DAYLIGHT CONTROL USING BUILDING ENVELOPE FOR KUNSTHAUS ZURICH

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ABSTRACT

Generally and in most cases for museums, daylight is an integral part of interior illumination. This is due to daylight's full spectrum and its ability to showcase the arts' story, meaning and emotions. Moreover, depending on the museum's location, the availability of daylight varies greatly and this impacts the experience of seeing art. Various forms of art collection require different level and intensity of daylight for optimum viewing at any angle. For paintings especially, daylight plays a crucial part but also comes with some consequences. No paintings are immune to infra-red and ultra violet which are part of the daylight's spectrum. This research will focus on Kunsthaus Zurich in Switzerland as the author's case study. Originally designed with the same façade design for all elevations, this research will attempt to elaborate a new façade design with regards to its specific elevation and the building programs it will ultimately enclose. Different building elevations' orientation requires different treatment and the outcome of this research will be comprehensive applications in each building elevation in responds to the daylight movement throughout the year.

Keywords: *daylight, museum, building envelope, computer simulation*

A. INTRODUCTION

Daylight

Firstly, we have to realize is the light from the sun varies depending upon where it strikes on the earth based on its altitude and longitude and also when it strikes based on earth's rotation throughout the year. Moreover, the earth does not rotate around the sun in a circle but rather in an elliptical shape as shown in Fig. 1 below

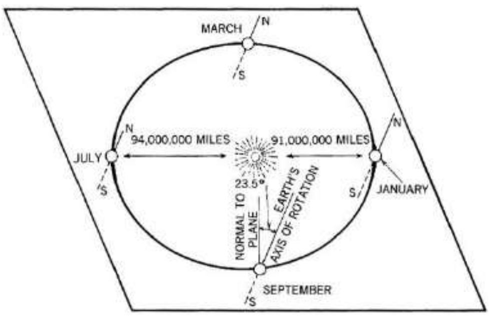


Fig. 1 Graphic representation of earth's rotation around the sun *(*Lechner, 2001*)*

Fig. 1 also shows that during the month of July, the earth is further away from the sun than in the month of January. The distance in miles can be converted to kilometers by multiplication factor of 1.6 (1 mile = 1 kilometer).

Secondly, any daylight designer has to be aware that the earth's tilt on its own axis. The angle of tilt is 23.5 degrees on the north-south axis (Fig. 2 below)

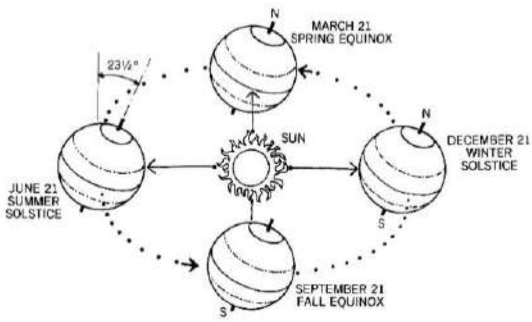


Fig. 2 Tilt angle of the earth's north-south axis *(*Lechner, 2001*)*

Relative position of the earth and its tilt to the sun can be divided into two states called **Solstice** and **Equinox**.
Solstice is a condition where the sun's rays will be *perpendicular* to either the Tropic of Cancer or the Tropic of Capricorn, which is at the latitude of 23.5 degrees north or south. Solstice can also be divided into two states, Winter and Summer. Winter solstice, which occurs on December 21, has the longest night for the northern hemisphere and the longest day for the southern hemisphere.

Consequently, summer solstice, which occurs on June 21, has the longest day for northern hemisphere and the longest night for southern hemisphere.

Although modern sciences have shown that the earth rotates around the sun, which Copernicus and Galileo proposed under threats of torture and death, the author will follow a simpler and easier general way of thinking that the sun rotates around the earth. This has led to the invention of Sky Dome. A sky dome is a large clear hemisphere which is placed over the building site in question, according to Lechner[2].

A sky dome shows the hour of the sun movement throughout the year but scientists have determined the three dominant lines, the summer solstice, the winter solstice and the equinox line to be placed within.

Fig. 3 and Fig 4 below show the sky dome in Iso-view and elevation, respectively.

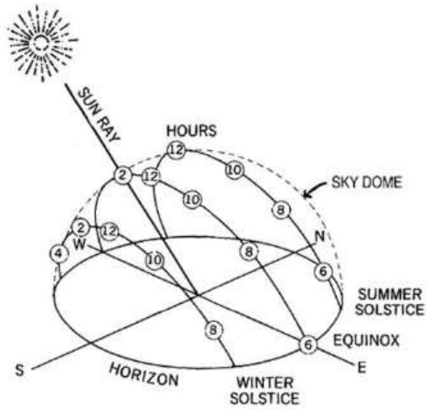


Fig. 3 Sky dome with the division lines (Lechner, 2001*)*

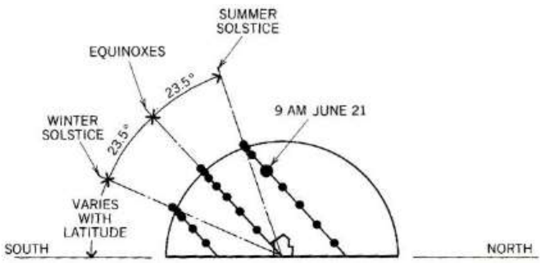


Fig. 4 Elevation of Sky Dome *(Lechner, 2001)*

Fig. 4 determines that on the longest day of the year in northern hemisphere on June 21, the sun will never be above a site perpendicularly if a building site is beyond 23.5 degrees in altitude.

It is also apparent that sun's relative height and position varies greatly throughout the day and the year. In order to understand the concept better, a different concept called **azimuth** and **altitude** are devised.

Altitude, in its basic terms, is to show how high the sun is in the sky at a particular hour. In contrast, azimuth is the angle of sun's position relative to the north-south axis. The concept is shown in Fig. 5.

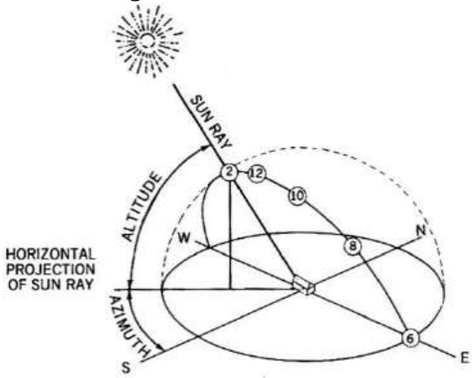


Fig. 5 How azimuth and altitude are determined *(Lechner, 2001)*

Combining all of the above information, a system called **sun-path diagram** is produced. A sun-path diagram is a combination of the sky dome with the solstice and equinox lines, added with the azimuth and altitude, which then is projected unto a horizontal plane (Fig.6 in the next page)

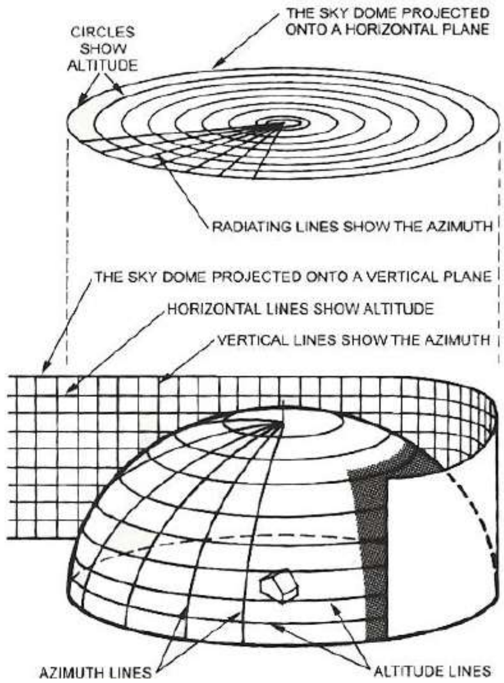


Fig. 6 Development of horizontal sun-path diagram *(Lechner, 2001)*

A typical sun-path diagram for 36N latitude is shown in Fig. 7 below.

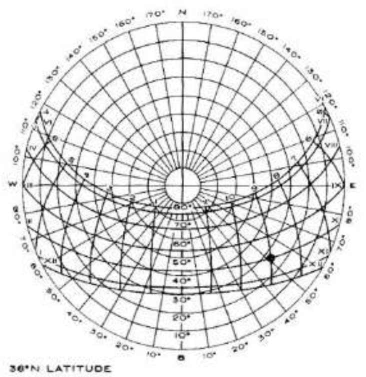


Fig. 7 Typical horizontal sun-path diagram *(Lechner, 2001)*

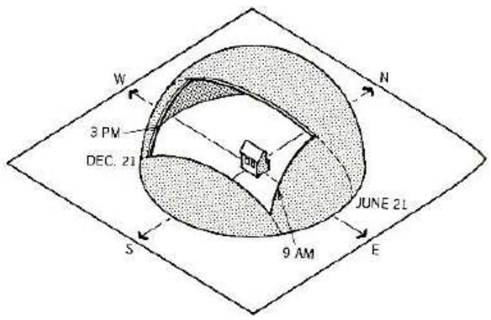


Fig. 8 An example of solar window between 9 AM until 3 PM throughout the year *(Lechner, 2001)*

From the diagram, an architect or a lighting designer can determine how much sun is best 'used' during the day since the sun's intensity is lower in the afternoon and in the morning. according to Lechner this method is called **'solar window'**.

Since we, as architects and/or lighting designers, usually deal with the built environment, careful consideration of the intensity of the sun and its radiation has to be taken into account. Therefore it is advised to observe that light we receive on a particular surface is not always from a direct sunlight. Lechner also supports this theory in his book by providing a simple image shown in Fig. 9 below. In addition to that, he clearly shows that two additional conditions have to be calculated: in a clear sky and in an overcast sky.

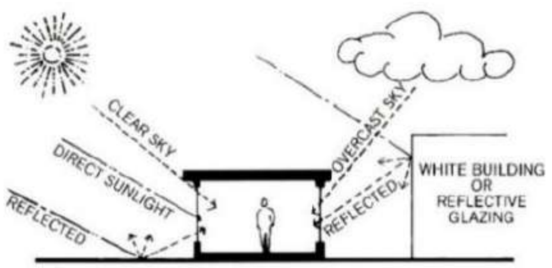


Fig. 9 How daylight can affect an interior space *(Lechner, 2001)*

The Art of Seeing

Is it true the opinion of daylight that what we see is what we get?
The answer is shown in Fig.10, where the daylight spectrum carries different wavelengths and the visible spectrum is only a portion of it.

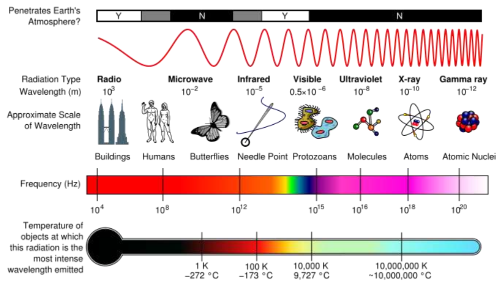


Fig. 8 An overlay and scale of solar radiation to its frequency and wavelength *(Wikipedia.org)*

To understand the visual perception, it is more important the process involved in the interpretation of this information[6] rather than the visual transportation.

Hoffman asks a question in his book whether our ability to perceive the world around us is innate or through a learning process. Although he states that there is no clear answer to this question, the author believes it is a combination of both.

Taylor also notes that to free the eye from traditional forma preconceptions is through a notable step. However once the relationship between eye and mind is considered not fixed but subject to investigation, there is no reason to suppose that the more adventurous artists will be always change the perception where the mind is always challenged. In placing the content of an art to give pleasures of sight provided by nature, they wanted an art that could stimulate the mind to the point of creativity. Taylor argues that color plays a decisive role in the production and experience of art. He states the difficulty of art description by color and he adopts the terms *hue*, *saturation*, and *value* to clarify the description.

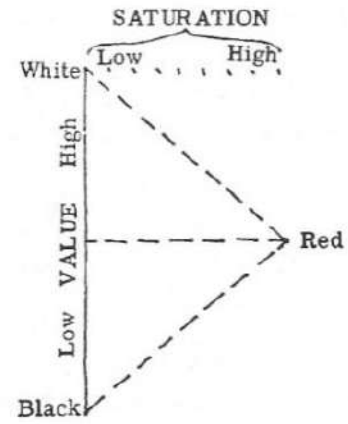


Fig. 11 Saturation and Value diagram (Taylor, 1981)

In the development of modern art in the twentieth century, Taylor in dissecting the works of Picasso, Klee, Mondrian, Kandinsky and Max Bill, concludes three quite different ways by which content is generated in art. He states that we have concerned with creating a live sense of order through form that makes the work of art a point of concentration to the exclusion of all extraneous thoughts or feelings; we have noted how the energy of forms and colors, without reference to external things, can excite the mind to plunge it into a world of heightened emotional and spiritual experience; and we have seen how all of these properties can play in counterpoint to the appearance and memory of known objects and beings of the physical world. All of these actually to be a part of our modern perception in art and to change the way we look at and discuss some works from the past.

Daylight and Museum Architecture

Novkovic's research found the first museum as a building typology dated back to the era of Renaissance. Donatello Bramante, the most important architect of that time, designed the courtyard of statues in the belvedere of the Vatican in 1508. This was the first space created to display works of art. The museum and the statues still exist and more importantly, all the statues are exposed to daylight. This gives us a clue that, originally, works of arts were designed and supposed to be seen under natural sky.

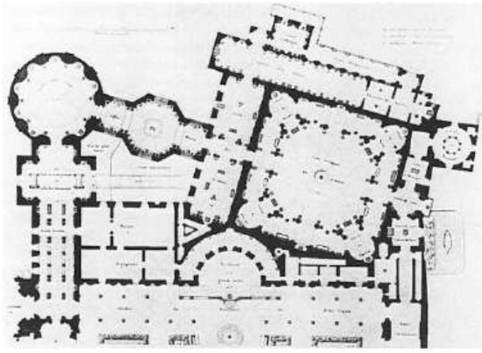


Fig. 12 Plan of courtyard of statues, Vatican *(*Novkovic, 2005*)*

A courtyard in Fig. 12 shows completely open to natural elements and daylight. Museum lighting, on the other hand, is partly shifted to an enclosed room with windows at one side, and the other side for artwork display. This is successful in its implementation during the middle of 16th century. Novkovic wrote that this design is the birth of gallery development. The earliest examples are Galleria della Mostra in Pallazo Ducale as shown in the figure 13 below.

Fig. 13 Galleria della Mostra *(* Novkovic, 2005*)*

Another notable development that the author needs to share is the central hall with skylight. The most impressive example of this is the Pantheon in Rome, built in 17th Century. The purpose of this central hall is similar to the Courtyard of statues in Vatican. The only difference is the relatively small opening in the skylight to let the sunlight into enter the room below, creating an ethereal feeling. This effect is purposefully created since the room below is a place for statues of gods.
Additionally, Novkovic found that the central skylight technique is favorable for museum technology and lighting perspective. She provided another example in the Tribuna of Uffizi. She argued that this particular project is the turning point in the history of museum architecture and lighting design. Naturally, the progression of with galleries with side windows became the staple of museum architecture at that time. The simplest way to configure a building to allow daylight in all of its interior spaces is a E-shaped, U-shaped or T-

shaped plan as stated by Lechner in his subchapter History of Daylight.

A textbook example can be found in Jacques Nikolas_Louis Durand, that was designed in 1803. The square ground plan is divided into four courtyards with four inner and four outer galleries, which form a Greek cross. The central cupola space is punctured by a central skylight. Leo von Klenze in 1822 designed a linear gallery for the collection of paintings. Novkovic argued in her thesis that this particular building pointed the way of lighting in modern picture gallery.

A. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

There are two main types of opening: **sidelighting** and **toplighting**. Robbins, in Daylighting: Design and Analysis, mentioned that there is a rule of thumb for sidelighting that daylight can penetrate into an interior space about 2.5 times the height of the opening of a window. However, he noted that this rule of thumb is flawed since it does not take into consideration questions such as whether the sky condition is clear sky or overcast, the width of the room, the glazing medium, and the interior surface reflections, whether the opening is obstructed by other buildings or plants, or whether direct sunlight is considered**.** Robbins also carries this further in his book that there should be a proportional relationship between the daylighting concept and the space being daylight-ed. He states that there are three categories for such relationship: **spatial proportions, aperture proportions, spatial/aperture proportions**.

Robbins also continued his research about daylight penetration using clerestory. In its traditional definition, a clerestory is an opening above the aisle roof of a church nave, transept, or choir while the modern definition identifies it as any opening whose sill height is greater than eye height.

For clear direction, a clerestory is a window opening above 2.1 m high and above with the maximum opening below or equal with the ceiling height.

The author found out in relation to viewing art on a wall, clerestory is an effective to prevent shadowing, as seen in Fig. 14.

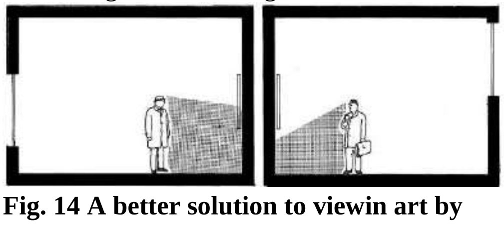


Fig. 14 A better solution to viewin art by clerestory *(Robbins, 1986)*

Robbins stated that toplighting is a concept where daylight penetrates a space from an openings that are located above the ceiling line and usually part of the roof construction. In most cases, daylight penetration is not as a concern as it is in sidelighting. In toplighting concepts however, usually provide a greater view of the sky dome or zenith, therefore the available exterior illuminance is higher**.**

The hypothesis for this research is to dissect the existing design of Kunsthaus Zurich by Barkow Leibinger that each elevation for the museum receive variable daylight penetration by differentiating and alternating each façade as opposed to uniformly provide the same design for each elevation as opposed to uniformly provide the same design for each elevation.

B. RESEARCH METHOD

This research began with literature studies regarding various types and possibilities of controlling daylight in museums respective to its elevations. This research observes the existing design of the project, location of the project, its site orientation, and a corresponding sun-path diagram in order to determine the existing solar window. The research then attempts to apply a new façade to the existing project, with a consideration of a specific design for each façade appropriate for controlling the daylight. The application for observing and implementing this research is 3D Studio max with IES lighting within the software. The object of this research is Kunsthaus Zurich, a competition design submitted by architectural firm Barkow Leibinger which is based in Berlin, Germany

The figures 15, 16 and 17 show the existing design of Kunsthaus Zurich.

Fig. 15 Exterior view of Kunsthaus Zurich proposal *(Barkow Leibinger with permission) source tidak tercantum di daftar pustaka*

Fig. 16. Interior rendering of atrium *(Leibinger n.d)*

Fig. 17 Interior rendering of museum entrance *(Leibinger, n.d.)*

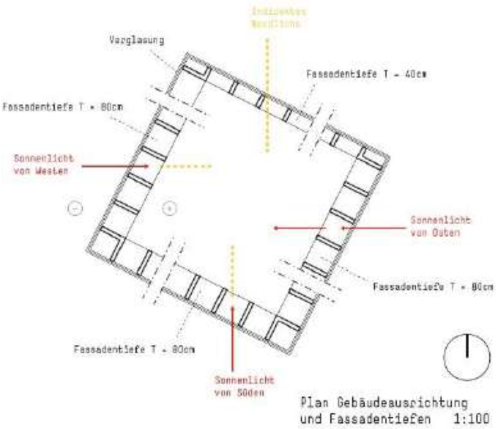


Fig. 18 Site Orientation *(Leibinge, n.d)*

It is clearly indicated in Figure 18 that the building is rotated approximately 45 degrees relative to the north elevation. Barkow Leibinger applied the same circular concrete openings and depth of 80 cm for south, east and west elevations with the exception of 40 cm of depth in the north elevation.

Summary of existing design:

- All top floor galleries have ceiling aperture in the center of each.
- A few of first floor galleries have partial ceiling apertures.
- Ground floor galleries either have partial-width and full-height or full-width and full height wall apertures.
- All sides of the façade (including the roof) have the same façade system, which consist of 80 cm-thick prefab concrete panels with circular openings, with the exception of north façade of 40 cm-thick panels. No specific strategy concerning daylight was found at each façade

C. RESULT AND DISCUSSION

The research stripped down the initial design of façade and created the inside of stacked galleries to determine the design of the new façade as shown in Figure 19.

Fig. 19 Exterior renderings of existing galleries without the existing facade *(Leibinger , n.d.)*

The aim of this research is to design a passive daylight system for each façade (north, south, west, east and roof) in responds to the specific sun movement within the site. The daylight exposure is reduced in the ceiling apertures at the top floor galleries by cutting off the highest sun angle and providing as much northern light as possible. Translucent glass panels are installed in all ceiling apertures.

Optimal filtered daylight is provided at the first floor galleries by the layout and orientation of each gallery with partial ceiling and wall apertures; while at the ground floor galleries, only wall aperture is used. From Figure 20 the modifications for the interior galleries are as follows: Top floor galleries are equipped with translucent glass panes for the ceiling aperture. This is to provide even daylight illumination and internal climate buffer. First floor galleries are equipped with full height and full length translucent of glass panes for the wall apertures wherever the layout allows and translucent glass panes for the ceiling aperture wherever this occurs. Ground floor galleries are equipped with full height and full length of translucent glass panes for wall apertures wherever the layout allows.

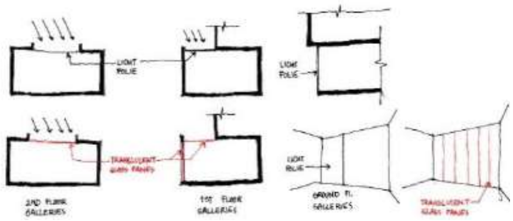


Fig. 20 Changes to interior galleries *(Personal sketches)*

The design objectives for exterior façades: For east and west façades, vertical shading is dominant to cover the low sun angle throughout the year. For south façade, a combination of vertical and horizontal shading will be dominant. For roof plan, vertical and tilted shading will be designed to cut-off the peak sun angle on June 21. For north façade, minimal obstruction is desired to allow the northern light as much as possible.

The first step in this process is to design the inner 'skin' of the building. The decision was made by enclosing the project with glass structures with low-iron content. The purpose is to avoid "polluting" the experience of viewing the artworks by removing the green tint from the glass. Figure 21 shows the design intent for the internal skin of the project.

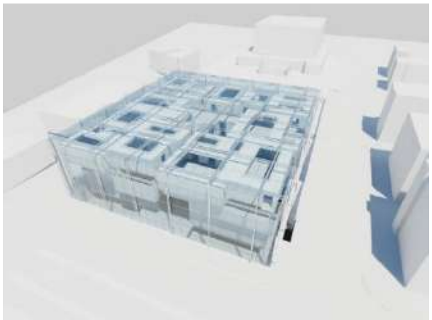


Fig. 21 Aerial view for the southeast showing clear tint of external glass enclosure ***(****Personal Rendering)*

The second step starts with superimposing the sun-diagram of Zürich onto the outer perimeter plan of the new museum as shown in Figures 22 and 23. Then a line from the peak sun angle of the diagram was derived. A spacing of 1 meter was offset throughout the outline of the roof plan.

From then, a study of the shading fin for the roof was conducted. A peak sun angle from June 21 was determined from the diagram and the aim of the study is to design a fin that cuts-off the sun angle and provide most exposure from the northern light. The whole process and options is shown in Figure 24.

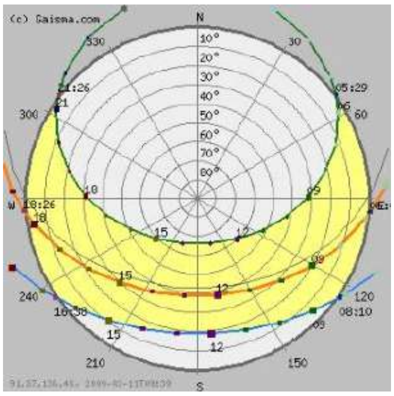


Fig. 22 Sun-diagram of Zurich *(Gaisma.com)*

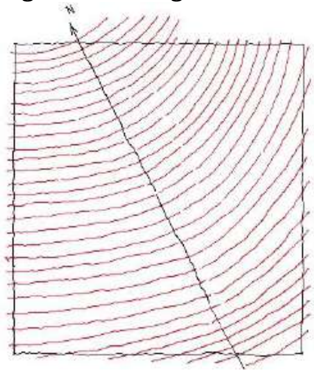


Fig. 23 Superimposed sun-path line on perimeter outline *(Personal sketches)*

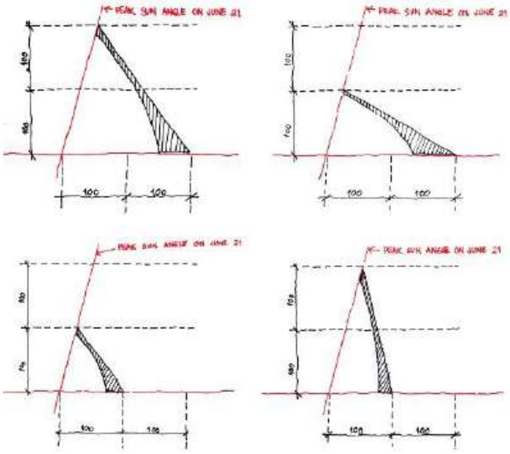


Fig. 24 Shading fin studies (Personal sketches)

The next step is to extrude the fins following the superimposed line pattern for the rooftop of the building. The edges are trimmed by the perimeter of the project, creating different spacing for each of the façade. The selected fin has a height of 2 meters with interval of 1 meter. The finished extrusions are shown in Figures 25 and 26.

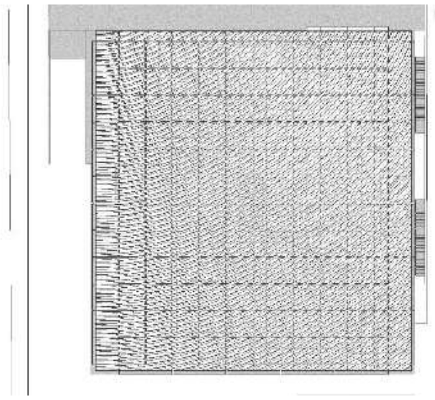


Fig. 25 Roof plan with extruded fins to cut-off the highest sun angle *(Personal rendering)*

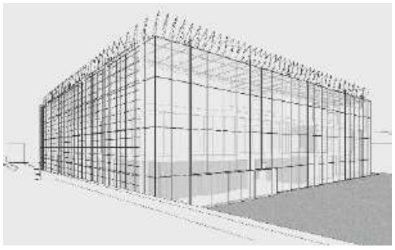


Fig. 26 Perspective of trimmed roof fins *(Personal Rendering)*

The north façade is followed by continuing the fins down and obstructing nothing from the northern light. The fins are 40 cm wide with spacing to follow the roof fins. The result is shown in Figure 27.

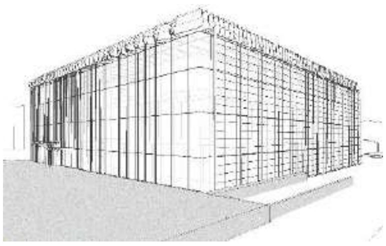


Fig. 27 North façade with 40cm-wide fins *(Personal Rendering)*

The south façade follows the same design strategy but the result is expansive exposure of the southern light as shown in Figure 28.

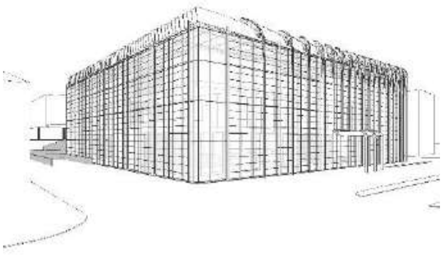


Fig. 28 South façade with extreme exposure to southern light *(Personal Rendering)*

The west façade has vertical fins similar to the north and south façades, with the exception of some fins are ‚bent' and ‚twisted' to form horizontal fins covering the corner gallery on the first floor. The fins are then carried into the south façade to protect the same gallery from the harsh southern light. The angle of horizontal fins on the east façade is 15 degrees to allow the low sun-angle in the afternoon penetrating into the building. However, the angle of horizontal fins on the south façade is 45 degrees in order to block and inter-reflect the light. The second floor and ground floor areas are intentionally not covered with horizontal fins since the second floor galleries do not have side opening and the ground floor area where the museum shop is located. The overall result is shown in Figure 29.

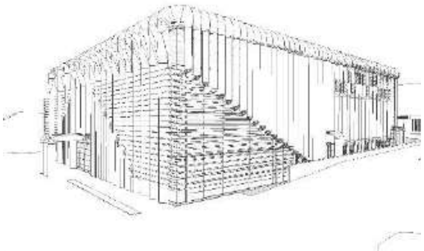


Fig. 29 Vertical fins on west façade and horizontal fins on south façade *(Personal Rendering)*

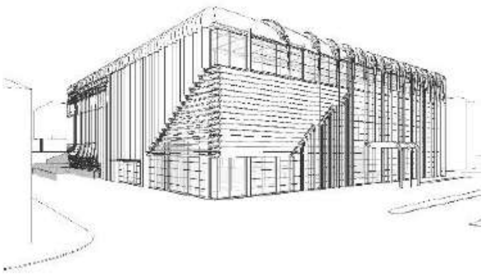


Fig. 30 Vertical fins on east façade and horizontal fins on south façade *(Personal Rendering)*

The east façade follows the strategy as the west façade partly where partial of the vertical fins are turned into horizontal fins and carried into the south façade as shown in Figure 30.

The continuous ribbon of fins covering the whole facade create a new architecture typology that interacts with the movement of the sun throughout the year and yet they provide functional passive daylight control for the building.

The movement of the sun throughout the year morphs the building with the playfulness of light, shade and shadow. The transparent skin provides glimpses of the interior activities without fully exposing the galleries. It creates a natural curiosity for the visitors outside the building to experience the interior atmosphere.

The natural light is allowed to a certain extent to create a more extroverted feeling and to challenge the notion of introverted nature usually found in other museums. Many elevations have been produced to study the sun's and the shadow's movement in the exterior which in turn impacts the interior. Three typical dates have been chosen which are June 21, September 21, and December 21. Three different times have been selected for each elevation and one can observe how the building acts and reacts during the day.

Rendering results and summary for June 21

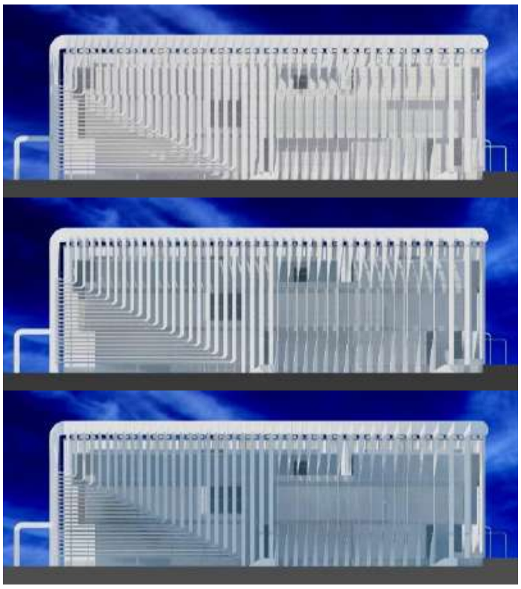


Fig. 31 June 21, East elevations, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

Shown in Figure 31, it can be observed for the east elevation at 9 AM, that most of the morning is still filtered through since the museum does not open until 10 AM. At 12 PM, the shadows are visible in almost 90% of the facade. By 3 PM, the entire east elevation is almost in shadow including the fins.

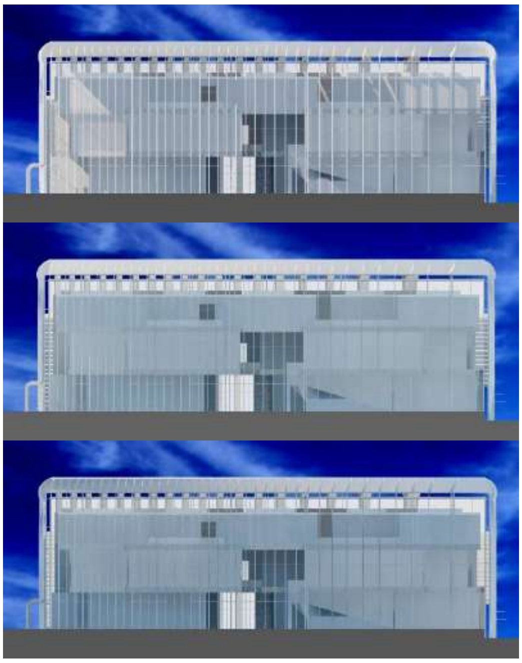


Fig. 32 June 21, North elevations, 9 AM, 12 PM, and 3 PM *(Personal Rendering)*

From Figure 32, it is visibly obvious for the north elevation at 9 AM that some areas get some morning light. At 12 PM and 3 PM, all north elevation does not receive any direct light tha makes it quite dark. On June 21, it is quite dependent on reflected light from the northern sky.

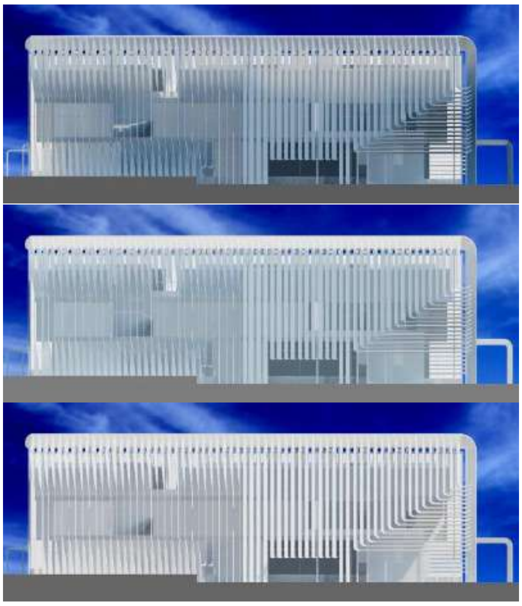


Fig. 33 June 21, West elevations, 9 AM, 12 PM, 3 PM *(Personal Rendering)*

Shown in Figure 33, at the west elevation, the intense shadowing occurs in the morning at 9 AM. By 12 PM, it is shown to be slightly brighter and the building facade by 3 PM still provides proper shadows into the interior.

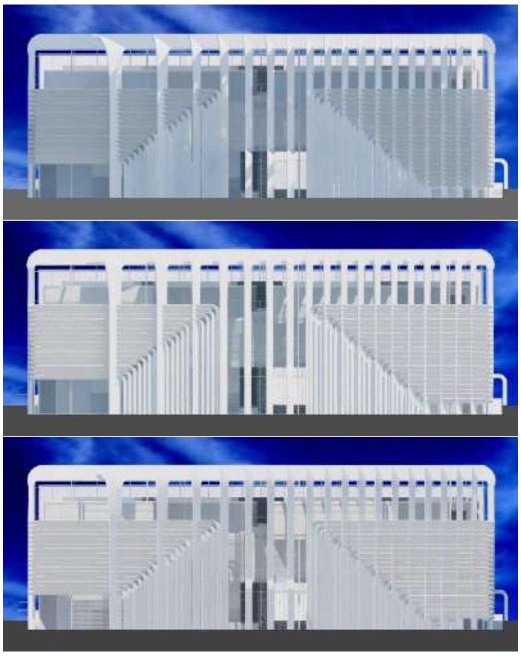


Fig. 34 June 21, South elevations, 9 AM, 12 PM, 3 PM *(Personal Rendering)*

Shown in Figure 34, at the south elevations on June 21, at 9 AM, the south façade is still partially covered in the shadow area, the highest peak of the sun direction happens at 12 PM, which provides the most adequate filtering of the sunlight due to the previously designed of the roof fins angle. At 3 PM the horizontal fins are covered in light shadows which indicate the high sun angle still occurs at this particular hour.

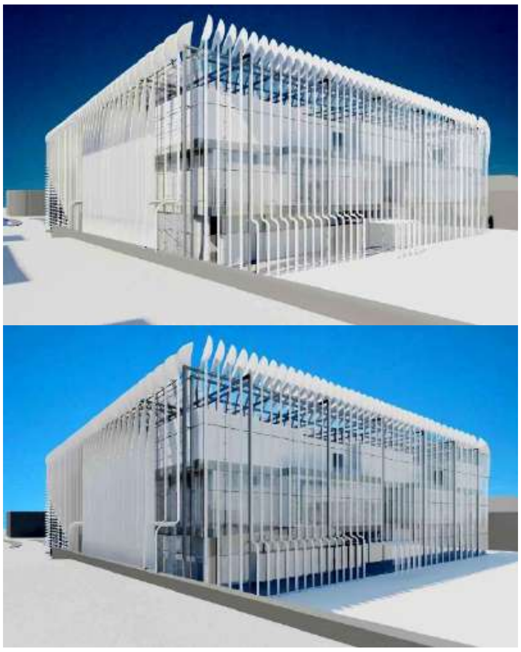


Fig. 35 June 21, Northeast views, 9 AM, 12 PM, and 3 PM *(Personal Rendering)*

Shown in Figure 35, the northeast view at 9 AM provides the brightest elevation with the north façade partially illuminated from the morning light. At 12 PM, the façade creates a shallow shadowing on the ground on the north side and at 3 PM, the east and north facades create dramatic shadowing due to the position and height of the fins.

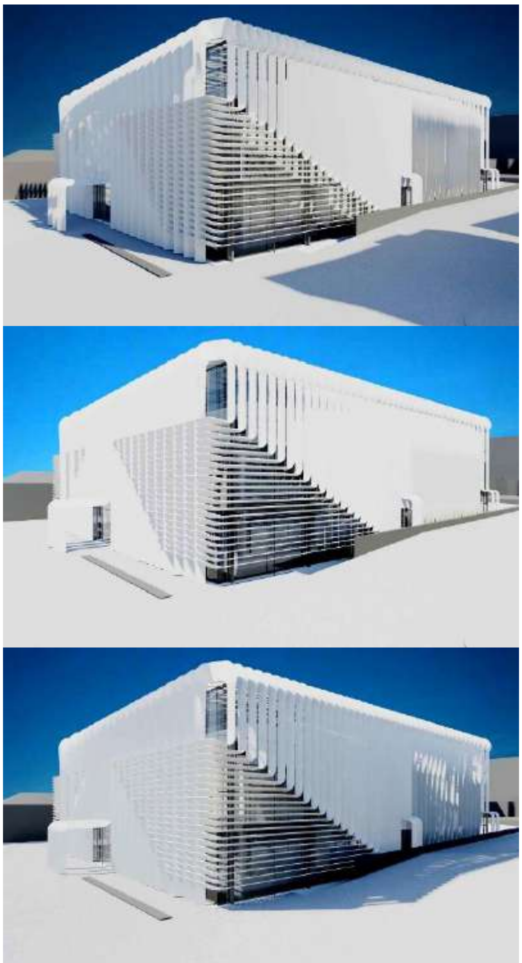


Fig. 36 June 21, Southeast views, 9 AM, 12 PM, and 3 PM *(Personal Rendering)*

For the southeast exterior views on June 21, at 9 AM the fins provided shadows on the south elevation and partially on the east elevation. At 12 PM the vertical fins receive almost equal exposure whereas at 3 PM the east elevation is covered in the shadows from the fins. The result is shown in Figure 36.

Fig. 37 June 21, Southwest views, 9 AM, 12 PM, and 3 PM *(Personal Rendering)*

In Figure 37 it can be observed at 9 AM at southwest exterior views on June 21, the south elevation already receive a small portion of sunlight exposure but the west elevation is still under the shadows. At 12 PM, the west elevation is still under the shadows from the fins and the south elevation looks almost the same with view at 9 AM. At 3 PM, it is visibly apparent that the west elevation receives the most exposure especially on the fins.

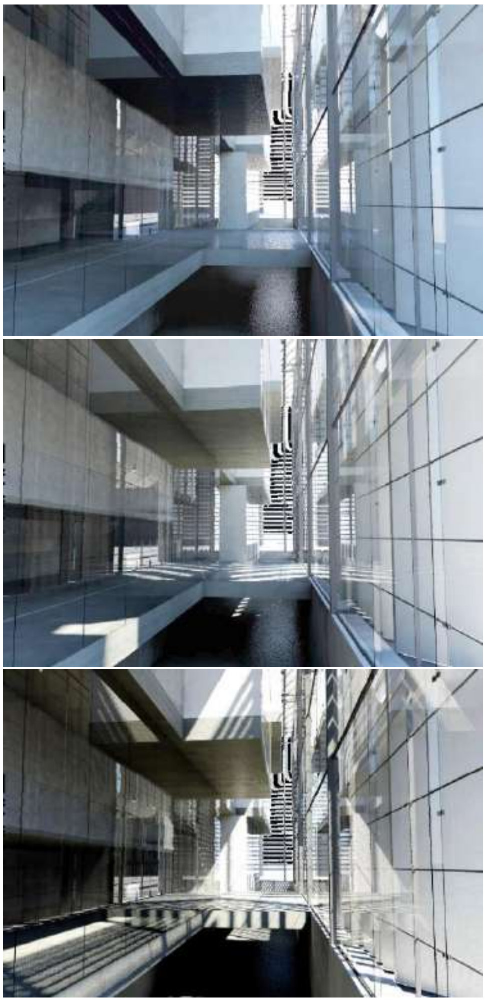


Fig. 38 June 21, Entrance Lobby, 9AM, 12PM, and 3PM *(Personal Rendering)*

Shown in Figure 38, the entrance lobby from 9 AM until 12 PM does not look too different with only modest increase in filtered light. At 3 PM, the filtered light provides a more dramatic effect on the lobby.

Rendering results and summary for September 21

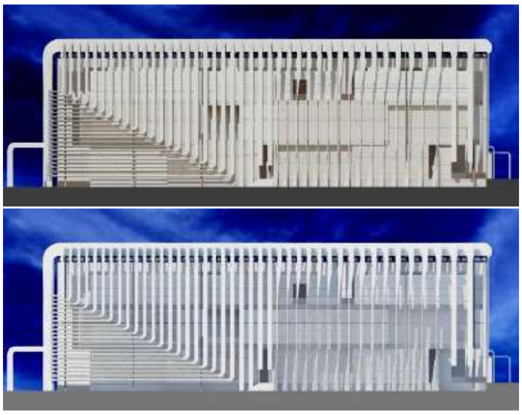


Fig. 39 September 21, East elevation, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

Shown in Figure 39 the morning sun at the east elevations on September 21, the morning sun on this particular date and time fully enters the building almost at a perpendicular angle so that every gallery receives light. At 12 PM, the galleries are shadowed again and at 3 PM, the entire elevation is in shadow.

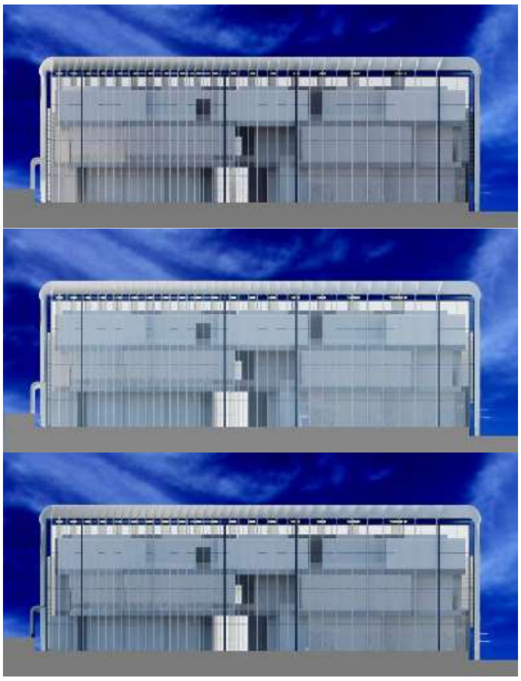


Fig. 40 September 21, North elevations, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

In Figure 40 it can be observed that at north elevations on September 21, all the views are almost consistently in the shadows therefore lending the building a transparent look throughout the day.

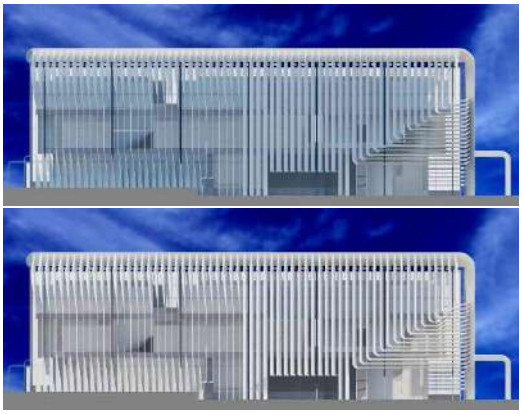


Fig. 41 September 21, West elevation, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

In Figure 41, at the west elevations on September 21, the shadows take a prominent role even at 3 PM. The galleries are properly shadowed without going completely dark.

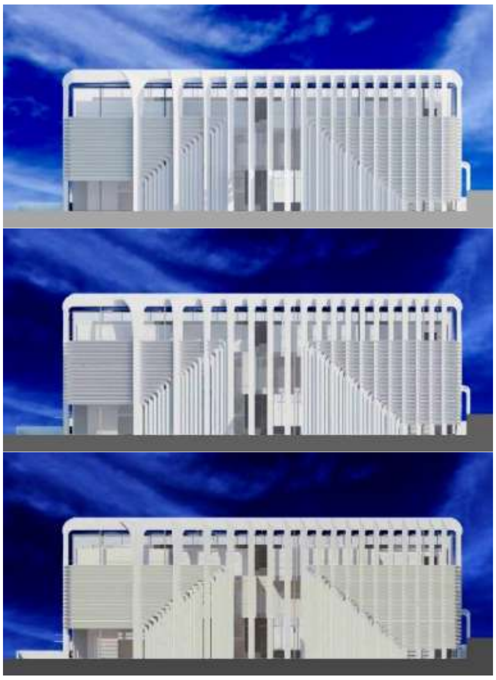


Fig. 42 September 21, South elevation, 9 AM, 12 PM, and 3 PM *(Personal Rendering)*

Figure 42 shows the south elevations on September 21, at 9AM and 12 PM looks almost the same in terms of fins shadowing with more prominent exposure on vertical fins. At 3 PM, throughout the elevations is almost equal sunlight exposure.

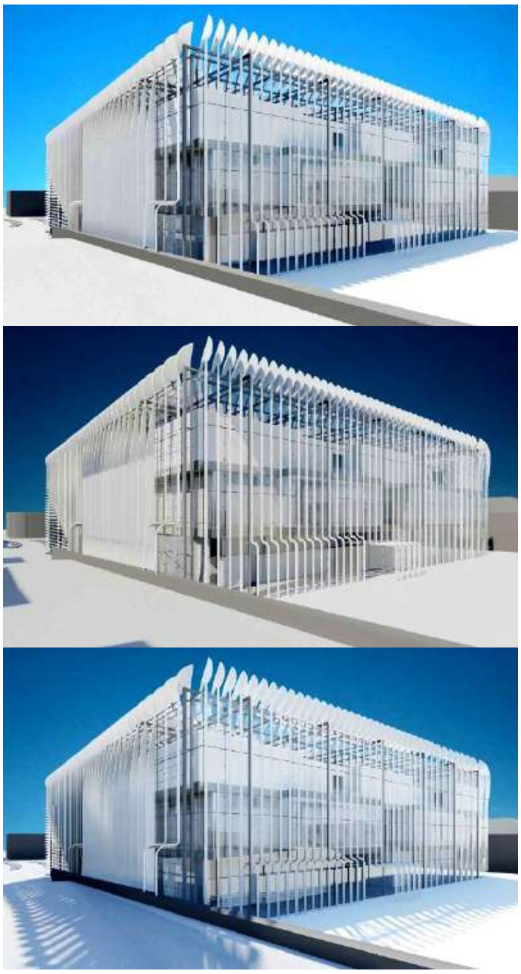


Fig. 43 September 21, Northeast views, 9AM, 12 PM and 3 PM *(Personal Rendering)*

Figure 43 shows the arrangement at the northeast views at 9 AM and 12 PM can be considered almost the same in terms of sun exposure and shadowing. At 3 PM, the building itself casts shadows on the surrounding site on the east and north elevations.

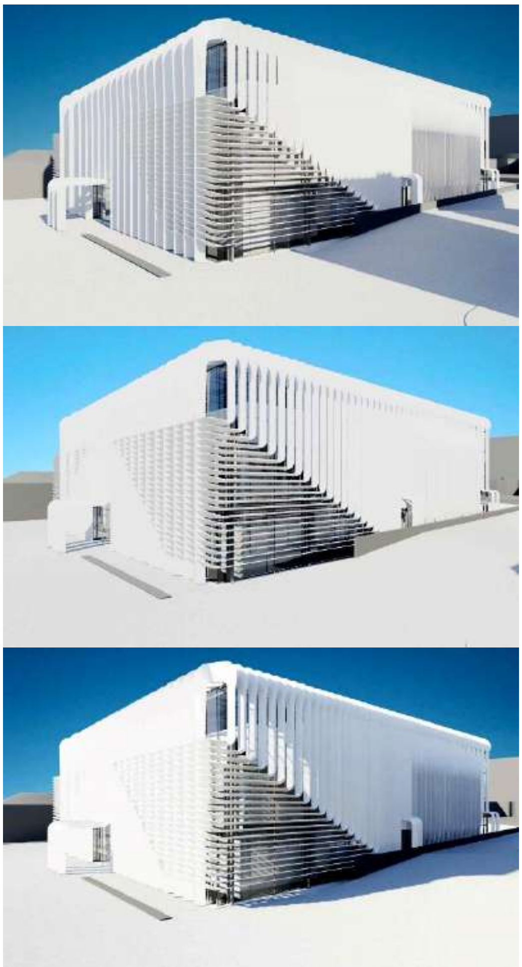


Fig. 44 September 21, Southeast views, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

Shown in Figure 44, the southeast view at 9 AM shows that the east elevation receives partial shadowing from the neighboring buildings. At 12 PM, a direct sunlight is visible on the east and south elevations. At 3 PM, the east elevation casts shallow shadowing on the site and most of the verticals fins on the east façade cast and receive shadows.

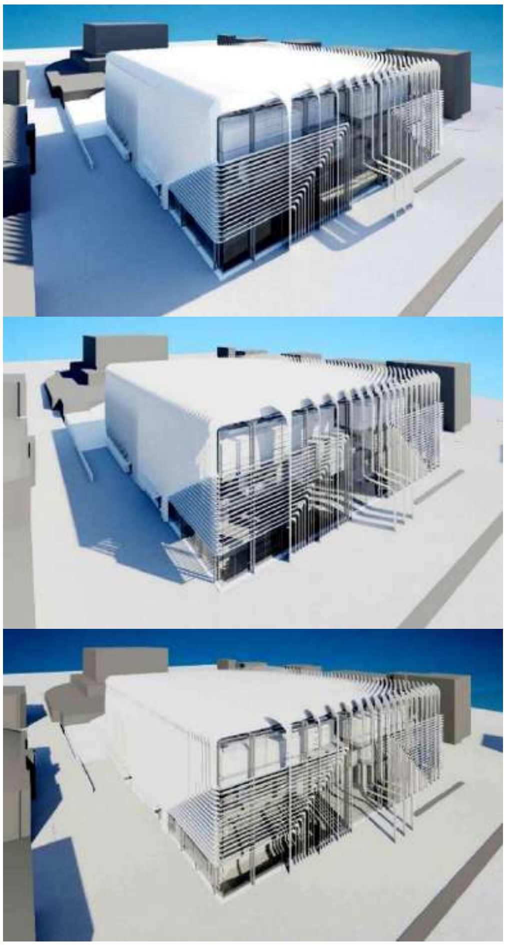


Fig. 45 September 21, Southwest views, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

As seen in Figure 45, at the southeast views, the west elevation at 9 AM casts shadows on the buildings around the site due to the low sun angle. At 12 PM, shadowing still occurs but at the half of depth of 9 AM shadow.

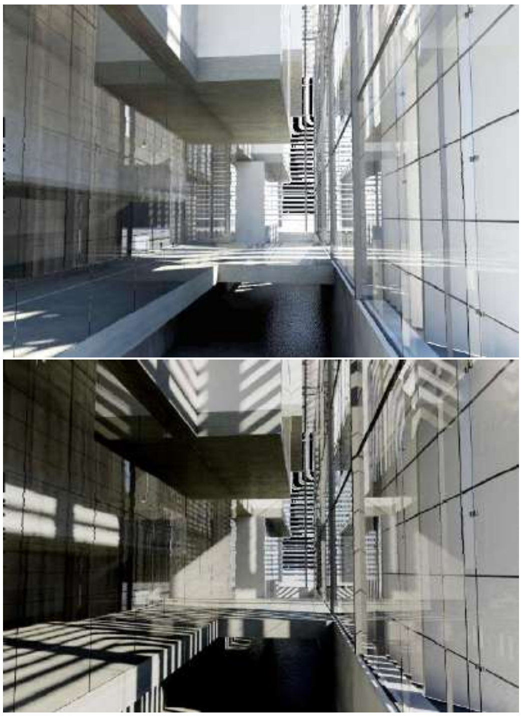


Fig. 46 September 21, Entrance Lobby, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

As seen in Figure 46, in the entrance lobby on September 21 occurs a playful shadowing throughout the day with the most prominent at 3 PM. This is allowable since the program is intended only for the museum shop not for the inner galleries.

Rendering results and summary for December 21

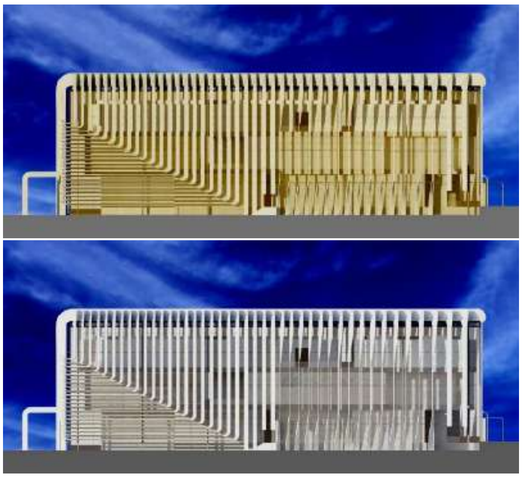


Fig. 47 December 21, East Elevations, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

Shown in Figure 47, the east elevations on December. 21, at 9 AM still receives a warm color temperature and no distinctive shadowing from the vertical fins. The horizontal fins provides only thin shadowing. At 12 PM all the east-facing galleries receive light shadowing and almost complete shadowing at 3 PM.

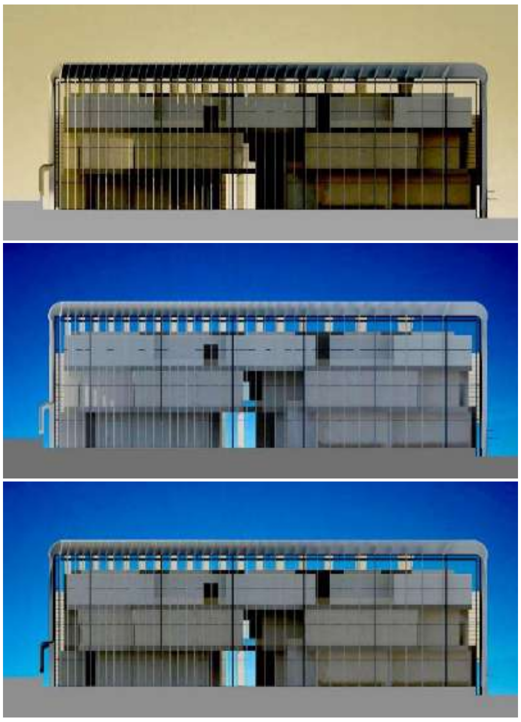


Fig. 48 December 21, North Elevations, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

Obvious from the result of Figure 48, the north elevation at 9 AM looks dark and foreboding due to the low angle of the sun. At 12 PM, all the building looks transparent all the way to the south elevation. The same case also happens at 3 PM with the difference of a partial warm color temperature hitting the west elevation.

Fig. 49 December 21, West Elevations, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

As seen in Figure 49, the west elevation, almost identical throughout the day in terms of shadowing. The only difference is the color temperature at 9AM and partial sunlight exposure near the lobby at the bottom galleries.

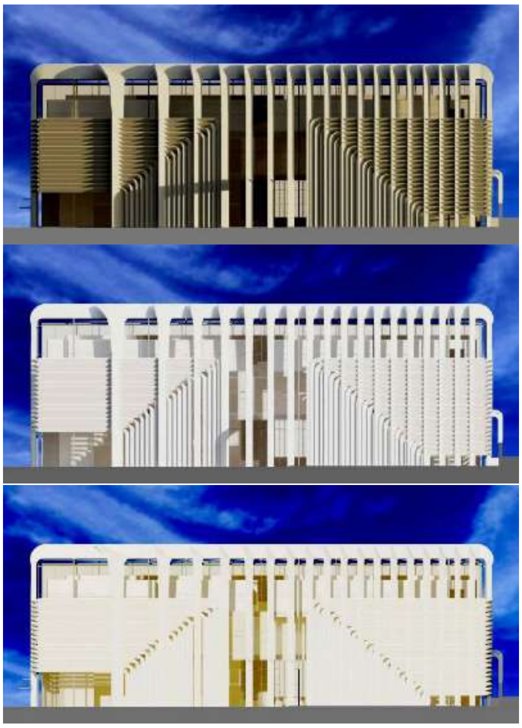
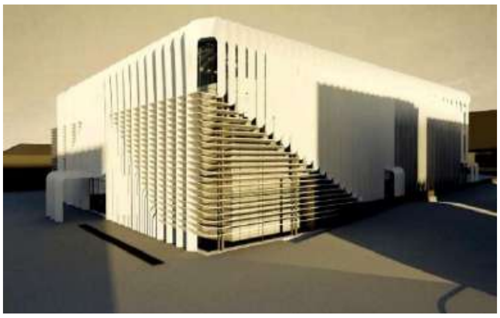


Fig. 50 December 21, South Elevations, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

Results from Figure 50 shows the south elevation at 9 AM already receives almost even sunlight exposure and shadowing except on the left part due to the thickness of the fins. At 9 AM and 3 PM, the south elevation receives full sunlight exposure with a warmer color temperature at 3 PM.

Fig. 51 December 21, Northeast Views, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

Shown in Figure 51 at the northeast view on December. 21, at 9 AM the east elevation receives deep shadows from the neighboring buildings due to the low angle of the sun. At 12 PM, however, the east elevation receives almost full sunlight exposure. At 3 PM, back to the previous condition, the east elevation is almost in the shadows.



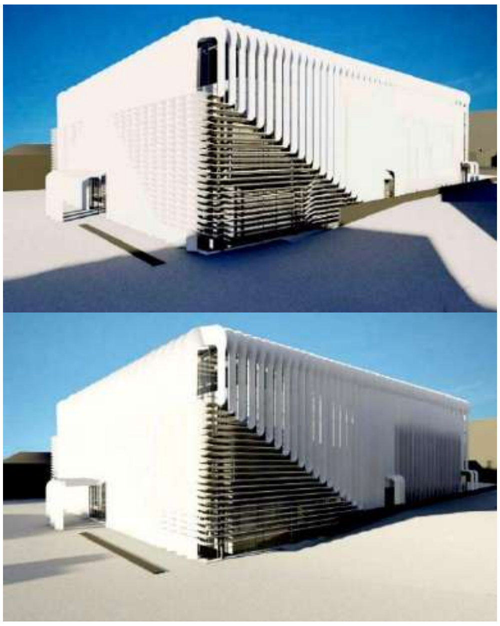


Fig. 52 December 21, Southeast Views, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

Results in Figure 52 show that the southeast view at 9 AM is almost covered halfway in shadows from the buildings around site. At 12 PM, a partial shadowing occurs from the building in front but otherwise the east and south elevations receive full sunlight exposure. At 3 PM, the east elevation is in the shadows when the museum already casting its own shadows.

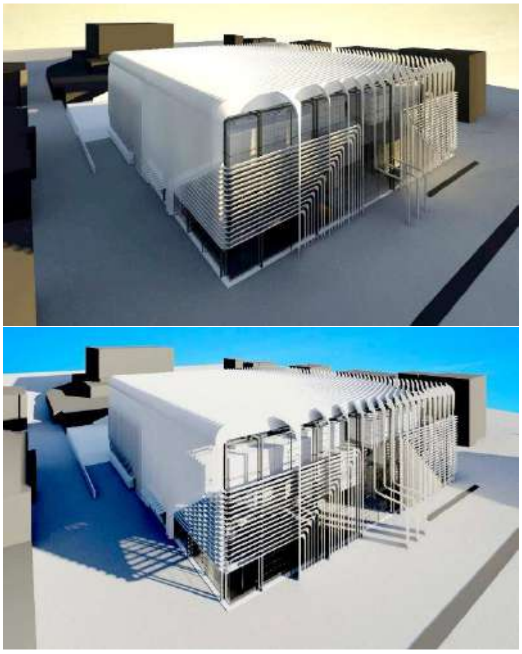


Fig. 53 December 21, Southwest Views, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

In Figure 53, at the southwest view, the museum is subdued at 9 AM. At 12 PM, the museum cast a long shadow but the south elevation is in good sunlight exposure but still shadowing on the west façade . At 3 PM the sunlight exposure is the harshest on the west façade while on the south façade it is almost covered in shadow by the surrounding building.

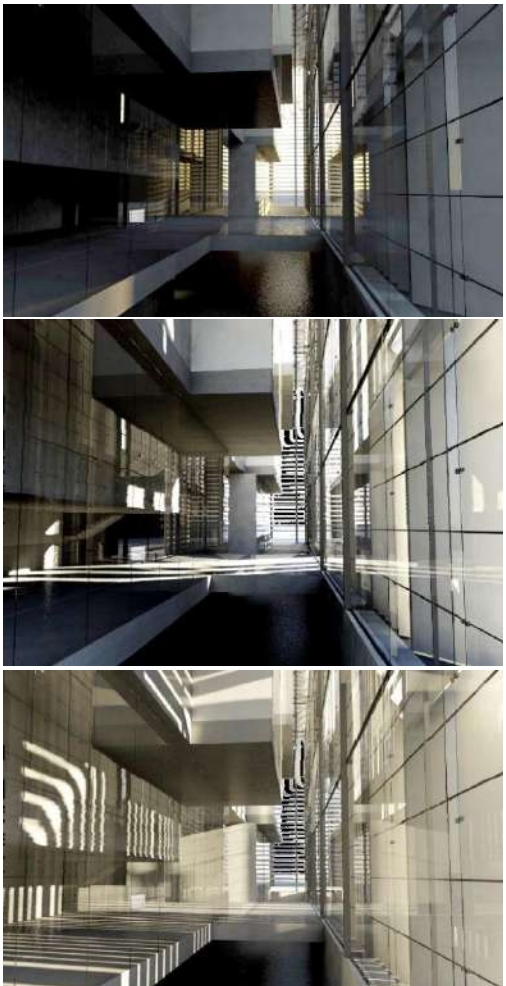


Fig. 54 December 21, Entrance Lobby, 9 AM, 12 PM and 3 PM *(Personal Rendering)*

In Figure 54, the entrance lobby on December 21 is mostly in warmer color temperature. The most prominent shadows occur at 3 PM whereas at 9 AM the lobby is mostly dark and in shadows and at 12 PM only partial sunlight exposure near the entrance bridge.

D. CONCLUSION

Based on the application of the simulation method on the case study, daylight control for Kunsthaus Zurich shows different results in sunlight exposure and in shadow areas depending upon the sun movement. It is found that the design on the north façade is the most straightforward in letting daylight into the building. Sunlight exposure only happens when the sun angle is low and around the summer months. Most of the north façade relies upon the reflected light from the northern sky and clouds. No particular daylight control is needed, only the design of fins is required, which are variously spaced between 1.0-2.2 meters and depth of fins of 0.2 meter. At the east elevation, most of the daylight control has to be applied through vertical fins with the interval of 1.3-1.5 meters and depth of 0.8 meter. The design is occupied by twisted fins partially to the south elevation as a break of monotony in design as well as a horizontal sunlight shades in the second floor galleries. At the south elevation, most articulation of vertical and horizontal fins are applied since this elevation receives the most direct daylight exposure in a time. Vertical fins are placed at intervals of 2.2 – 4.3 meters and depth of 1.0-1.8 meters. This is actually a poor solution and it is mitigated with more intermediate fins with the intervals of 0.6 and depth of 0.8 meters. The intermediate vertical fins are part of the horizontal fins coming from the east and west elevations that are twisted downward to shield the busiest galleries on the second floor. After the design intervention, the south elevation receives the most optimum sun-shielding façade and provides the most dramatic interior result as part of the design. The west elevation follows the same design rule as the east elevation. The vertical fins are spaced at 1.0 m interval with depth of 0.8m. The vertical fins are partially twisted sideways toward the south elevation with the similar design intention as the east elevation. On the rooftop, the fins are provided in order to protect the area from daylight for most of the year. The only allowance for daylight to penetrate the area is during the low sun angle in the morning and afternoons. It is therefore creating more dramatic shadows in the interior atrium.

In adapting Robbins' theory regarding sidelighting and toplighting with the addition of aperture and spatial proportions, this research demonstrates that the daylight control can be customized for each elevation and adapted to its particular interior programs. A design of combination of vertical and horizontal fins with simple ‘twist’ accent found meaningful and useful for daylight control in particular, without acting as a visual barrier into the buildings.

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