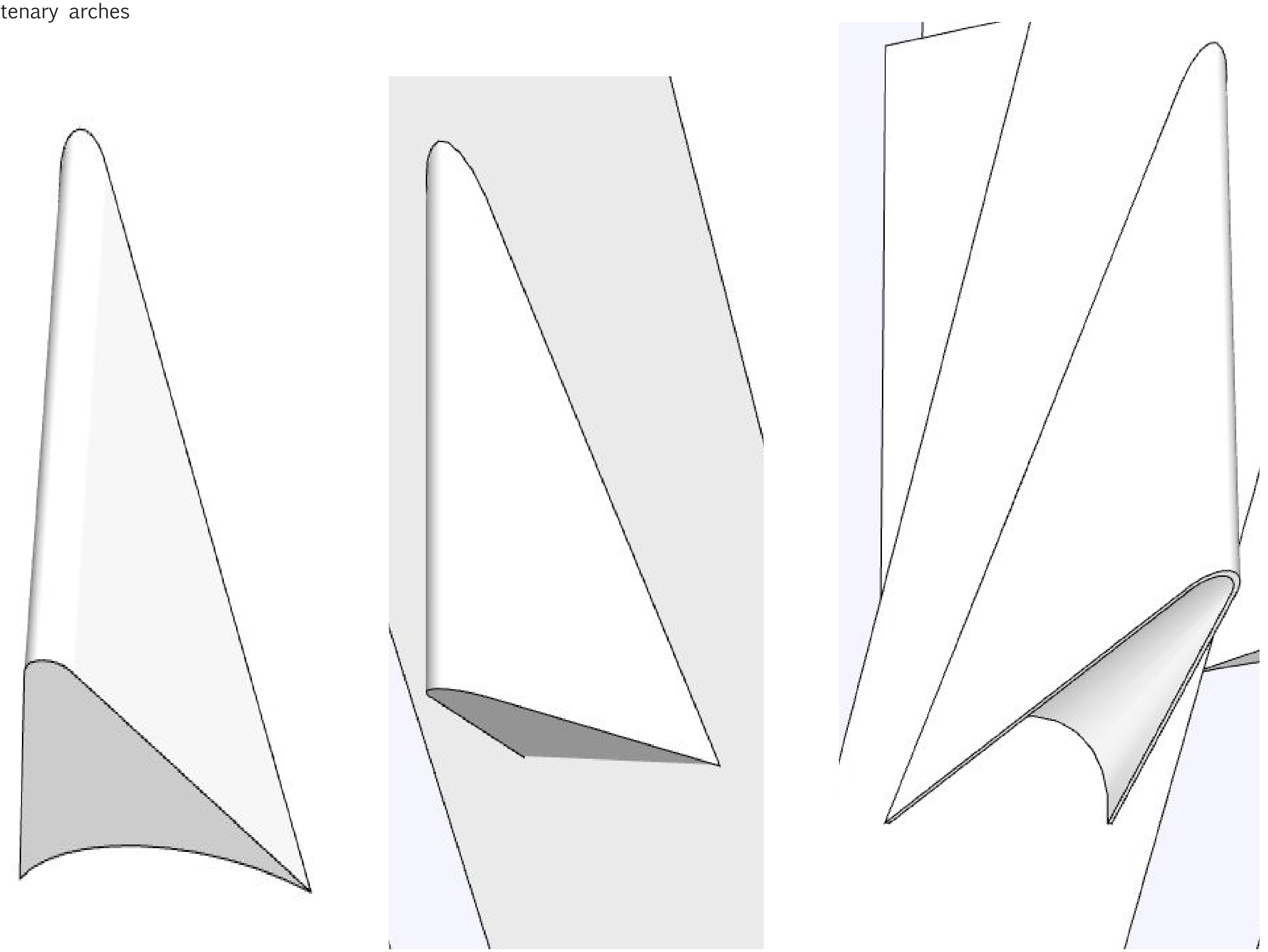


A “lapel” sheath

A fully minimalist take: The only drawback was that there needed to be a diffused material underneath to spread the incoming sunlight

2. Diffusive Cloth

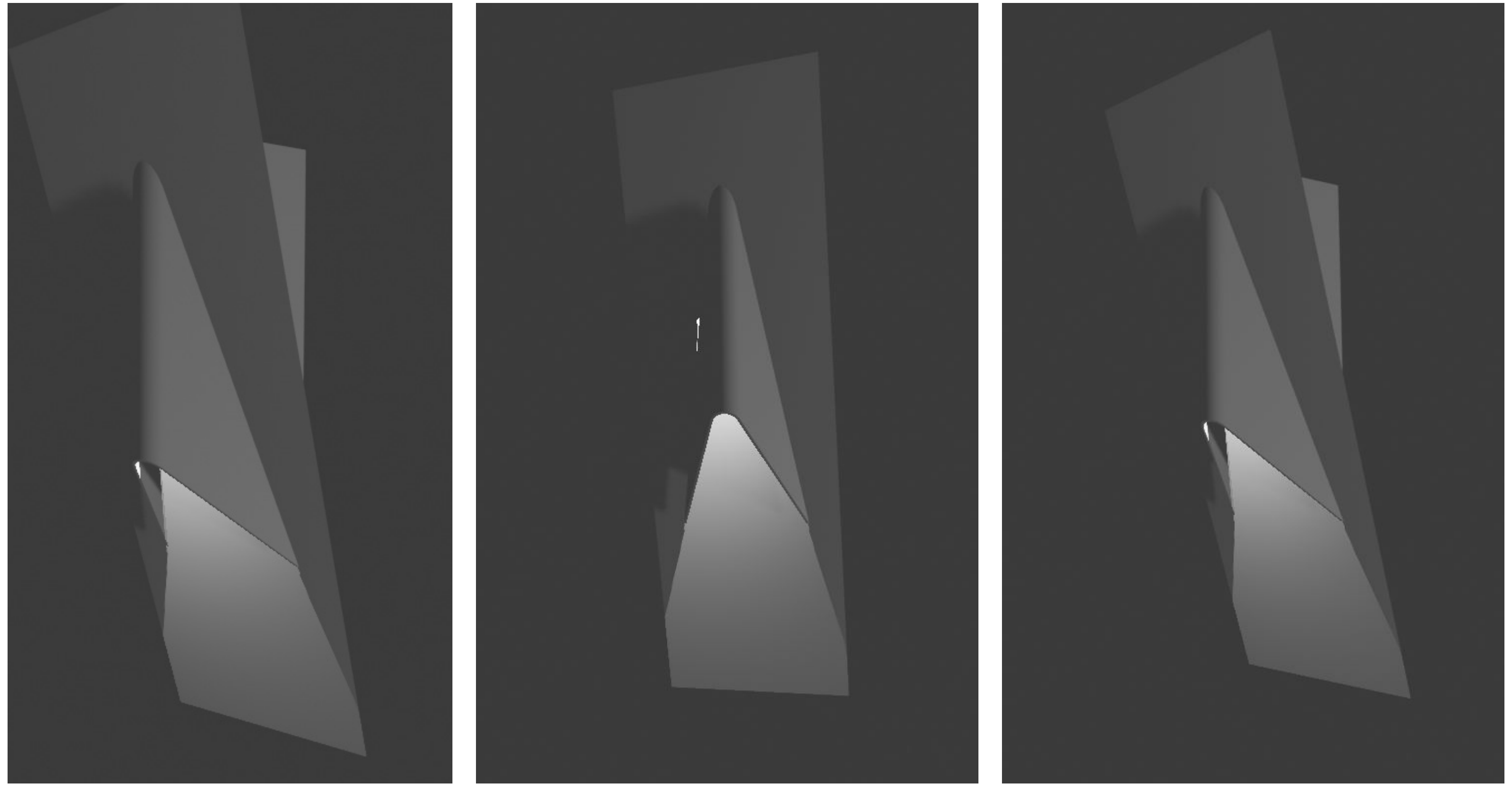
Minimal and elegant but it may not complement the catenary arches



3. Minimal Design 2

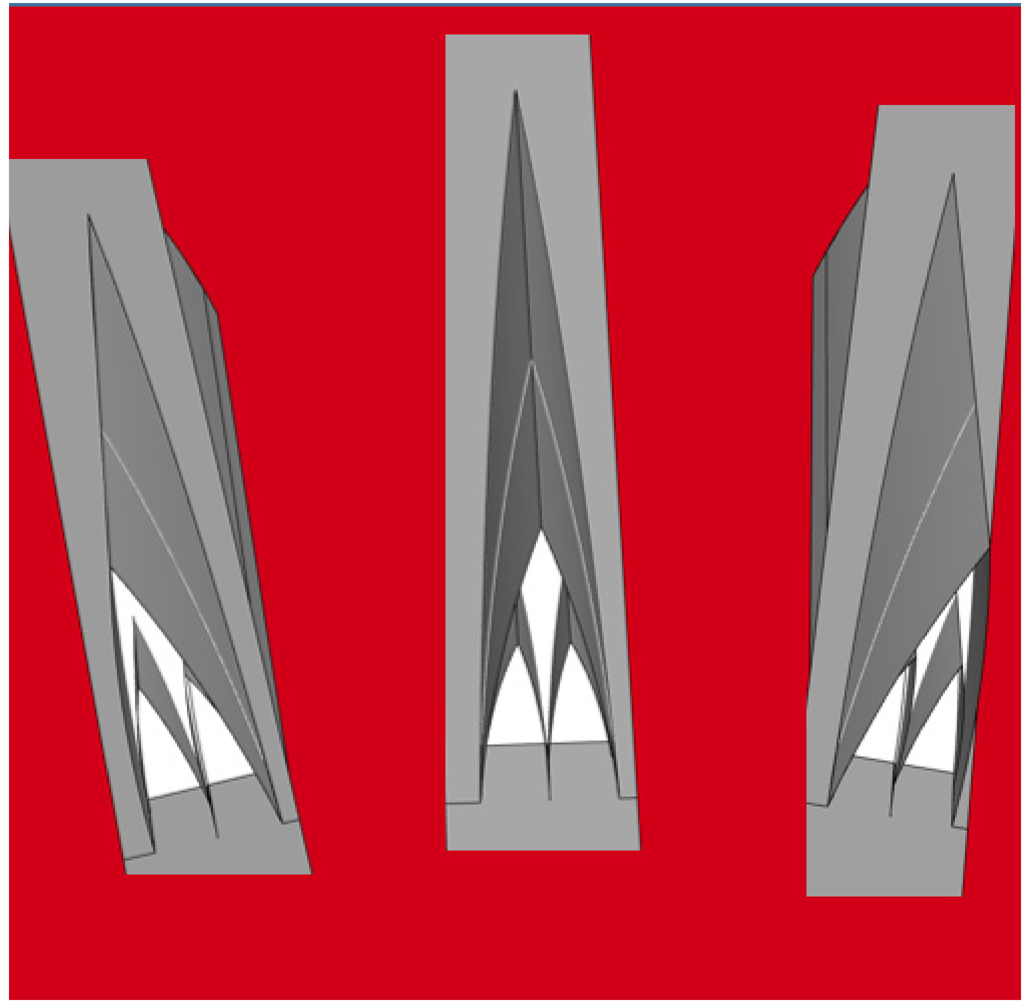
As someone who really likes minimalistic design, I came up with multiple variations of it.

As the pipe is hidden a bit underneath, only this wash of light hits the wall.



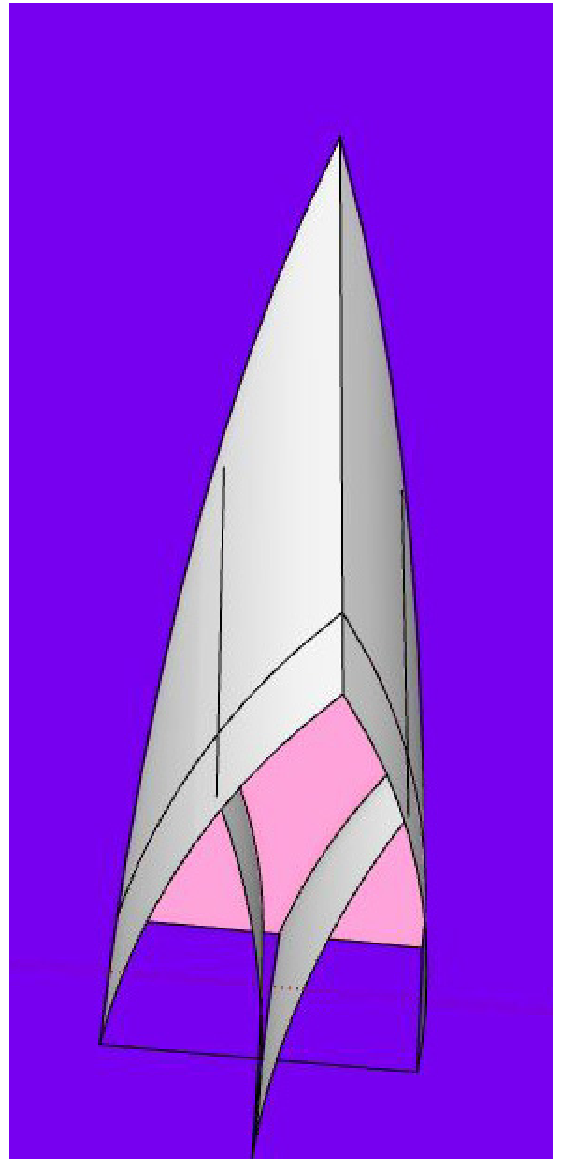
4. **Elongated Form Chandelier**

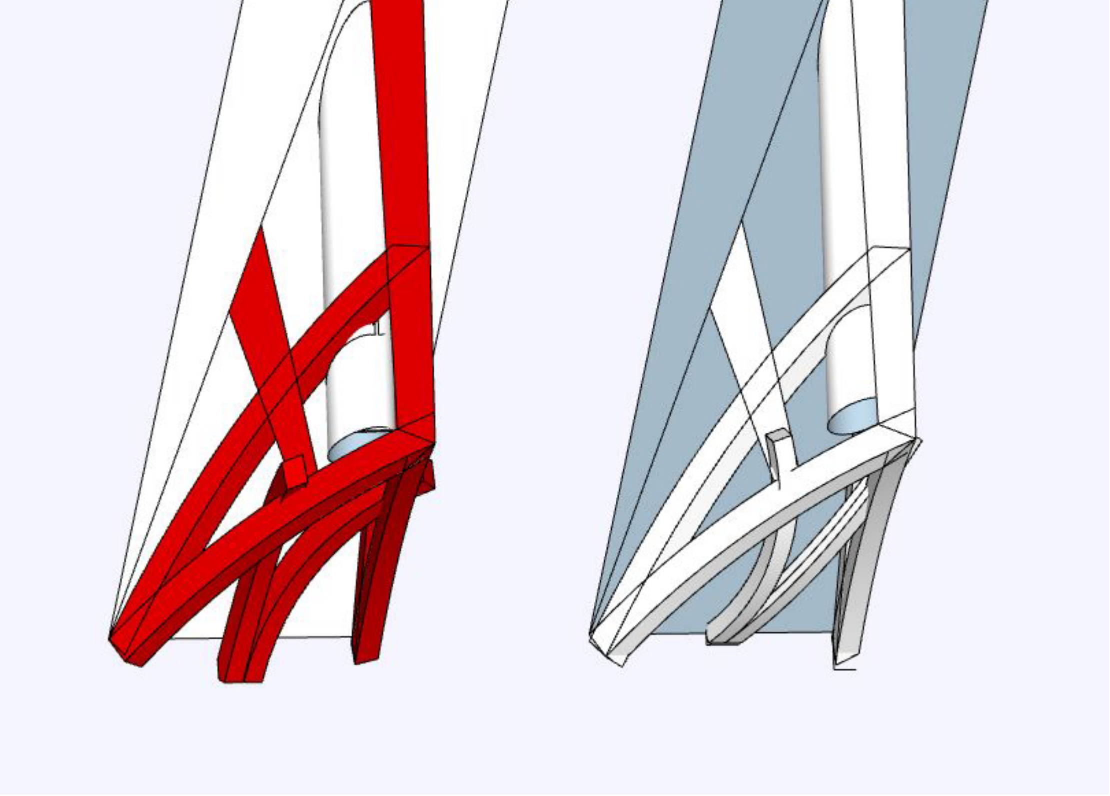
Dramatic, formally interesting.



4. **Long-Septum**

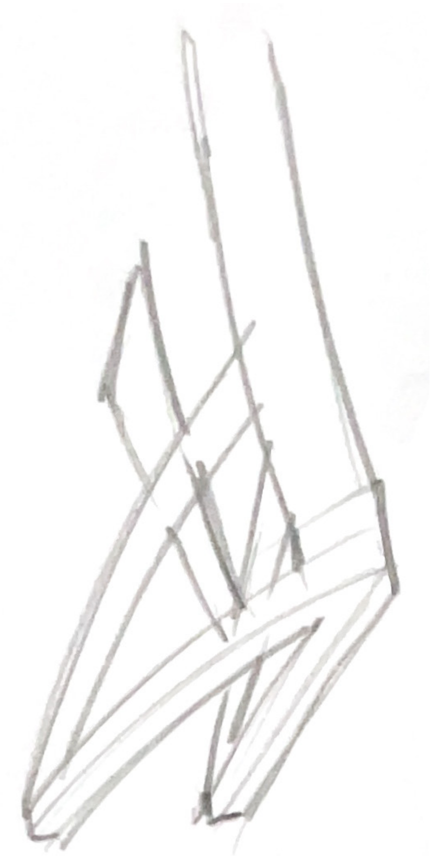
A variation of the same form. A 'septum' is the part under our nose. In this case it acts as a metaphor

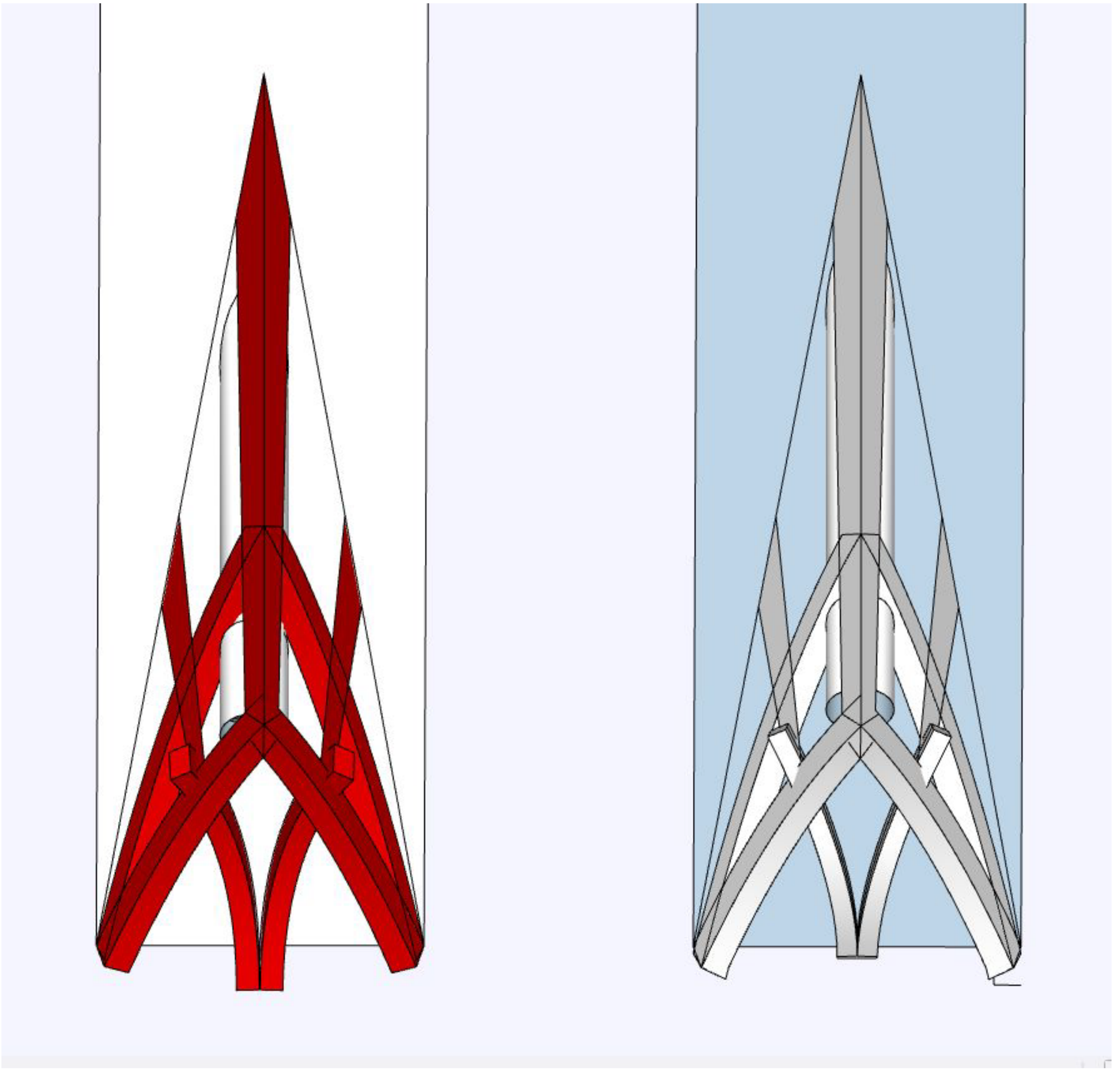


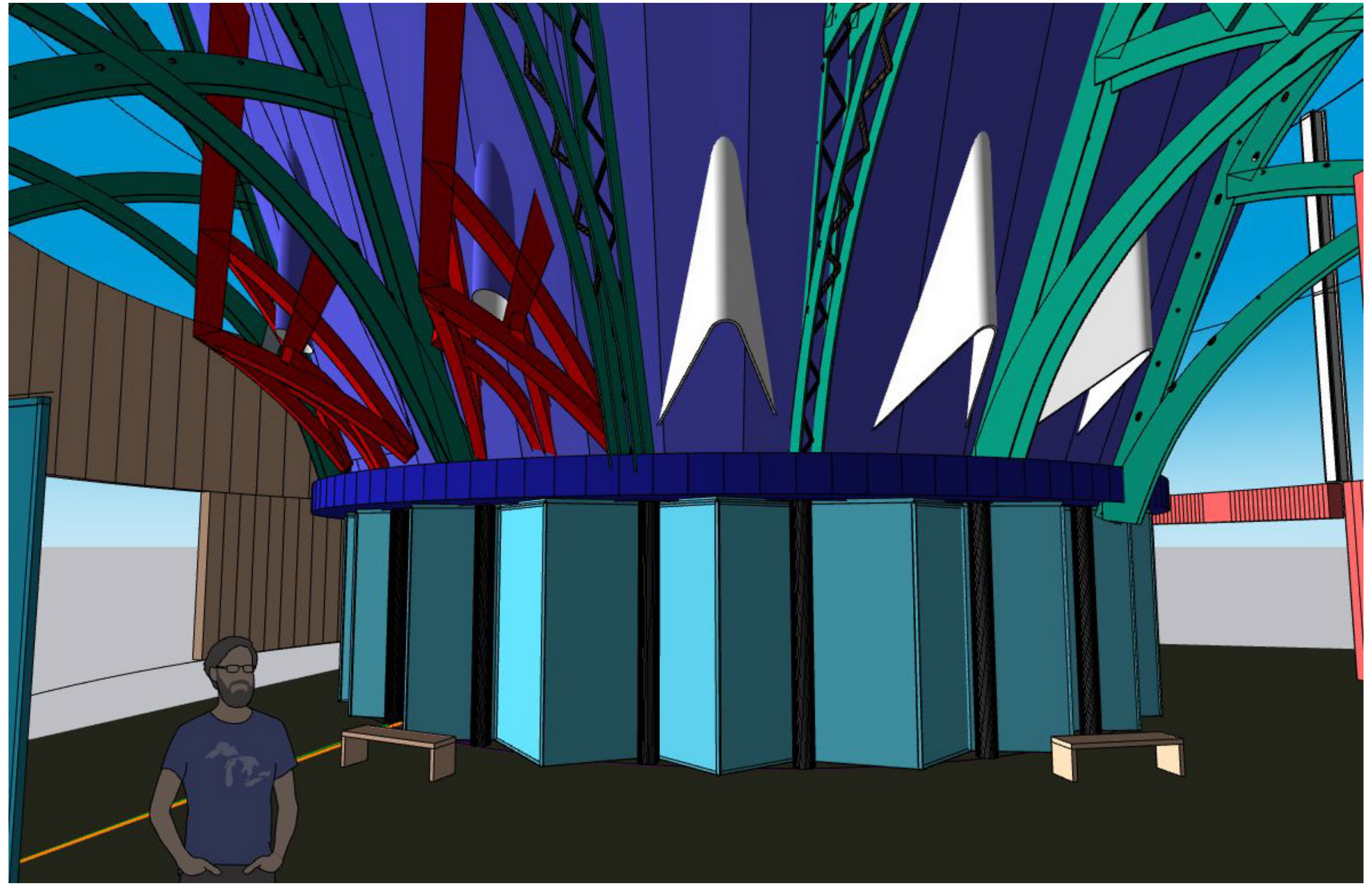


5. Truss inspired form

An exterior inspired entirely by the catenary arches. They are made to look structurally harmonic and similar to the beams. I thought these were quite interesting and aesthetically harmonious too. I wasn't however confident in their fabrication or their ability to really be the best possible solution for the design

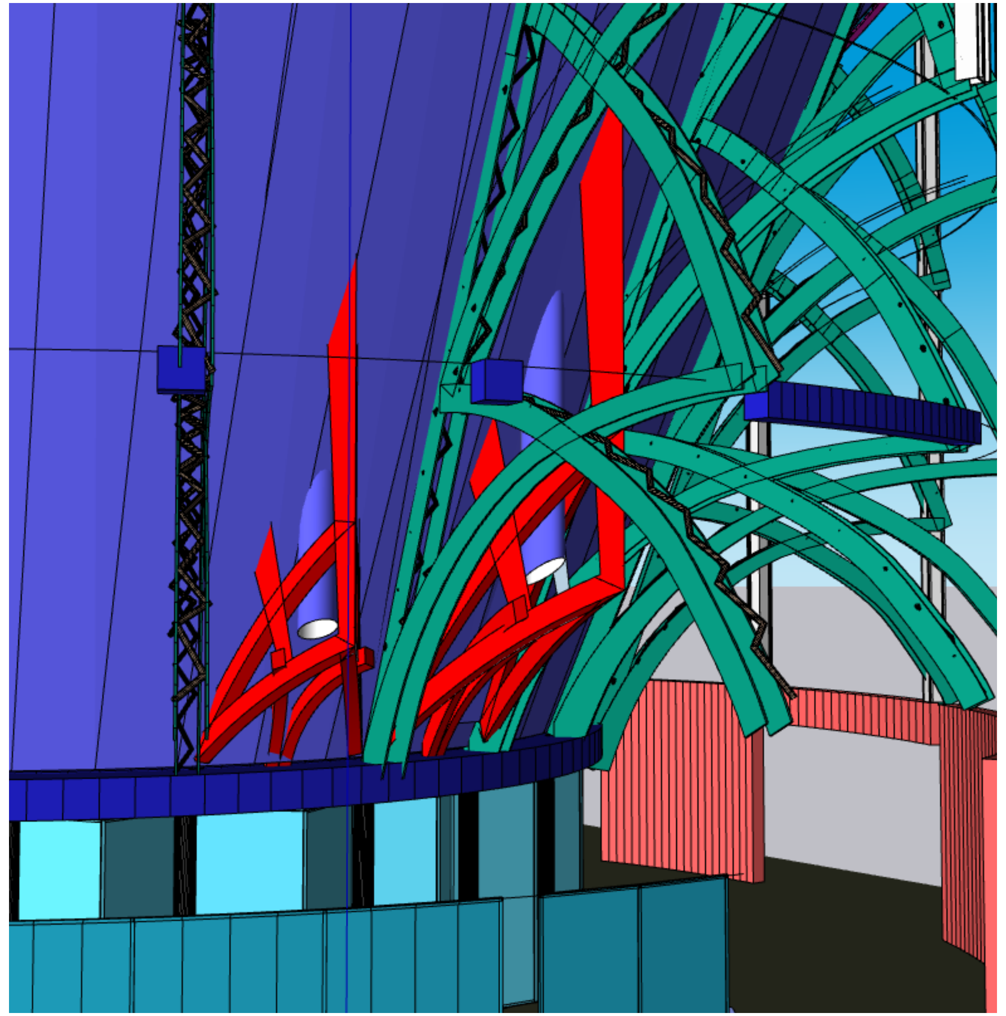


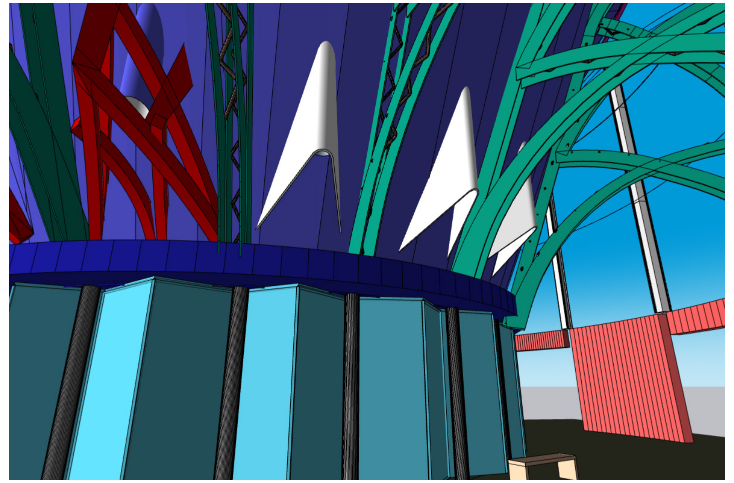


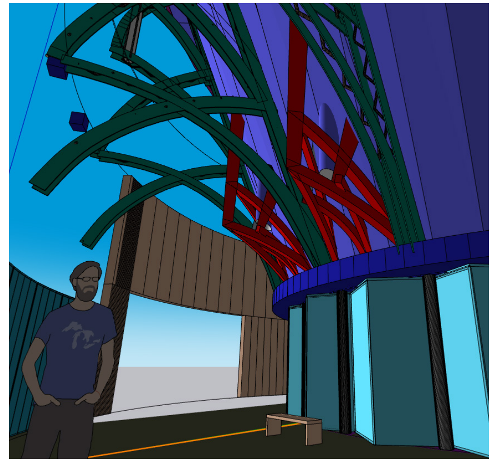


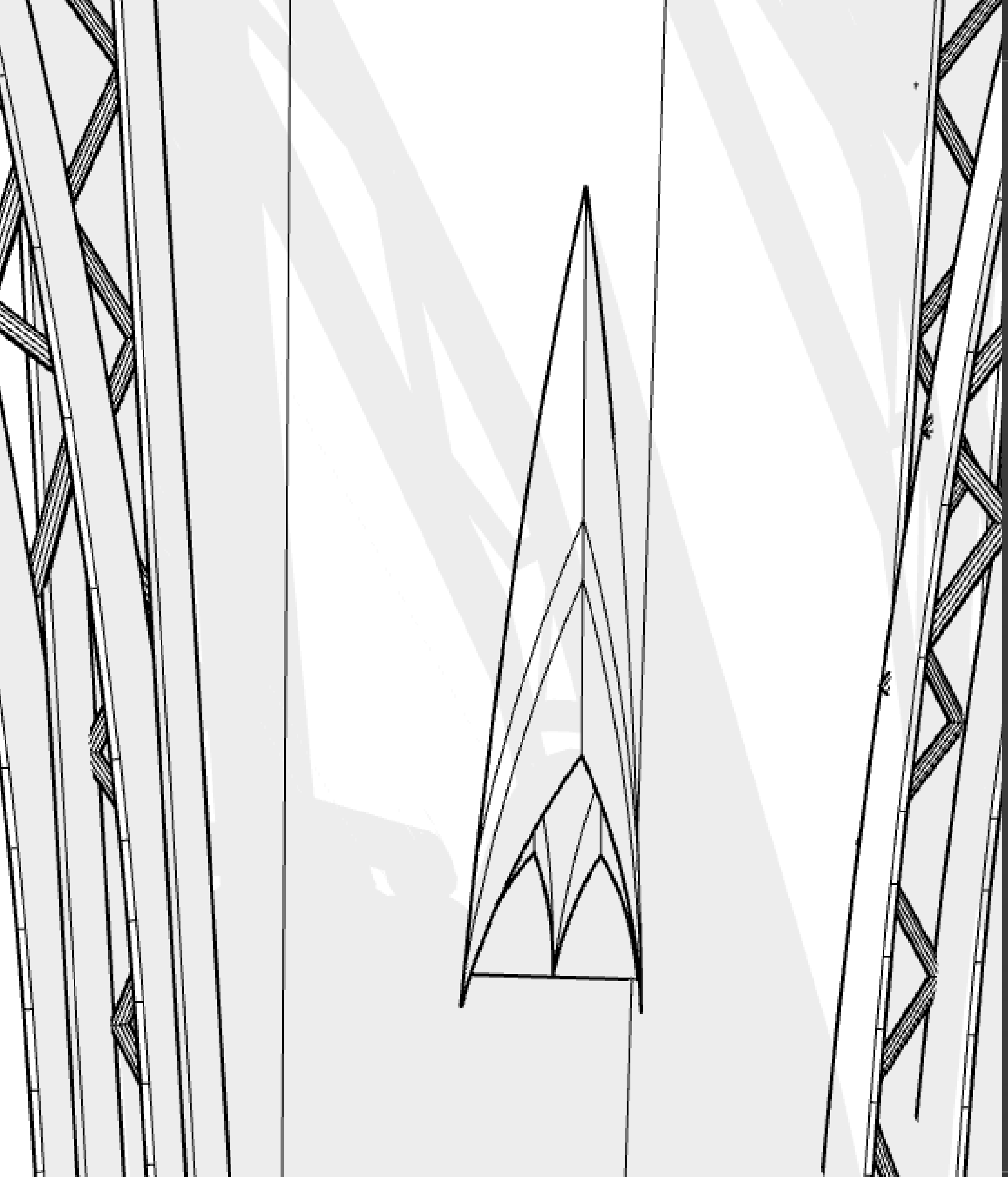
Representing the Appearance and Scale of the fittings

I tried to model their appearance in the atrium. This was the wrong scale, the fittings would have been much smaller. I was simply experimenting with the size and this scale was unfeasible and highly costly to build I was told





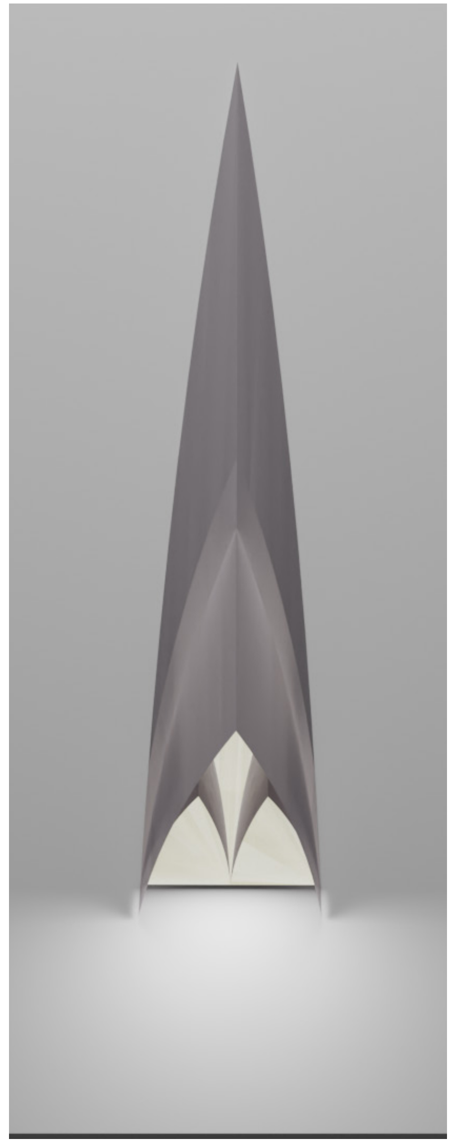


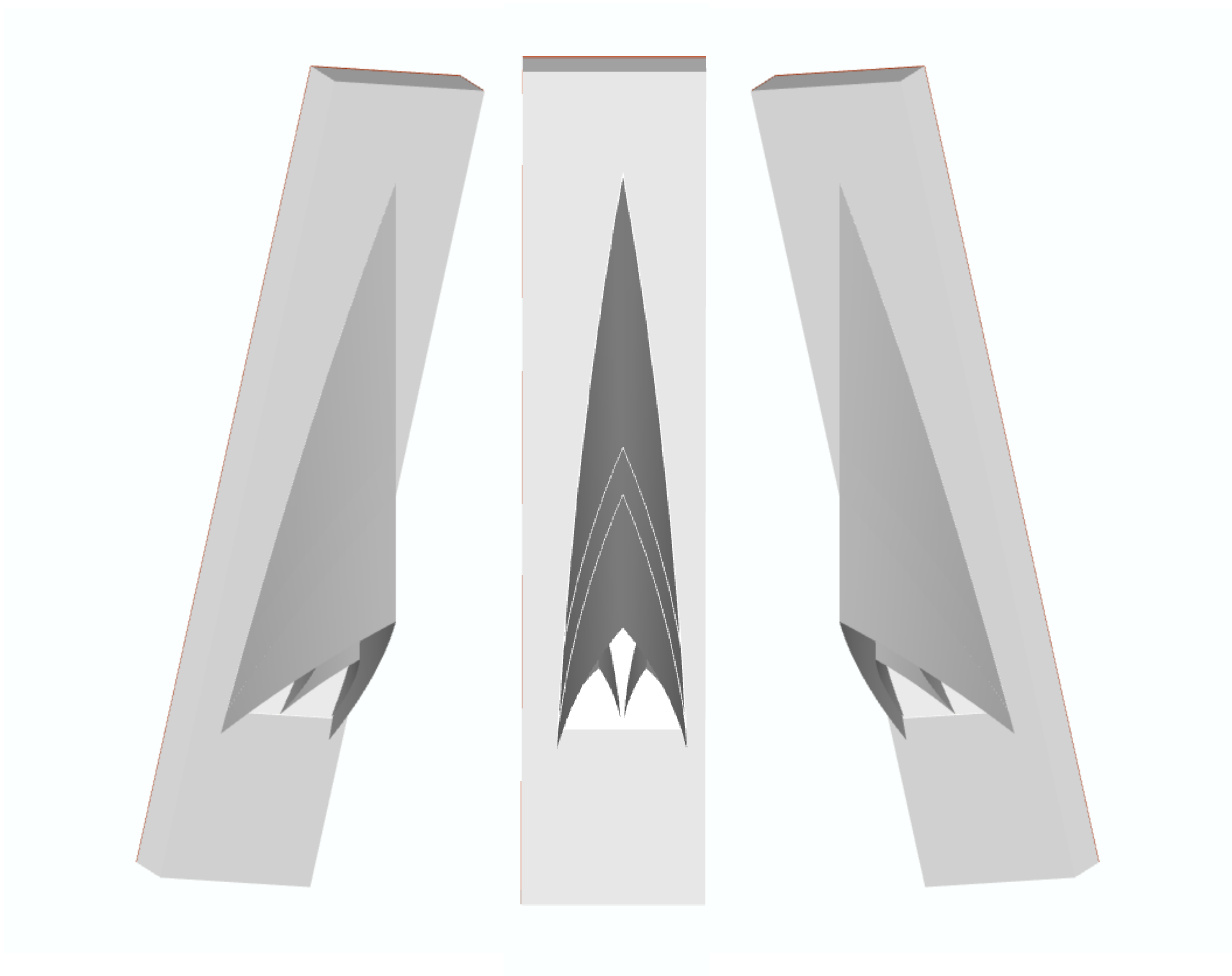


Final Design

I refined the form more to make it look better. The proportions had to look balanced so that it would look nice. In the end this is the form that emerged as a result:

The right is a photoshop visualisation of the fitting in the Atrium. It donned an aluminum finish which matched the off white color of the wall. Later I also created a more detailed render for the final effect.

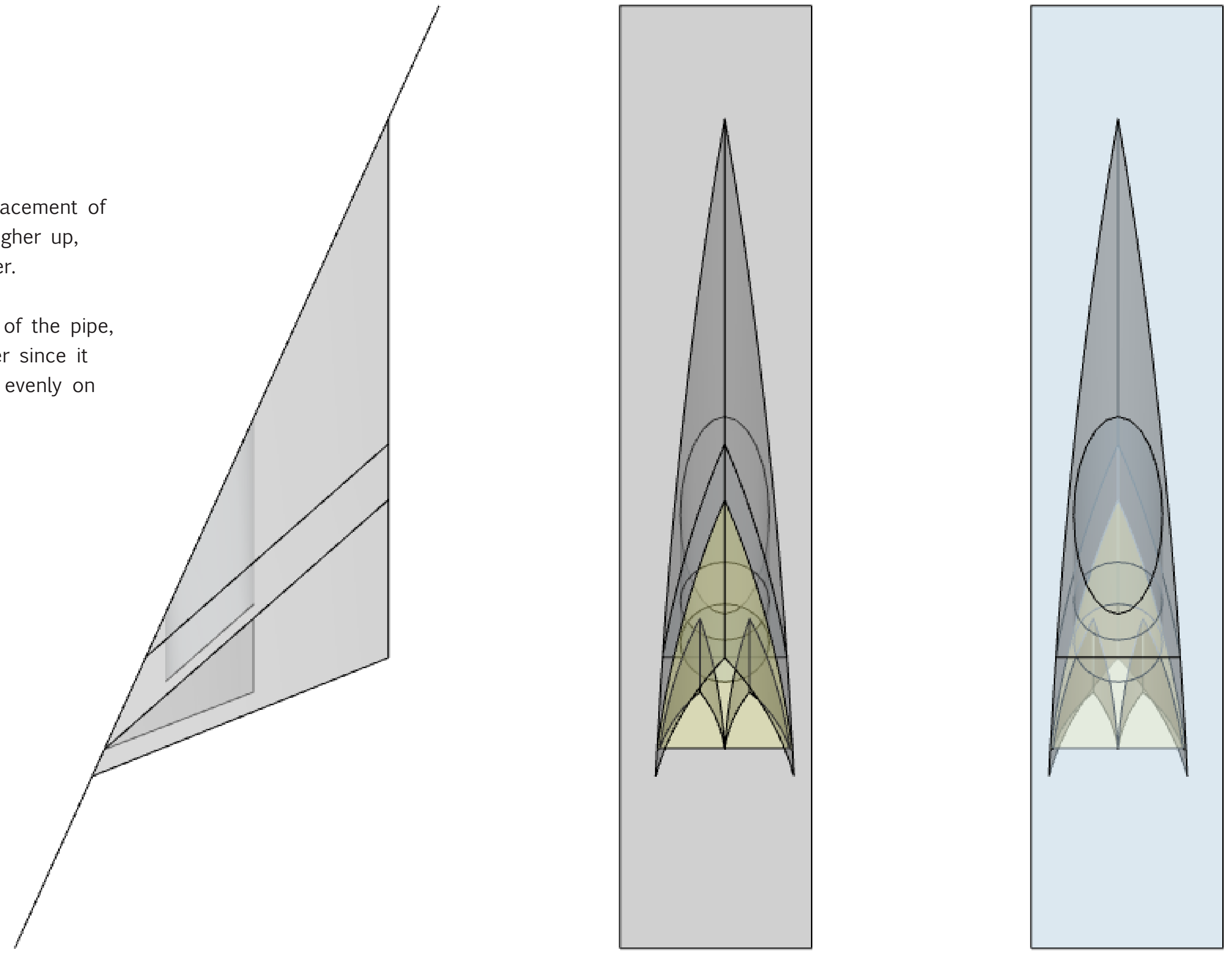




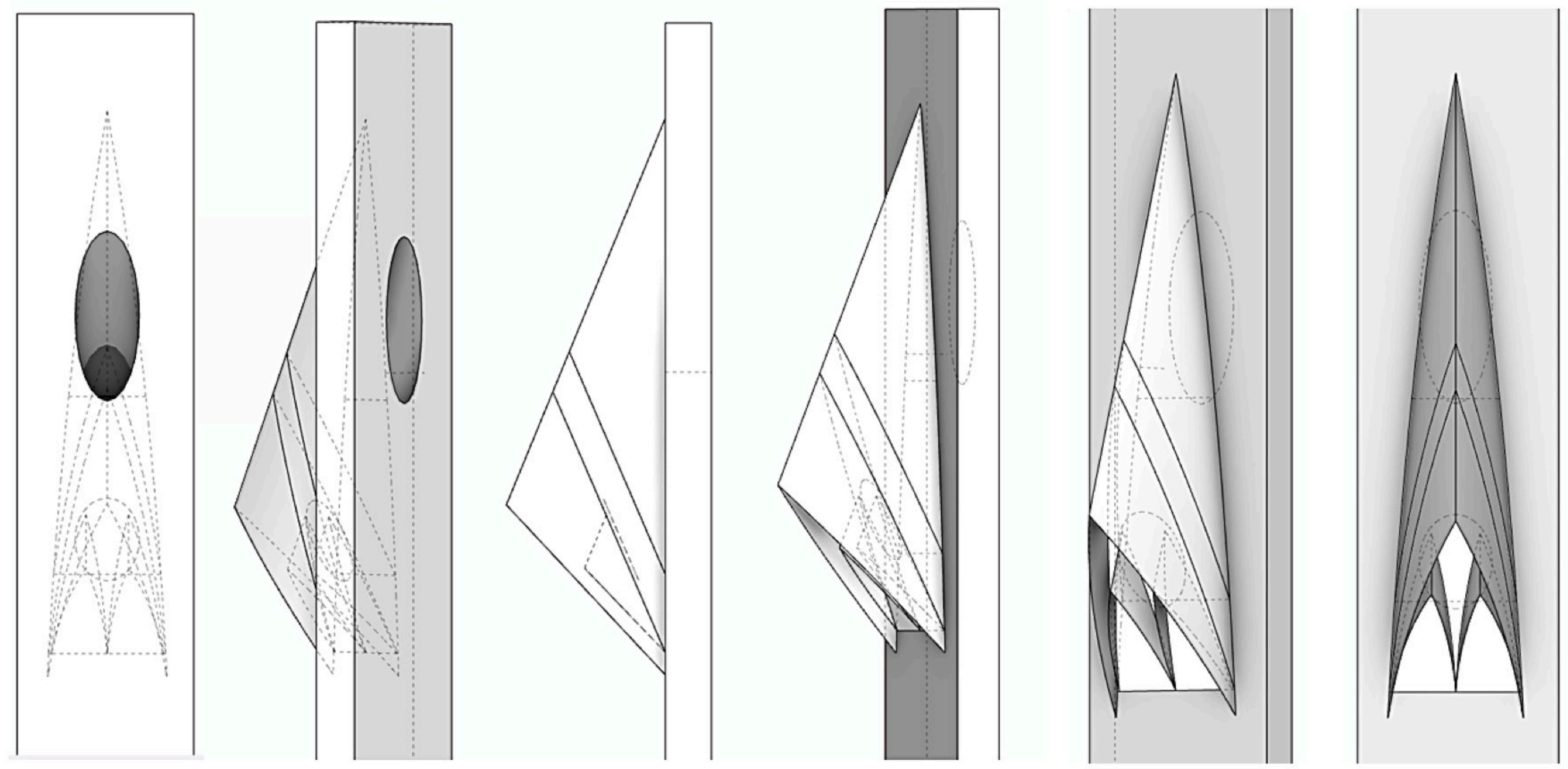
See-through view

There was a lot of deliberation on the placement of the pipe inside the fitting. Should it be higher up, aligned with the top, or should it be lower.

After considering the shape and the size of the pipe, a lower placement was found to be better since it allows us to make the light spread more evenly on all the “triangles”



Final Design Form

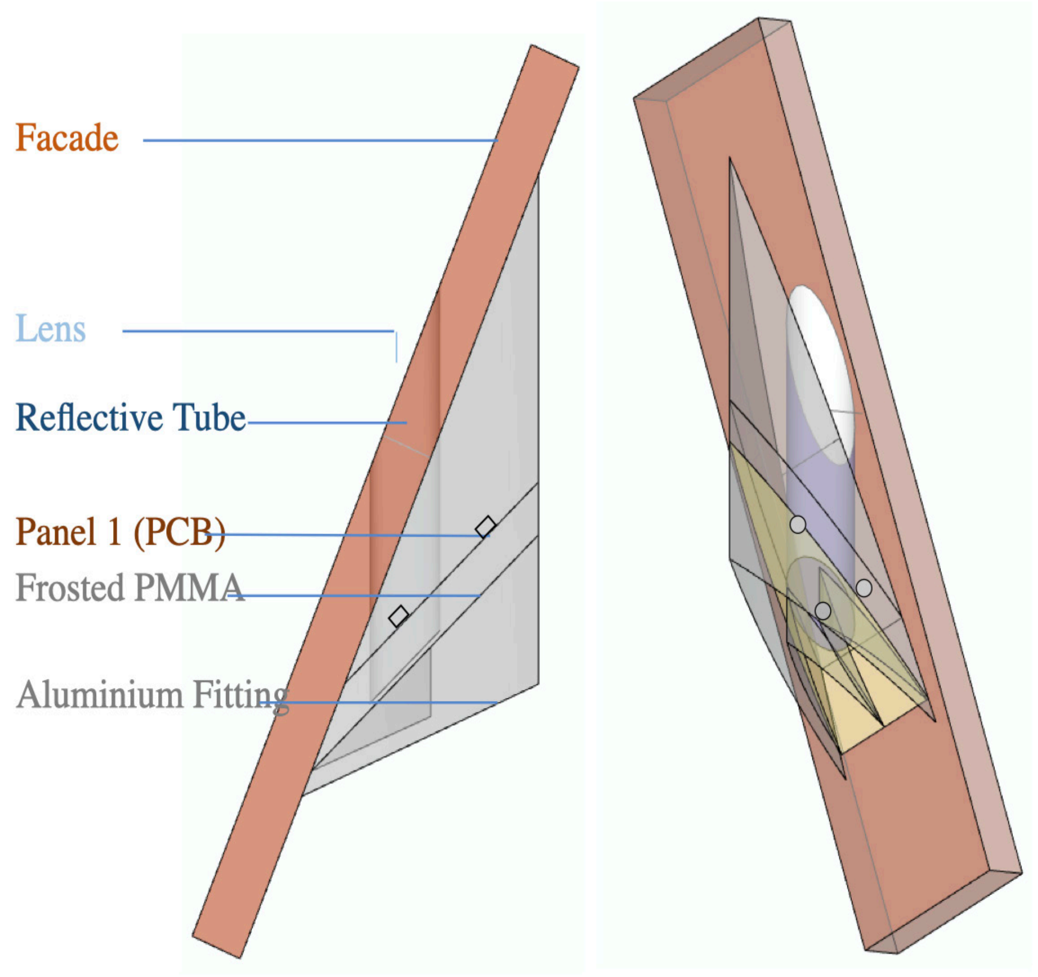


Components Involved in the Light

The interior of the light contains a frame for the light diffuser and an opening where the lens is placed.

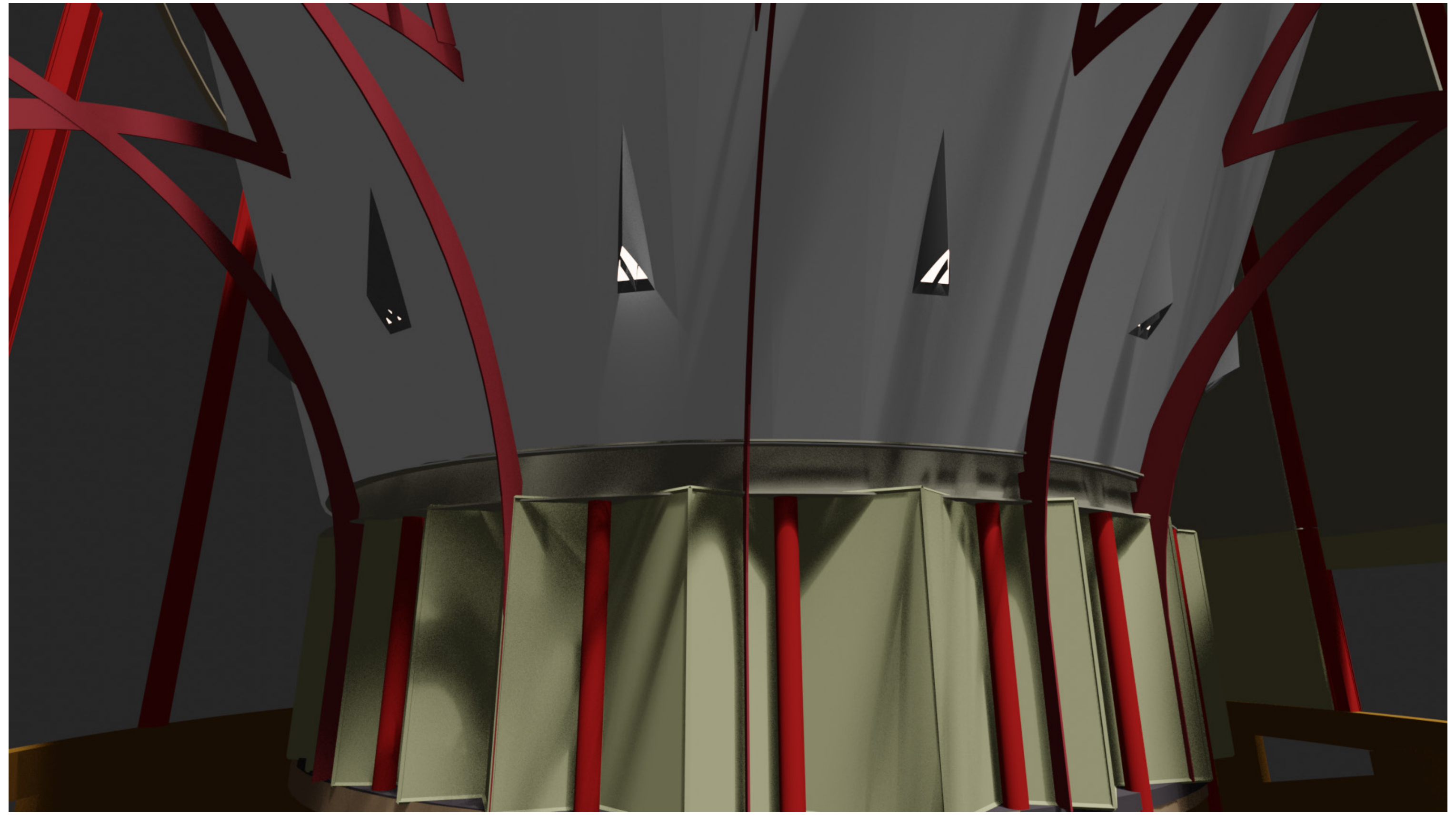
Lighting at night

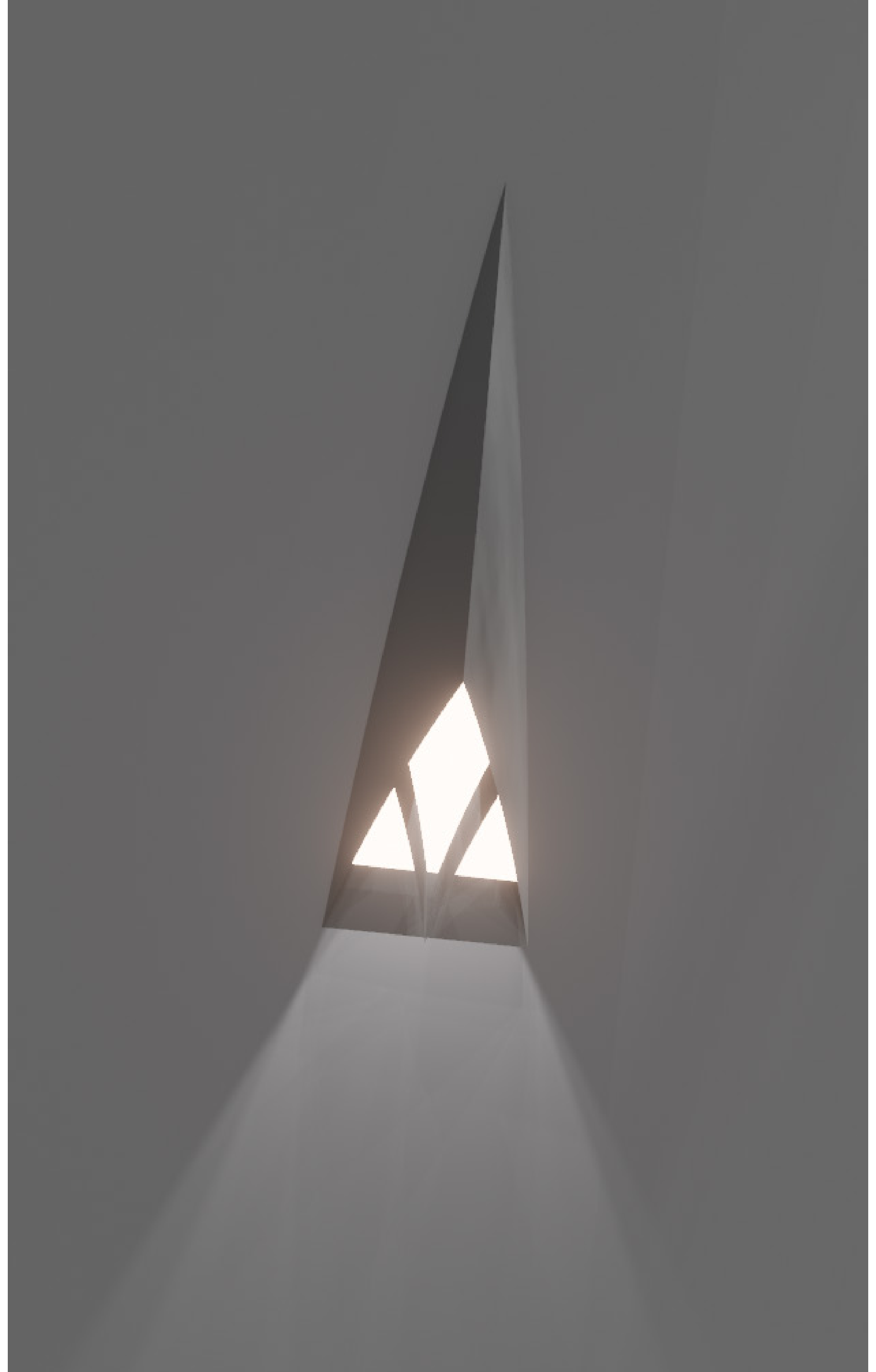
The PCB has 3 smaller LED's which would light it up at nighttime. This would create quite an impactful effect inside the atrium we reckoned. The LED placement is indicated by the 3 small circles.



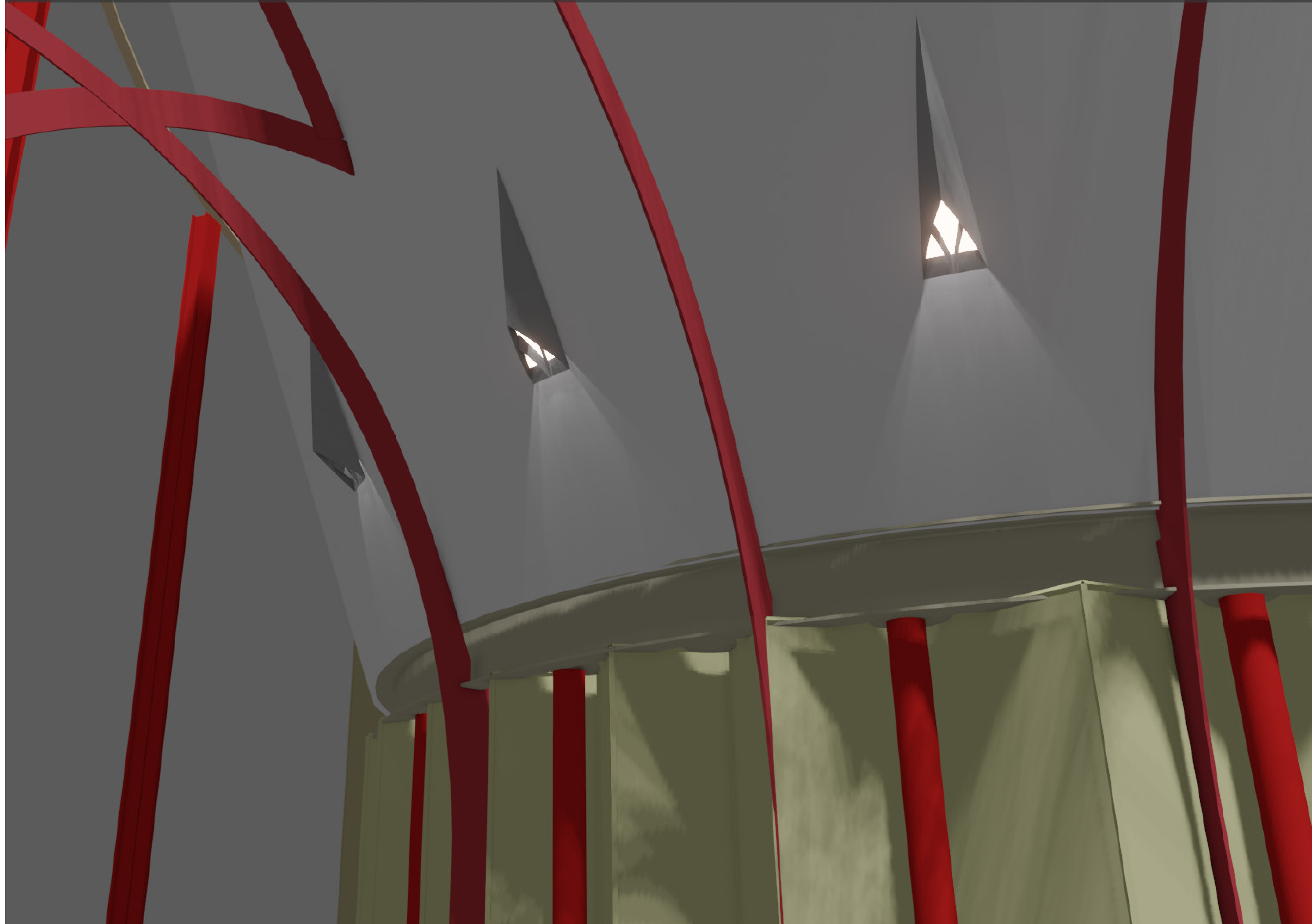
Presentation Renders

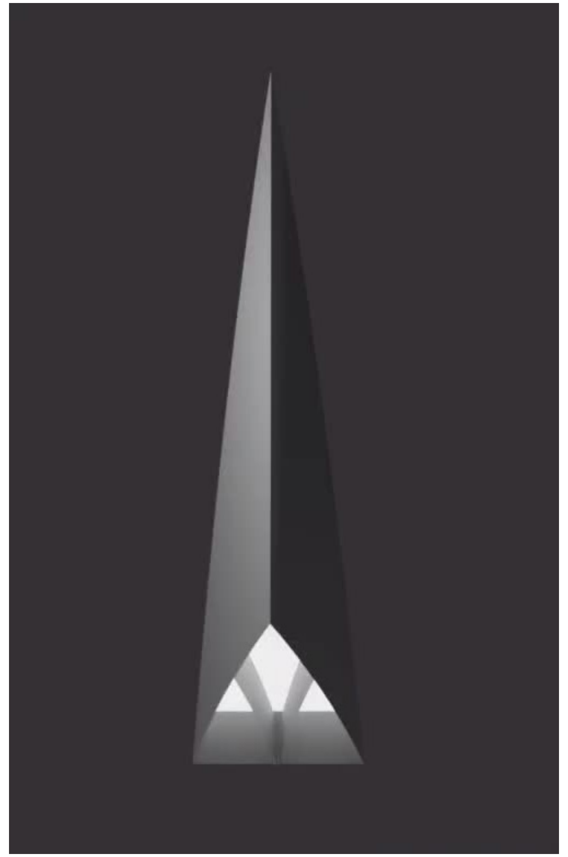
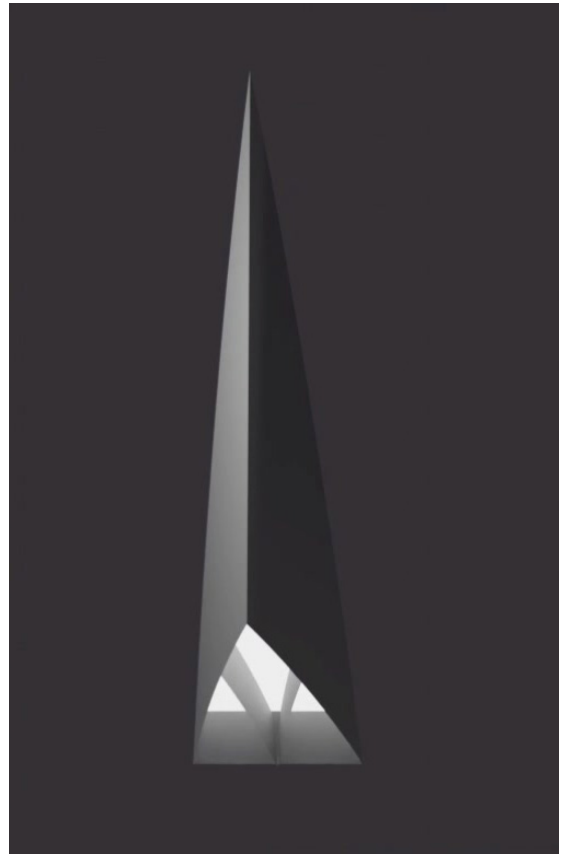
The following renders have been made in Blender for the goal of showing visualisations to the architect in a presentation. Following this, the idea was approved for construction and installation





Nostra Dormer is a solar-tube lighting fixture designed for the Ark Foundation Museum Vadodara. It is placed concentrically in a circular corridor such that it invites a slow transition of lighting throughout the day - reflecting the time outside. At night, the fixtures are powered by LED lights placed on the inside, creating an impactful lighting spectacle inside the atrium.



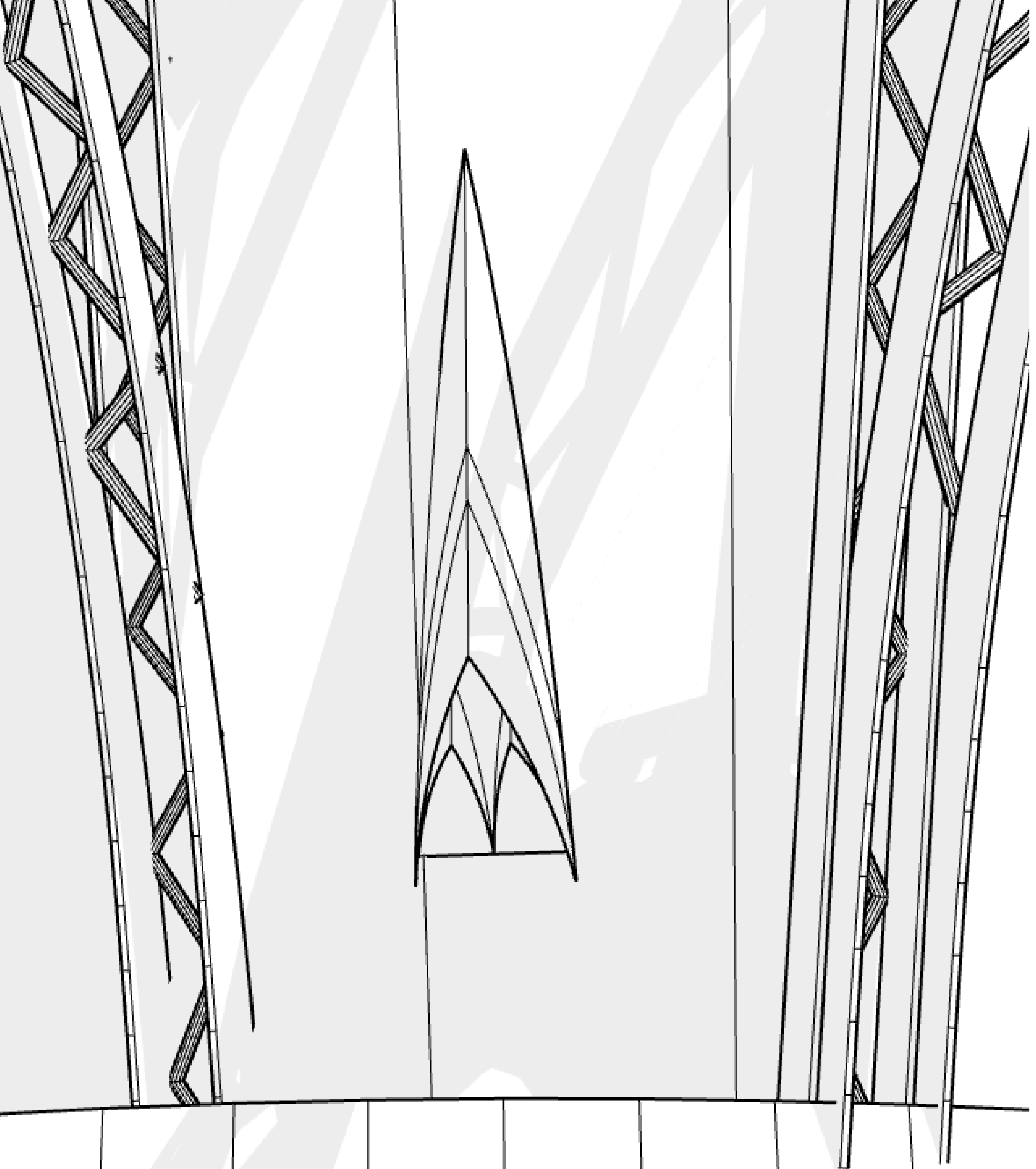




Final Design and Visualisation

These renders showcase the idea in a dark setting. Realistically. There will be ambient light and other light sources at daylight. At night, one can expect to see the light stand out a lot more, and provide a slight illumination to the red arches.



Revolving GIF



Final Presentation

The visualisations were compiled into a presentation and showcased to the architects

Construction Update

The latest update: The plan to implement NostraDormer was approved by the architects and well-recieved. The Ark project is currently still in Phase 1 of construction, the realisation of this project may occur much later, as lighting is one of the final steps in the construction process.