EVOKING HUMAN EMOTIONS BY A SYNTHETIC SKYLIGHT STRATEGY IN THE PUBLIC SPACE OF NURSING INSTITUTION

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***ABSTRACT**:*
Under the circumstances of functional transformation of future hospital, AMC in this case, a complex of health institution providing medical services and nursing facilities for the elders is one of the possible directions that existing hospitals can be transformed to. Based on this situation, this research paper investigates how to reinforce the connection between daylight and human perception in a positive way within the public space of nursing institution with respect to people's mental health. The research indicates that different daylight conditions correspondingly have different emotional reactions that consequently stimulate human behaviors. Based on the related design program focusing on the future transformation of hospitals, a unified daylight strategy need to be made in order to evoke positive psychological reactions through manipulating skylight conditions in public space. Therefore, by case study, a comprehensive analysis of daylight strategies was conducted, based on which an initial design concept of an integrated skylight system was proposed and tested at the end of the paper, which will give a kick off for the following design project technology wise.

***KEYWORDS**: skylight, public space, psychological perception, nursing institution, integrated roof*

I. INTRODUCTION

Background: hospital towards future

With the rapid development of modern science and medical technology, it has already become an urgent issue *to promo*te the functional transformation of existing hospitals towards the foreseen future. Under such circumstances, how to reprogram the future identity of hospitals and wisely take the advantage of existing medical spaces in the process of transformation is quite a challenge, especially to a medical monolith like AMC (Academic Medical Centre), within which a mass change could possibly take place both functionally and spatially in the future. A healthcare complex involving medical care and nursing institution is a possible transformational method affected, and in turn, supported by two major factors that current hospitals are faced with. First of all, the application of the artificial intelligence and information technology has already been leading a revolution on the filed of medicine. It is easy to argue that the future hospitals will be small and extremely acute by the wide use of remote diagnose technology and information sharing based on big data between hospitals. A new business model might occur in future hospitals on the basis of big information management systems built upon the cooperation of multi-medical institutions, which makes doctors and medical facilities not bound to each single one of hospitals anymore, on the contrary, a wide variety of healthcare services will be the major source of profit (Katwijk, 2001). Besides, the prolonged life expectancy and the growing population of aged people have become another factor that should not be ignored (*Figure* 1). In the Netherlands, the

population of older adults (>65) will increase from 3 million by 2015 to 4.2 million by 2030. As a result, the population of institutionalized older people in long-term care will reach over 350,000 in 2050 (Sinoo, 2016). Therefore, a spatial need for better arrangement of long-term nursing has been aroused. If we draw these two significant factors back to hospitals from the architectural point of view, it is obvious that the first factor would cause low occupancy in existing medical buildings, particularly to outpatient clinics and bed wards, whereas the latter in turn need additional space for nursing. Therefore, a clear transformational strategy could be drawn from the above analysis: by gradually changing the surplus existing bed tower and outpatient clinical space of AMC into nursing apartments and nursing center through several stages with respect to finance. This way, a medical complex towards future of both hospital and nursing center would be fully developed.

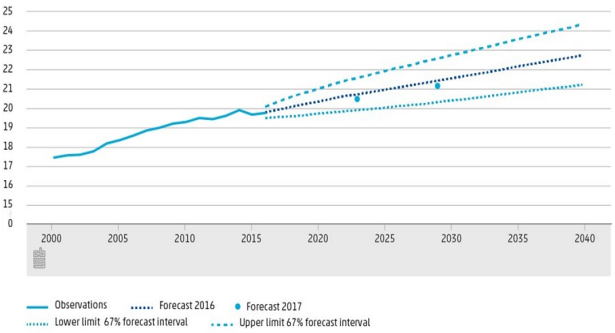


Figure 1. Life expectancy at age 65, observations and forecasts in Netherlands (source: Statistics Netherlands CBS, 2017)

Design focus: skylight in public space

As the basic function of future AMC will change to nursing, the relocation and adaptation process of the elders to the new environment is a basic need. According to the adaptation model of (Roy & Andrews 1991, 2009), conscious adaptive processes resulting from complex processes related to perception and emotions play an important role in individuals' adaptation to the environment (Kerouac, Pepin, Ducharme, & Major, 2003); Besides the object environment, adaptation to groups is another aspect that matters. Study shows that the participation in leisure activities is associated with a better integration of individual to the group (Coleman & Iso-Ahola, 1993; Kelly et al., 1987). Therefore, strategically, on the one hand, creating a public space with well-arranged leisure activities for the elders, on the other, evoking positive emotions by the surrounding environment would synthetically attribute to the adaptation process in a nursing center. In the AMC project, the existing large public squares and streets can already afford the leisure activities, how to manipulate human perception and emotions is the crux. As many studies show, light is "cognitive map" and "emotional driver" as it not only influence physical health, but also be able to induce specific emotions and behaviors. Skylight, therefore, is the most suitable source to achieve this goal as most public space can have access to it, AMC no exception. Hence, my design in transforming AMC to a new nursing center will be on the skylight performance in its public space. Consequently, it clearly leads to the research question:

"*How to evoke human emotions in the public space of future nursing environment by manipulating skylight performances?*"

II. METHODS:

The study is conducted in both theoretical and practical aspects within which the two are mutually weaved and reflected. Theoretically, based on the published papers on psychological and medical aspects, part 3.1 gives a clear mutual relation between specific lighting environment and human emotion that it can stimulate. Based on this, a set of design guidelines with regards to the mutual cooperation between skylight and human

behavior in public spaces of nursing institution can be concluded. With such, a more detailed design strategy targeting to building parts, such as roof system, could be easily promoted towards the AMC project in a both technological and architectural way; Part 3.2 involves a series of case studies regarding to different methods of daylight shaping. By matching the daylight strategies featured in actual architecture projects to the various lighting environments that the nursing space need to have according to part 3.1, this part clearly answers the question of how to actually implement those different skylight environments in a building; Part 3.3 investigates the possibility of a synthetic skylight strategy implemented on a unified roof system. In order to give it an answer, an initial design concept is proposed and a series of tests regarding daylight performance follows. It will give a strong vision for the following design project. A complete overview of the steps in detail can be seen in *Figure* 2, more details are included in the *Appendix I*.

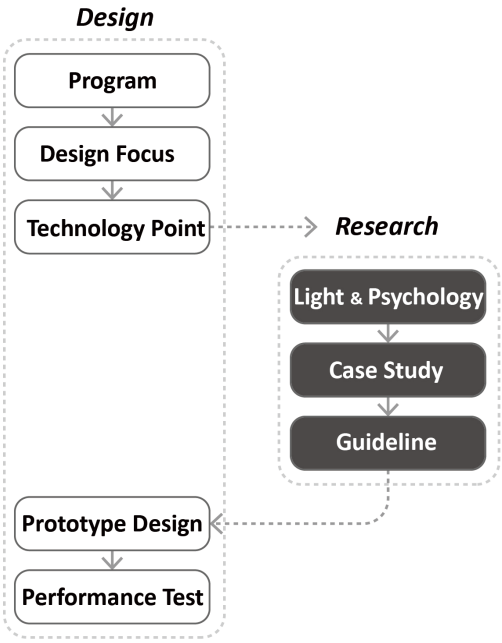


Figure 2. Research for design

III. RESULTS:

3.1 Ambient light environment & Cognitive and emotional human response

3.1.1 The Importance of Ambient Lights and Its Biologic Foundation

On what level the light is affecting the connection between human and the environment is the main issue that has been studied in human adaptation process. Biological and innate factors embedded in the human psyche play an important role of how a space is perceived. Therefore, to answer this question, biological and psychological point of view is a secure foothold. Research results show that in two major aspects that the light plays an important role in cognitive and emotional human response to the space they inhabit. First of all, light can influence human brain in a very short term. Light modulates human mood by acutely affecting brain emotional processing. Instead of vision, ambient light is a powerful source that regulates human brain in hormone secretion, body temperature, sleep and cognition (Cajochen, 2007). This influence can happen in a few seconds. For instance, study shows that ambient light directly and immediately modulates ongoing cognitive brain function, such as attention, memory and sensation within seconds (Perrin et al., 2004). This neuron-perceptive reaction mechanism attributes to human environmental adaptation by exposing perceiver to a specific ambient light of certain characteristics, including its intensity, saturation and modulation, and by such stimulus, a specific human emotional reaction occurs that can further leads to a certain human behavior (Birren, 1969a, 1969b; Flynn et al., 1973). For example, office space uses bright and white artificial light to activate cognitive skills that externally performed as efficiency, excitation, but also stress and anxiety, so inside this ambient light the employees are able to work in a more productive way. In this sense, light is seen as an environmental “cognitive map” and an “emotion driver”. Secondly, psychological influence can be shaped not only by short-term

ambient light, but more importantly, long-term changes in ambient light seem to restore normal mood regulation (Terman, 2007). This research result has been used in light therapy, a psychological treatment by exposing people in different light environment in different times during a day. Based on the short-term and long-term effects the ambient light has on emotional human reactions and behaviors, it is easy to have a clear overview on daylight shaping strategy in nursing institutions:

On the one hand, to shape specific daylights for certain functional spaces according to the short-term influences that the ambient light has on human, on the other hand, to be able to shape as many types of daylight environment as possible to ensure the diversity with regards to the light's long-term effects.

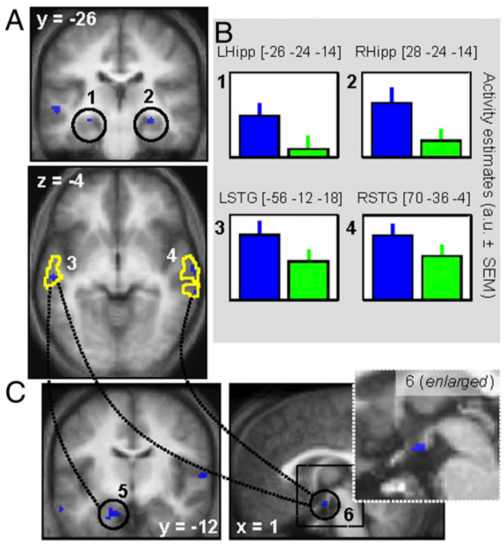


Figure 3. Impact of the wavelength of the ambient illumination context on the brain processing of emotional auditory stimuli. (Vandewalle, G. (2009) Light as A Modulator of Cognitive Brain Function. Trends Cogn Sci, 13:429-438.)

3.1.2 Four lighting modes & Related emotional responses

Since the importance of ambient light has been known, how to link each stimulus of lighting environment to the full array of cognitive human reactions becomes the consequent issue this research targets. In order to find out which attributes of lighting environment relate to the multiple emotional reactions that could cause, John Flynn who's dedicating to the research on human impacts of lighting has identified four of these attributes, which was called the "lighting modes". Every pair of mode illustrates a continuum of changes in lighting between two extremes. On such basis, it becomes possible for the designers to influence human emotional reactions by manipulating the parameters of lighting – bright/dim, directional/ diffused, central/ perimeter, and warm/ cool. (Flynn, 1973). The paper will discuss the emotional stimulus that each pair of lighting modes can result as follows:

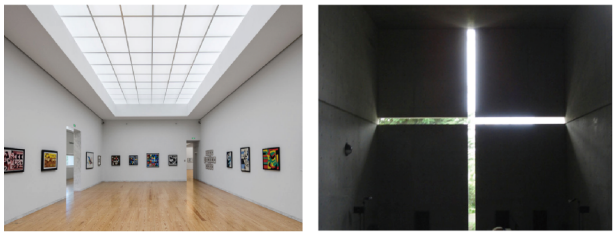
Bright/Dim

Brightness is also called light intensity, normally expressed in lumens or lux. Generally, high intensity of light corresponds to high level of concentration and attention. Moreover, a research from University of Toronto indicated that a brighter light could intensify human emotional response; no matter it is positive or negative. This character gives designer a clue that a high intensity or brightness needs to be used with caution, especially to a relatively small space inside which an amplified negative emotion is hard to be released due to lack of social contact. Whereas, low intensity of light doesn't erase our emotions, instead, it can cool them down and keep them steady. Therefore, under a dim ambient light people could be able to have more rational mind and have a peaceful and deep self-reflection. It is no wonder that many meditating spaces in churches and temples tend to be designed dim and gloom. However, in most cases we need to include an extra important parameter, which is time. Endless bright or dark is no good to human health. Recent study shows that prolonged darkness causes structural brain changes and

increases depression risk (Bramley & Peeples, 2008). Similarly, over-lighting, which affects people's visual performance, induces discomfort and stress, and if sustained over time it could possibly cause neuropsychiatric disorders (Bruce & Green, 1990; Daurant et al., 1993). To conclude, a bright lighting environment is suitable to be implemented in a spacious room where a large number of people gather and public activities happen, such as the atrium and exhibition hall, or can be used in a room that involves people behavior needing concentration, for instance, the reading room; whereas a dim ambient light can be used in spaces that acquire calmness and sense of security, for example, meditating room and lounges (*Table 1*).

Light	Positive influence	Negative influence	Implementation
Bright	attention; exited;efficiency; intensify positive emotions	stress and anxiety when over-lighting	atirum; exhibition hall; reading room
Dim	calmness; steady; security	depression risk when prolonged	meditating room; lounge

Table 1. Emotional responses and implementations of bright light and dim light



Bright: Nadir Afonso Contemporary Art Museum Dim: Church of Light

(source left : https://www.architonic.com/en/project/alvaro-siza- vieira-nadir-afonso-foundation/5103884)
(source right: source: https://www.archdaily.com/101260/ad-classics- church-of-the-light-tadao-ando)

Directional/ Diffused

Directional lighting, also called non-uniform lighting, is considered to be able to express positive cognitive human reactions due to Kaplan's theory on environmental psychology. When presenting in a new space, the initial task for a person is to build a cognitive relation between the environment and his or her own memory so as to understand the surroundings. This coherence of environment that strengthened through perceptual clarity can be well established by directional lighting because more details can be unveiled and then seen by the people under such lighting environment (Kaplan and Kaplan, 1988). In other words, people always feel comfortable and pleased when in places that are familiar to their experiences and directional light happens to be the tool that helps establish this connection. However, not all directions of lighting are pleasant. Intense light directly from above can cause stress on the contrary. Besides, a directional skylight coming from outside can cast a strong texture of shadow in the interior and it changes with time so that people can feel the close connection to the nature. In a day, the light's changing obviously indicates the time corresponding to human circadian rhythm, which is the internal clock, influencing the melatonin secretion, when disrupted it can arouse sadness, anger and other negative emotions. Compared to directional lighting's natural rhythm, diffused lighting, also named uniform lighting, has the ability of perceptual isolation, inside which people lose the cognition of space and border, which might cause stress and sense of disoriented, This character of the uniform lighting was also used in *Ganzfeld*, a special art of James Turrell. The homogeneous perspective space expresses the disorienting experience of "fullness of emptiness" by using the fluorescent light uniformly enlighten the walls and ceilings (Tomassoni, 2014). However on the other side, it can help people focus their attention on the work in front of them since the surroundings are becoming obscure under the uniformly illuminated light. This strategy is widely used in the lighting design of libraries and exhibition halls, for example, in the skylight design of the library of Porto Architecture School, Álvaro Siza used an inverted pyramid structure to diffuse the skylight and scatter the light evenly as white cream in order to create a quiet atmosphere in which people can easily focus on reading. To summarize, in lighting design project, directional light can be used in most public spaces that provide relaxing and natural environment; whereas diffused lighting

is often used in the space that need high level of concentration, such as library and working spaces, but to be noticed, in order to prevent the side effects of perceptual deprivation, adding an extra visual connects to the outside nature could be a good solution (*Table 2*).

Light	Positive influence	Negative influence	Implementation
Direct	visual clarity; pleasant; sense of nature	intense dirctional light causes stress	most public spaces providing relaxing and natural environment
Diffused	attention; efficiency	stress; disoriented; spacialness	library; working space

Table 2. Emotional responses and implementations of direct light and diffused light

Direct: Seattle Public Library Diffused: Bagsvaerd Church

(source left : source: https://www.archdaily.com/11651/seattle-central- library-oma-lmn)
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Central/ Perimeter

Human perception of the space alters through different lighting methods. Lightings from different locations in a space can leads to different emotional reactions. A central lighting, for example, a central light from above a room, can concentrate all the attentions to the center, as the spotlight on the stage. This lighting method can not only focus people's attention, but also create an intense atmosphere, when the light is over intensified, this sense of intensity tends to be more negative, as stress or anxiety. On the contrary, perimeter lighting, in some cases called wall lighting, can induce a relaxed emotion. In actual projects, perimeter lighting is widely used in the lighting design of lounge bars, by only illuminating the circle of the room in lower height overhead, mostly warm colored, to create a relaxing and hospitable atmosphere. When it comes to the daylight design of public spaces in nursing institutions, it is likely to implement perimeter lighting in relaxing spaces such as chatting space and private booth in public squares (*Table 3*).

Light	Positive influence	Negative influence	Implementation
Central	attention; sense of intensity; efficiency	stress and anxiety when intensified	working space; stage
Perimeter	relaxing; hospitality	lack of sense of space; disoriented	lounge;chatting space; private booth

Table 3. Emotional responses and implementations of central light and perimeter light

Central: Warehouse Office Perimeter: Rothko Chapel

(source left:https://archello.com/story/41581/attachments/photos-videos/1)
(source right: https://www.atlasobscura.com/places/rothko-chapel)

Warm/ Cold

As we all know that natural light is important in creating comfortable environment, it is noticeable that colored light, weather created by artificial means or exists in nature, can induce emotional response as well. Studies show that ambient light and its spectral quality has impact on the process of emotional stimuli in human's brain (Vandewalle, 2009). It's easily to relate a green light to the sense of health, orange to energy and red to attention (*Figure* 4). The emotional changes due to the brain functions immediately result behavioral adaptation to the environment (Vandewalle, 2009). While in the full spectrum of lighting colors, the blue light is the most special one. Biologically, blue light can intensify the responses to emotional stimuli in the most areas of brain, such as voice area, amygdala, and hypothalamus. By strengthening emotional brain reactivity in these areas, ambient blue light could ultimately enhance efficient mood regulation process, which is good for preventing and curing Alzheimer's disease and seasonal affective disorder (SAD) (Vandewalle, 2009). Therefore, considering the elders' mental health, implementing ambient

blue light is essential in nursing institutions.

Figure 4. Lighting in different colors and corresponding emotional responses

3.2 Case studies

By analyzing each specific ambient light's corresponding human emotional responses, a clear overview of how to match a right type of ambient light to a space with specific function has been extracted from the previous studies. On such basis, this part is focusing on how to realize these different lighting environments in a building by architectural means, to be specific, architectural structure. To be noticed, this research will only focus on the daylight's shaping methods since the related design project mainly deal with the design of daylight in the public space of AMC. When analyzing, the case projects will be categorized into a few independent columns in correspondence with the lighting modes discussed in previous part; whereas as mode warm/cool and mode central/perimeter has less relation to the architectural structure, these two lighting modes is excluded in the latter discussion. Therefore, the selection of the projects in this part will be based on the following lighting modes: direct light, diffused light, bright light, and dim light. More over, in order to get a thorough result, there will be subdivisional parts to some methods. Finally, to be clear and concise, each specific method will be illustrated in a simple icon, and the related projects will be included in the *Appendix IV*.

3.2.1 Direct daylight

In order to create the ambient direct daylight, there are two major architectural methods, clearly shown through following projects.

Type: *direct light*
Method: *single bright spot*
Case Study 1: *Pantheon, Rome*

Case study 1: Pantheon, Rome

The simple round opening in the center of the coffered concrete dome above the rotunda is capable of introducing the natural light into the interior. The direct daylight projects a bright spot that can rotate on the surface of wall and floor, which indicates the time's change in a day, so that induces a consequent sense of universe.

Type: *direct light*
Method: *textural shades*
Case Study 2: *Seattle Public Library, U.S.*

Case study 2: Seattle Public Library, U.S.

Through the texture of steel structure on the façade, the outside light directly sheds into the building and cast a beautiful textural shadow in the interior. This extra-added texture onto the original interior space creates a sense of nature, mimicking the shadows caused by the branches of trees in the forest, expressing a comfort and relaxing atmosphere.

3.2.2 Diffused daylight

Technically, there are two major ways to create an ambient diffused daylight in buildings: *reflection* (1) and *filtration* (2). The method of reflection can be further divided into two subdivisional parts: *top-lighting* (1.1) and *lateral-lighting* (1.2).

Type: *diffused light*
Method: *top-lighting reflection*
Case Study 3: *Kimbell Art Museum, U.S.*

Case study 3: Kimbell Art Museum, U.S.

By reflecting the natural light for several times on the surfaces of voids shaped by the structure, the direct light can be softened into a diffused light that uniformly illuminates the interior. In the case of Kimbell Art Museum by Louis I. Kahn, the top light enters the opening on the arch structure, and then being reflected by a panel underneath, it changes its route upwards. Finally the curved surface scatters the light evenly and creates a creamy, uniform day lighting environment.

Type: *diffused light*
Method: *top-lighting reflection-deep void*
Case Study 4: *Herz Jesu Kirch, Munich*

Case study 4: Herz Jesu Kirch, Munich

Compared to the method featured in Kimbell Art Museum, in this case designed by Zumthor, the top light has to run through a deep void inside which the light be reflected back and forth between the inner surface. Finally the light that reaches the bottom appears as a diffused light but much darker because the prolonged void increases the reflection times and therefore weakens the intensity of light. This method will be also discussed in the part of ambient dim light.

Type: *diffused light*
Method: *lateral-lighting reflection*
Case Study 5: *Bagsværd Church, Denmark*

Case study 5: Bagsværd Church, Denmark

The big opening on the roof guides the light into the inner space laterally. The curved ceiling gently reflects and scatters the light. The whole roof structure can be seen as a single void with which daylight can be diffused.

Case study 6: Broad Museum, LA

The single void used in the previous project is scaled down here and combined as an array on the roof in order to not only provide a uniform lighting environment, but also present a texture of the ceiling that adds aesthetic value for the diffused daylight environment.

Case study 7: Daylight House, Japan

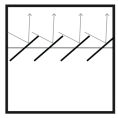
Other than reflecting the light by a structural void, it is also a simple and widely used method to generate diffused light by filtering the natural light through an extra layer. In the case of Daylight House by Takeshi Hosaka, the curved acrylic ceiling plates on the ceiling can perfectly perform the filtration with which the strong natural light coming from top can be uniformly diffused. The filtering layer can be implemented on the sidewalls as well, which generate a different sense of beauty.

3.2.3 Bright daylight

Type: *bright light*
Method: *big opening*
Case Study 2 & 3

To get a bright daylight probably is the easiest day lighting desire to be accomplished. The only requirement is just a wide opening that ensures a large amount of natural light coming in. Because of the simplicity, this method is always seen as part of a synthetic day lighting system. For example, in case 2, the façade can be seen as a huge opening on the wall, which maximizes the intensity of light and creates a space as bright as outside. Meanwhile, the diffused light can also results a brighter space because of its ability to widely scatter the light to every corner of the room. The case 3 is a brilliant illustration to this character of diffused light.

3.2.4 Dim daylight



Type: *dim light*
Method: *rebound*
Case Study 8: *Beyeler Foundation, SZ*

Case study 8: Beyeler Foundation, Switzerland

In order to create a dim daylight environment, one of the easiest ways is to control the amount of daylight coming into the interior. Therefore, implementing a shade on top of the roof, which rebounds the daylight, is an efficient method.

Type: *dim light*
Method: *small opening*
Case Study 9: *Church of Light, Japan*

Case study 9: Church of the Light, Japan

Also under the guideline of limiting the intensity of light, other than rebounding the daylight, Tadao Ando's church creates a very narrow gap on the wall in a cross, which induces a sacred atmosphere by a dim ambient light. This method can be easily expressed as using small openings.

Type: *dim light*
Method: *single bright spot*
Case Study 10: *Bruder Klaus Chapel, DE*

Case study 10: Bruder Klaus Field Chapel, Germany

This chapel designed by Zumthor simply creates a deep void in the center, surrounded by a circle of concrete, to let the light travel a long distance before reaching the bottom, during which the intensity of light is lowered by multi-times reflecting and rebounding.

3.3 Synthetic skylight strategy

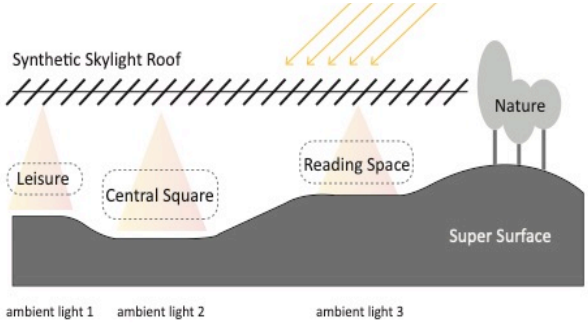
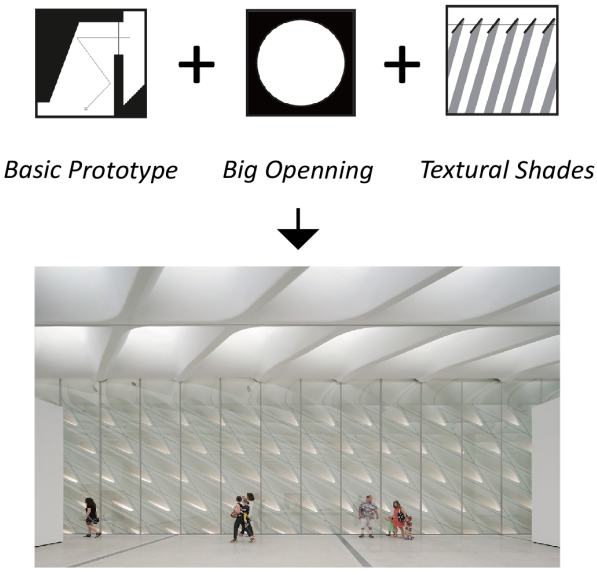


Figure 5. The strategy of shaping different ambient lights in the public space of AMC (Appendix V)

The purpose of previous studies is trying to find an efficient way to establish a cognitive connects between the ambient lights and human emotional responses so as to make people have a positive emotion. From the environmental psychological point of view built by Kaplan, daylight is just a part of the whole program, within which the whole aspects of environment, such as special height and decoration, are all involved to synthetically achieve the ultimate goal, which is establishing a balance between coherence and complexity in the environment. To achieve the coherence, the environment needs to match people's memory that makes the new environment easy to represent; To achieve the complexity, the space should have the ability to arouse curiosity and let people explore (Keplan & Kaplan, 1988). Under such guidelines, besides providing the right daylight, the whole space from the ground to the top need to be tackled with synthetically. In the case of AMC, under a continuous roof that provides different types of daylight environment, a surface on the ground enables different heights for each specific space so as to create a high level of coherence with regards to daylight (*Figure 5*). For example, the central square with a high ceiling creates a familiar experience of the outside square, which achieves a high coherence so that people initiatively feel as in nature; whereas the reading space is provided with a lower ceiling in order to establish a special experience that a normal reading room has.



Bright, textural and diffused skylight
Case Study 6: *High Museum, LA*

Figure 6. The example of shaping ambient light with a synthetic skylight roof system

For designing the skylight roof structure, results from previous studies can provide useful strategies. In order to make the roof structure capable of providing different daylight environments, a synthetic and uniformed way of thinking should be held, which can lead to a simple concept: *to make the roof units movable*. By recomposing the unit in a different way, the roof can present different shape of structure, as shown by the series of icons in case studies, so as to provide corresponding daylight environments. Therefore, how to design the single unit of the roof system becomes the essential challenge.

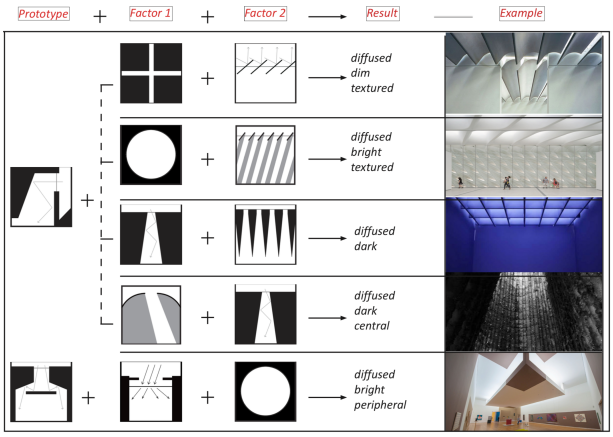


Table 4. The composition of roof unit and corresponding ambient lights (See in Appendix VI)

By re-analyzing the methods featured in previous case studies, it is not hard to see that there is a basic prototype, which is the lateral reflection; on its basis, all the other types of structure can be achieved by slightly changing the shape of the basic one. For instance, the single basic prototype provides the diffused lighting environment. By providing a big opening between the basic prototypes, we can get a brighter daylight; if we further recompose the basic prototype into a textural structure, we can get a ambient light which is both bright and textural (*Figure 6*). By applying this recomposing method into each mode of daylight quality, we can simply achieve every type of daylight environment by adding additional changes onto the basic prototype of structure. Therefore, a regular re-composition way of the roof unit can be obtained as follow (*Table 4*).

On such basis, an initial design can be done. The skylight roof can have different forms by controlling the shapes of each single unit in order to form different ambient lights (*Table 5*). By computer rendering test, it is obvious to see that the roof system really achieved the multi-ambient-light performance by changing the shape of roof units (*Table 6*). The initial design and testing proved that the strategies resulted from the case studies is correct and the research has laid a solid foundation for further developing of the synthetic skylight roof system in later design phase.

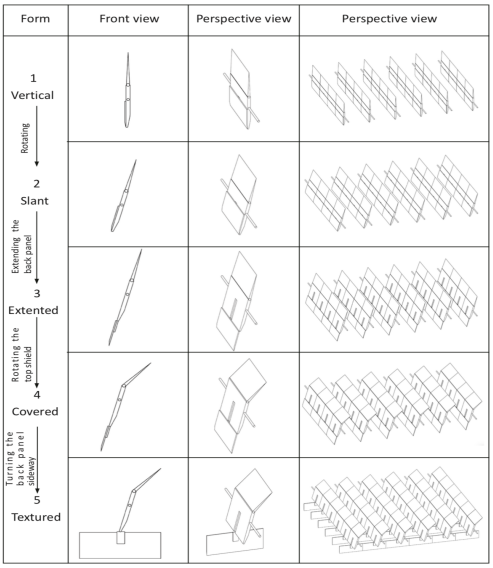


Table 5. The initial design of the roof system (Appendix VII)

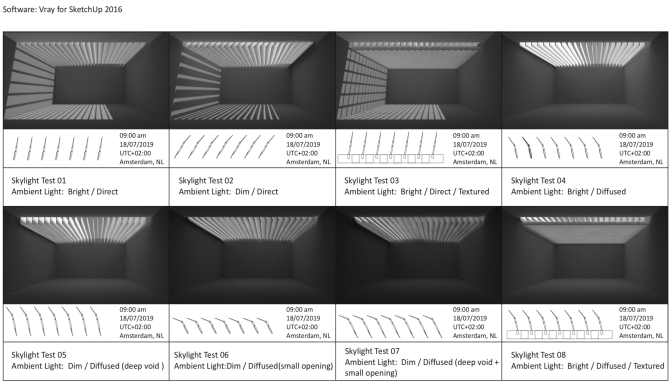


Table 6. Performance test (Appendix VIII)

IV. CONCLUSION:

This paper aims to find a way to shape different skylight environments through a roof system in order to help people psychologically feel comfortable when faced with the relocation process after moving in a nursing home. The premise of the study is the trend of transformation of future hospitals from medical institution to a complex of medical and nursing institution. By scientific studies, it is clear that the relocation process need to be considered on psychological aspect and the ambient light in public space of the nursing center is a good tool to be used as a way to trigger specific and positive human emotional reactions. Therefore, the research was zoomed in to study the architectural way of shaping skylights and by testing the initial synthetic roof system design, which was guided by the result of case study, we can clearly see the performance was as good as supposed.

Figure 7. The cooperation of tension-cable structure and membrane
(https://www.archdaily.com/553311/students-of-gallery)

The result of this paper will give a specific direction to the technological design of a skylight roof that can shape different ambient lights by only changing the shape of each single unit. Whereas, there are also other issues should be concerned on this roof system instead of the skylight. For example, although the roof system is designed for the control of skylight, under which the public space also needs artificial lights to light it up when it's gloom weather or during the night. Other than that, the indoor climate is also an important issue to which the roof needs to have its position. Therefore, the roof system will be an integrated architectural component, which not only tackle simple problems but more.

Moreover, it doesn't mean that the synthetic roof system proposed and designed in this paper can be promoted and implemented in any circumstances even though it is a modular system that can provide skylight solutions in many different architectural projects. This initial design was only to prove that the research was correct. It still has a long way to go before it can be practically used in actual projects. For aesthetic concern, the material and structure featured in the initial design is considered to be lack of deliberation. In the process of further development, in order to fit in different site conditions, there are many other possibilities in selection of structure and corresponding material. For instance, by shaping the single unit of the roof system with membrane, it can also achieve the ability of creating different ambient lights since the membrane has the characteristic of flexibility, which enables it the be in any shape that fulfills the conditions of reflecting skylight in different ways. In cooperation with tension-cable structure, the unit made of membrane can be organized in a rational way to become a complete roof system, which, to some extent, achieves high degree of architectural aesthetics (*Figure 7*).

*The author makes all graphics and illustrations not mentioned with a source

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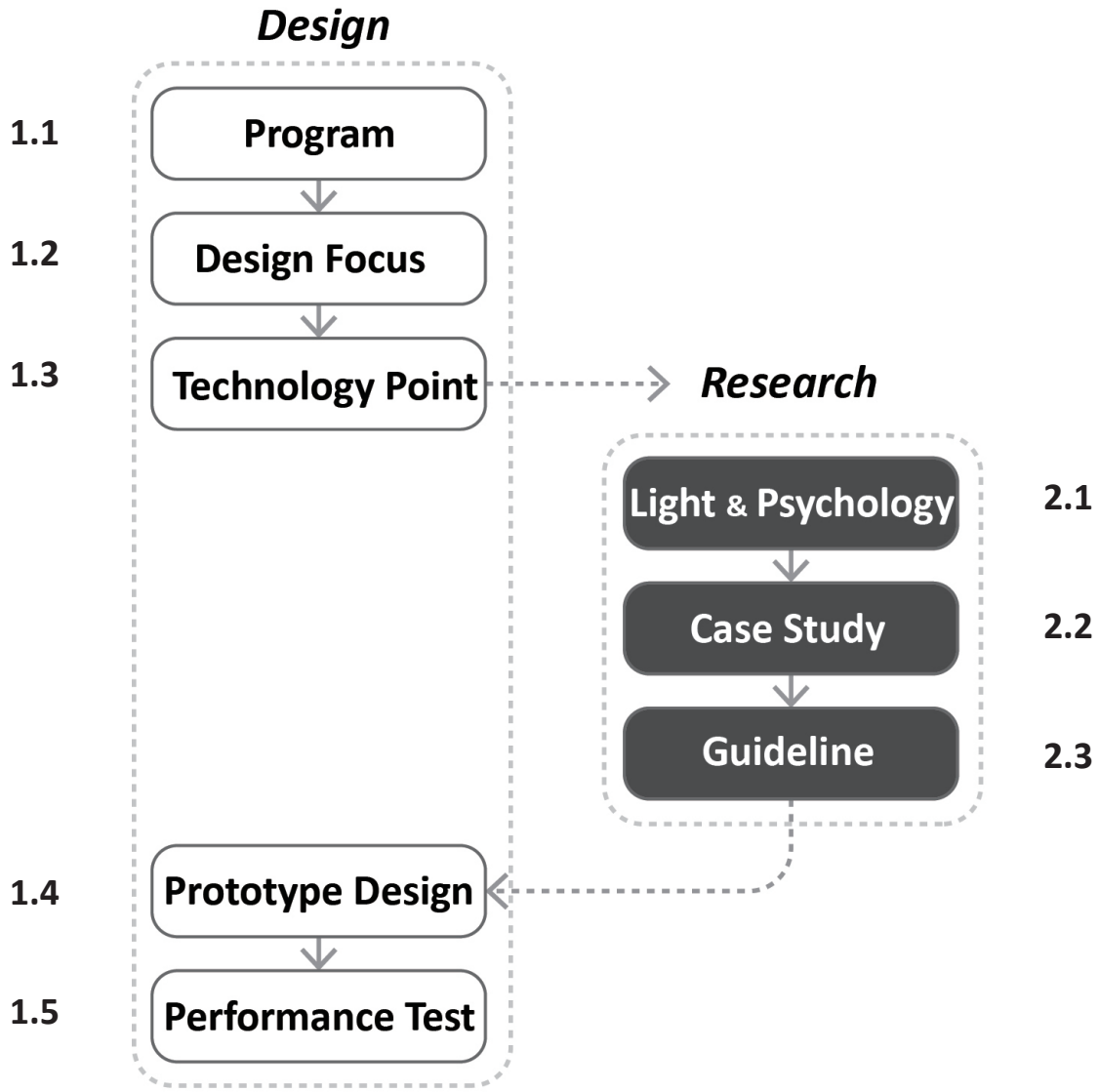
Appendix I

Research for design



Design

1.1 ***Program***: a transformation program for the AMC to be changed to a nursing center from hospital.
2.3 ***Design focus***: the design will be mainly focused on the multi-skylight shaping inthe public space.
1.3 ***Technology point***: to design a synthetic skylight roof system.
1.4 ***Prototype design***: an initial roof design on the basis of case study.
1.5 ***Perfrmance test***: using digital rendering to test the initial design to see if it's working as supposed.

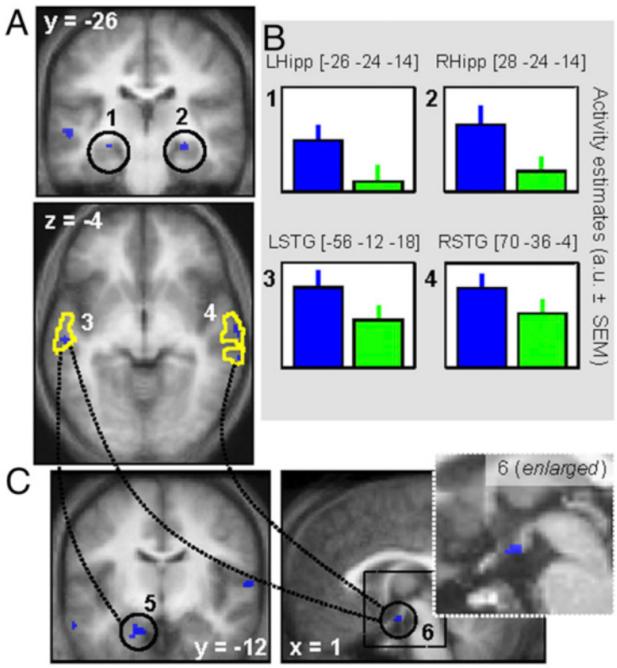
Research

2.1 ***Light & Psychology***: a theoretical research on the relationship between ambient light and human response.
2.2 ***Case study***: a series of studies of the architectural methods of shaping different skylights in actual projects.
2.3 ***Guideline***: a strategistic guide resulted from case study in order to provide the design methods.

Appendix II

Scientific research

1. Impact of the the wavelength of the ambient illumination context on the brain processing of emotional auditory stimuli.

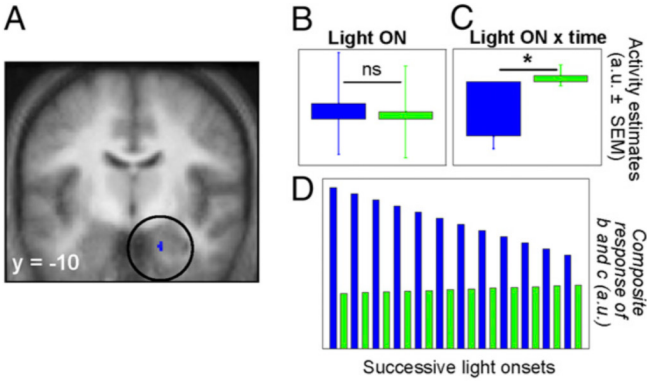


(A) Significant dif- ferences between blue and green monochromatic ambient light exposures in the modulation of the brain responses associated with anger prosody stimuli. Yellow lines indicate voice-sensitive regions activated during the voice localizer (task 2). Dotted lines refer to the functional connectivity analysis (see C). Statistical results are overlaid to the population mean structural image (Puncorrected < 0.001). 1, left hippocampus; 2, right hippo- campus; 3, left superior temporal gyrus; 4, right superior temporal gyrus.

(B) Mean activity estimates [arbitrary units (a.u.) ± SEM] of the brain responses associated with anger prosody during blue and green ambient illumination contexts.

(C) Increased functional connectivity with voice-sensitive regions for anger prosody under blue vs. green monochromatic ambient light ex- posure. Dashed lines/circles indicate higher functional connectivity between left superior temporal gyrus and (5) the left amygdala and (6) the hypo- thalamus (anterior to the mammilary bodies, posterior to the infundibulum) under blue relative to green ambient light exposure, and increased func- tional connectivity between the right superior temporal gyrus and (6) the hypothalamus (anterior to the mammillary bodies, posterior to the in- fundibulum) under blue but not under green ambient light.

2. Differences in responses to blue and green light onsets in the right amygdala.



(A) Statistical results for the blue > green onset contrast modu- lated by time, overlaid on the population mean structural image (Puncorrected < 0.001).

(B) Mean activity estimates [arbitrary units (a.u.) ± SEM] of the constant component of the brain responses associated with blue and green light onsets across the entire session; difference between conditions is nonsignificant (ns).

(C) Estimates of the linear change component (a.u. ± SEM) of the brain responses associated with blue and green light onsets across the entire session, showing a significant (*) negative component for blue light onsets, suggesting an adaptation of amygdala responses with time. (D) Composite of both components showing the evolution of the responses to the 12 blue and green light onsets of the session.

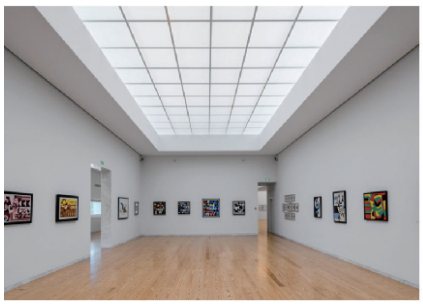
(Vandewalle, G. (2009) Light as A Modulator of Cognitive Brain Function. Trends Cogn Sci, 13:429-438.)

Appendix III

Lighting modes & Human emotional responses

1. Bright light and dim light and their corresponding human emotional responses

Light	Positive influence	Negative influence	Implementation
Bright	attention; exited;efficiency; intensify positive emotions	stress and anxiety when over-lighting	atirum; exhibition hall; reading room
Dim	calmness; steady; security	depression risk when prolonged	meditating room; lounge



Bright: Nadir Afonso Contemporary Art Museum

Dim: Church of Light

(source left : https://www.architonic.com/en/project/alvaro-siza- vieira-nadir-afonso-foundation/5103884)
(source right: source: https://www.archdaily.com/101260/ad-classics- church-of-the-light-tadao-ando)

2. Direct light and diffused light and their correspoinding human emotional responses

Light	Positive influence	Negative influence	Implementation
Direct	visual clarity; pleasant; sense of nature	intense dirctional light causes stress	most public spaces providing relaxing and natural environment
Diffused	attention; efficiency	stress; disoriented; spacialness	library; working space

Direct: Seattle Public Library

Diffused: Bagsvaerd Church

(source left : source: https://www.archdaily.com/11651/seattle-central- library-oma-lmn)
(source right: source: http://pikde.com/media/96686723221678623)

3. Central light and perimeter light and their correspoinding human emotional responses

Light	Positive influence	Negative influence	Implementation
Central	attention; sense of intensity; efficiency	stress and anxiety when intensified	working space; stage
Perimeter	relaxing; hospitality	lack of sense of space; disoriented	lounge;chatting space; private booth

Central: Warehouse Office

Perimeter: Rothko Chapel

(source left:https://archello.com/story/41581/attachments/photos-videos/1)
(source right: https://www.atlasobscura.com/places/rothko-chapel)

Appendix III

Lighting modes & Human emotional responses

4. Lighting colours and human emotional responses

In lighting and interior design, black can be used to portray: authority, power, strength, evil, intelligence, thinning/slimming, death or mourning, elegance, formality, mystery, fear, prestigious, aggressive.

Also known as the **"strength provider."** Green is the color of nature. Green light therapy stimulates the creation of growth hormones and strengthens muscles, bones and other tissues. It can also boost your immune system. In lighting and interior design, it can be used to portray: natural, growth, cool, money, health, envy, tranquility, harmony, calmness, fertility, safety, ambition.

Also known as the **"bringer of peace,"** blue can be used to lower high blood pressure or to calm people down. It's also used for light therapies for people who have circadian rhythm disorders. In lighting and interior design, blue can be used to portray: trust, loyalty, wisdom, confidence, intelligence, faith, truth, sincerity, cleanliness, air, sky, water, health, tranquility.

Purple light can help **reduce emotional and mental stress.** Lighting and interior design can implement purple to portray: royalty, power, nobility, luxury, ambition, wisdom, dignity, independence, creativity, mystery, magic, romantic.

In lighting and interior design, red can be used to portray: love, romance, gentle,warm, comfort, energy, excitement, intensity, life, passion, danger, leadership, courage, friendship.

Also known as the **"source of creativity,"** orange stimulates the creative thought process and help people come up with new ideas. In lighting and interior design, orange can be used to portray: happiness, energy, enthusiasm, warmth, wealth, prosperity, sophistication, change, stimulation.

Yellow can sometimes be beneficial in the **treatment for depression**. In lighting and interior design, yellow can be used to portray: happiness, laughter, cheery, warmth, optimism, hunger, intensity, frustration, anger, attention-getting, caution, sickness, jealousy, intellect, energy.

In lighting and interior design, white can be used to portray: purity, innocence, cleanliness, sense of space, neutrality, safety, beginning, faith, coolness.

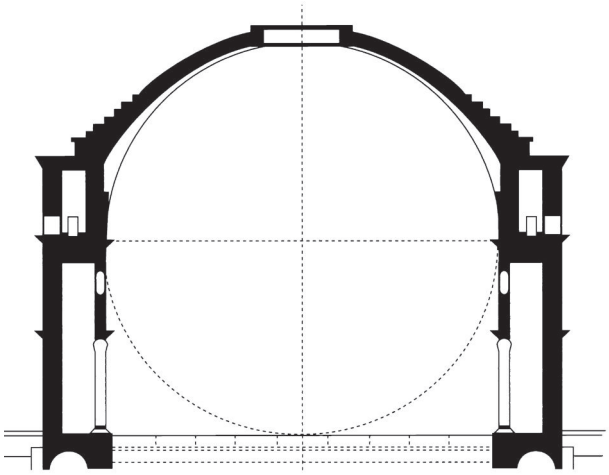
(*https://www.tcpi.com/psychological-impact-light-color/*)

Appendix IV

Case studies

Case study 1 : ***Pantheon, Rome***

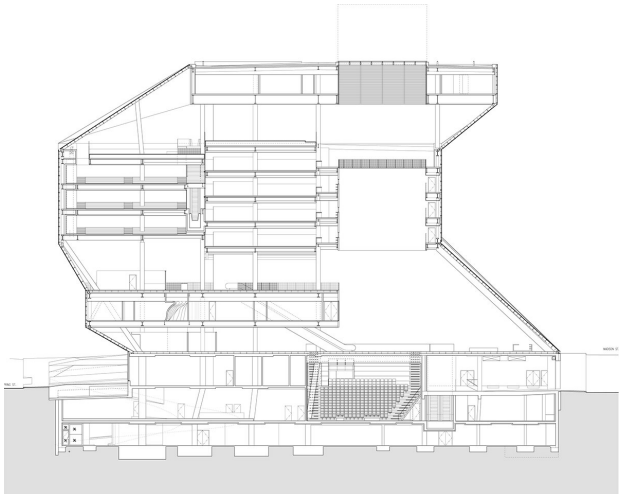
Type: *direct light*
Method: *single bright spot*
Case Study 1: *Pantheon, Rome*



source: https://www.shutterstock.com/zh/image-photo/ inside-pantheon-rome-italy-28-june-634914992?studio=1
source: https://www.pinterest.com/pin/91057223686454622/

Case study 2 : ***Seattle Public Library, U.S.***

Type: *direct light*
Method: *textural shades*
Case Study 2: *Seattle Public Library, U.S.*



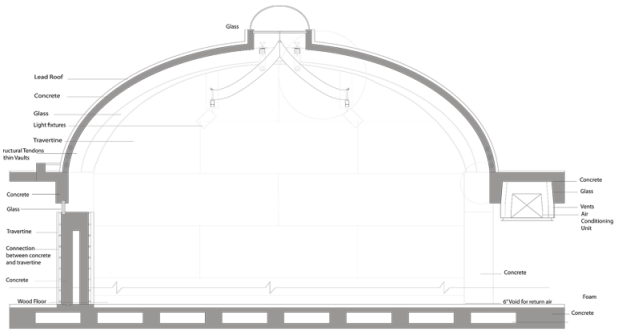
source: https://www.archdaily.com/11651/seattle-central- library-oma-lmn
source: https://lmnarchitects.com/case-study/seattle-central-library-curtain-wall-design

Appendix IV

Case studies

Case study 3 : ***Kimbell Art Museum, U.S.***

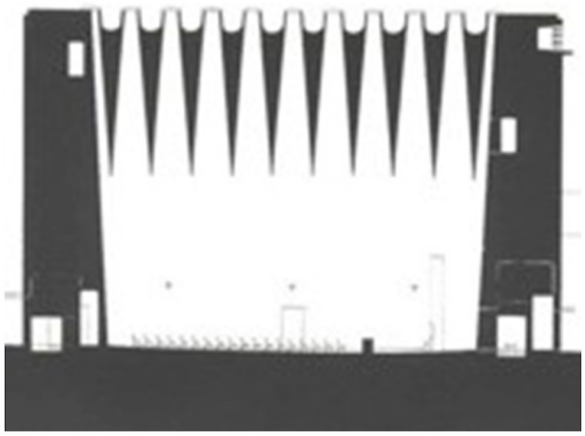
Type: *diffused light*
Method: *top-lighting reflection*
Case Study 3: *Kimbell Art Museum, U.S.*



source: source: https://www.kimbellart.org/
source: https://sites.google.com/site/ae390majorbuildingkam/home/hvac-system/drawings-and-diagrams

Case study 4 : ***Herz Jesu Church, Munich***

Type: *diffused light*
Method: *top-lighting reflection-deep void*
Case Study 4: *Herz Jesu Kirch, Munich*



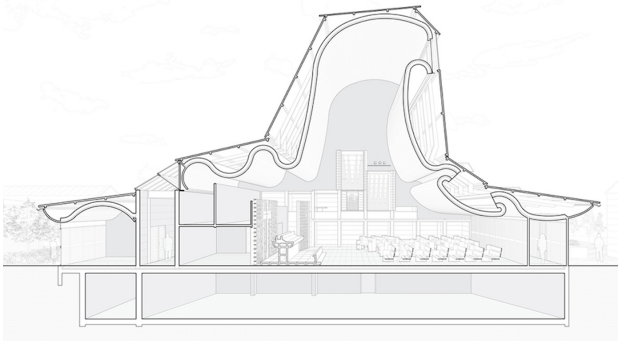
source: https://www.architectural-review.com/essays/reviews/ peter-zumthor-the-swiss-shaman/8667039.article

Appendix IV

Case studies

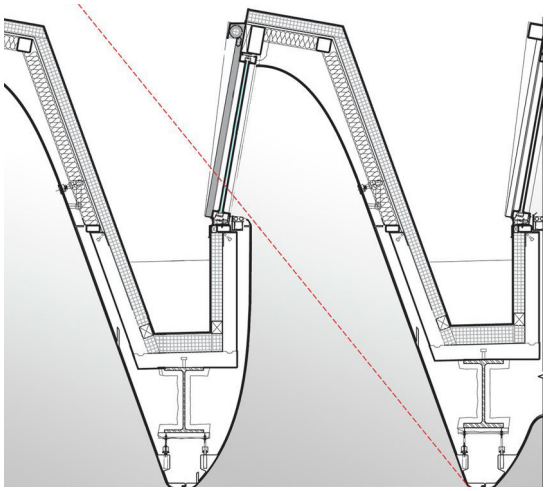
Case study 5 : ***Bagsvaerd Church, Denmark***

Type: *diffused light*
Method: *lateral-lighting reflection*
Case Study 5: *Bagsværd Church, Denmark*



source: http://pikde.com/media/96686723221678623
source: https://sites.google.com/site/ae390majorbuildingkam/home/hvac-system/drawings-and-diagrams

Case study 6 : ***Borad Museum, LA***

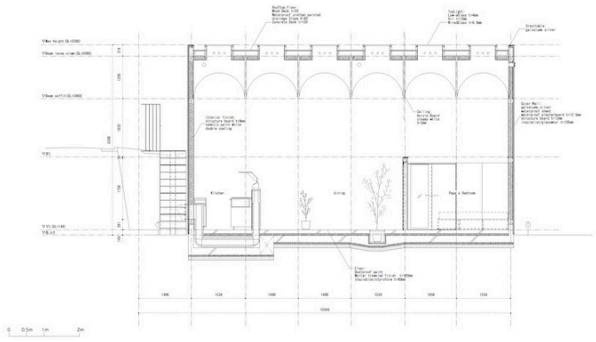


source: https://www.archdaily.com/101909/design-unveiled-for-the-broad-museum-by-diller-scofidio-renfro

Appendix IV

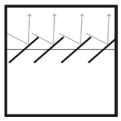
Case studies

Case study 7 : ***Daylight House, Japan***

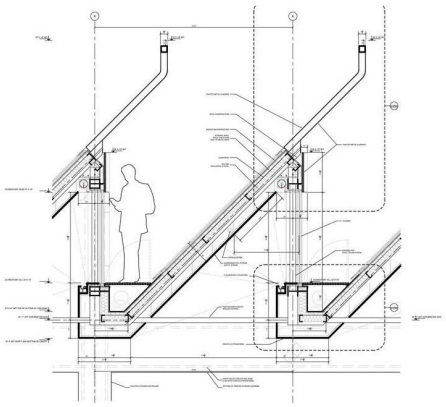


source: https://www.dezeen.com/2011/09/28/daylight-house-by-takeshi-hosaka/

Case study 8 : ***Beyeler Foundation, Switzerland***



Type: *dim light*
Method: *rebound*
Case Study 8: *Beyeler Foundation, SZ*



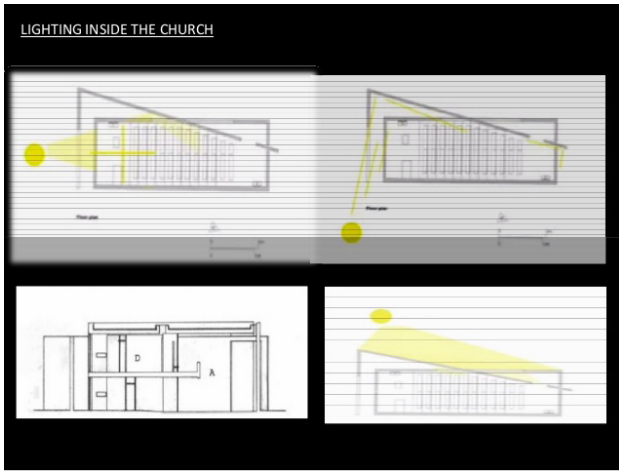
source: https://www.architectural-review.com/essays/reviews/ peter-zumthor-the-swiss-shaman/8667039.article

Appendix IV

Case studies

Case study 9 : ***Church of the Light, Japan***

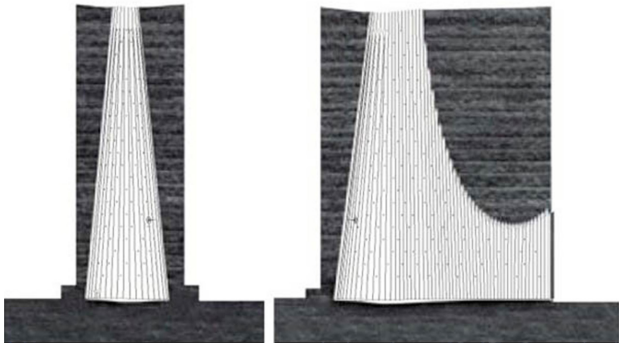
Type: *dim light*
Method: *small opening*
Case Study 9: *Church of Light, Japan*



source: https://www.archdaily.com/101260/ad-classics- church-of-the-light-tadao-ando
source: https://www.slideshare.net/hetalibhatt/5artadao-ando

Case study 10 : ***Bruder Klaus Field Chapel, Germany***

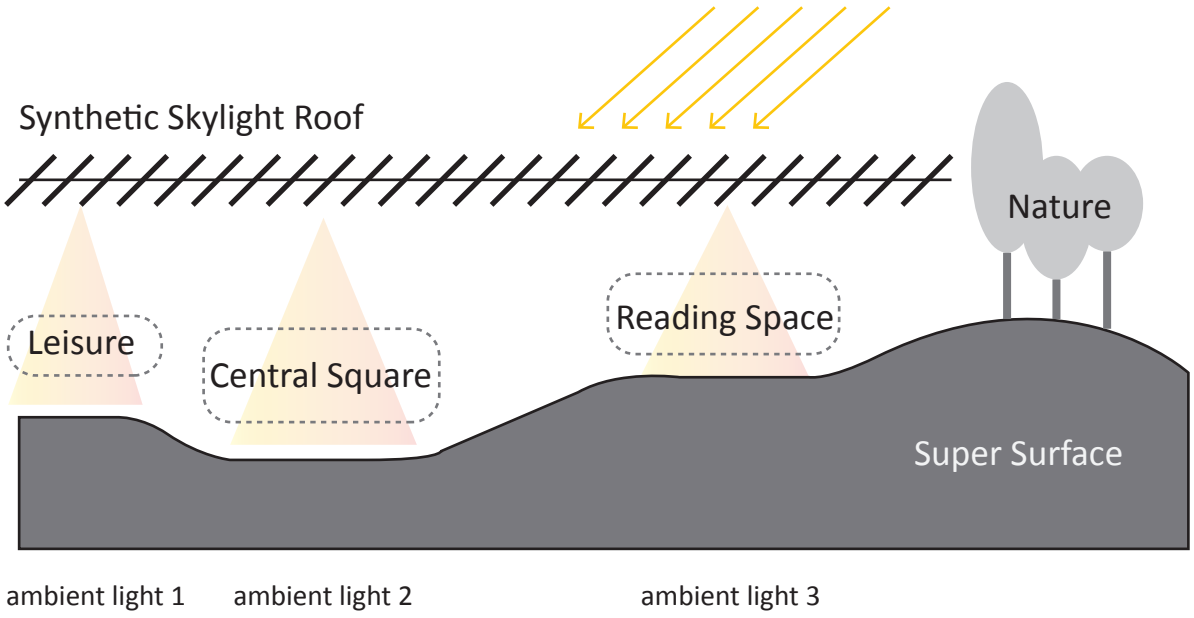
Type: *dim light*
Method: *single bright spot*
Case Study 10: *Bruder Klaus Chapel, DE*



source: https://www.architectural-review.com/essays/reviews/ peter-zumthor-the-swiss-shaman/8667039.article

Appendix V

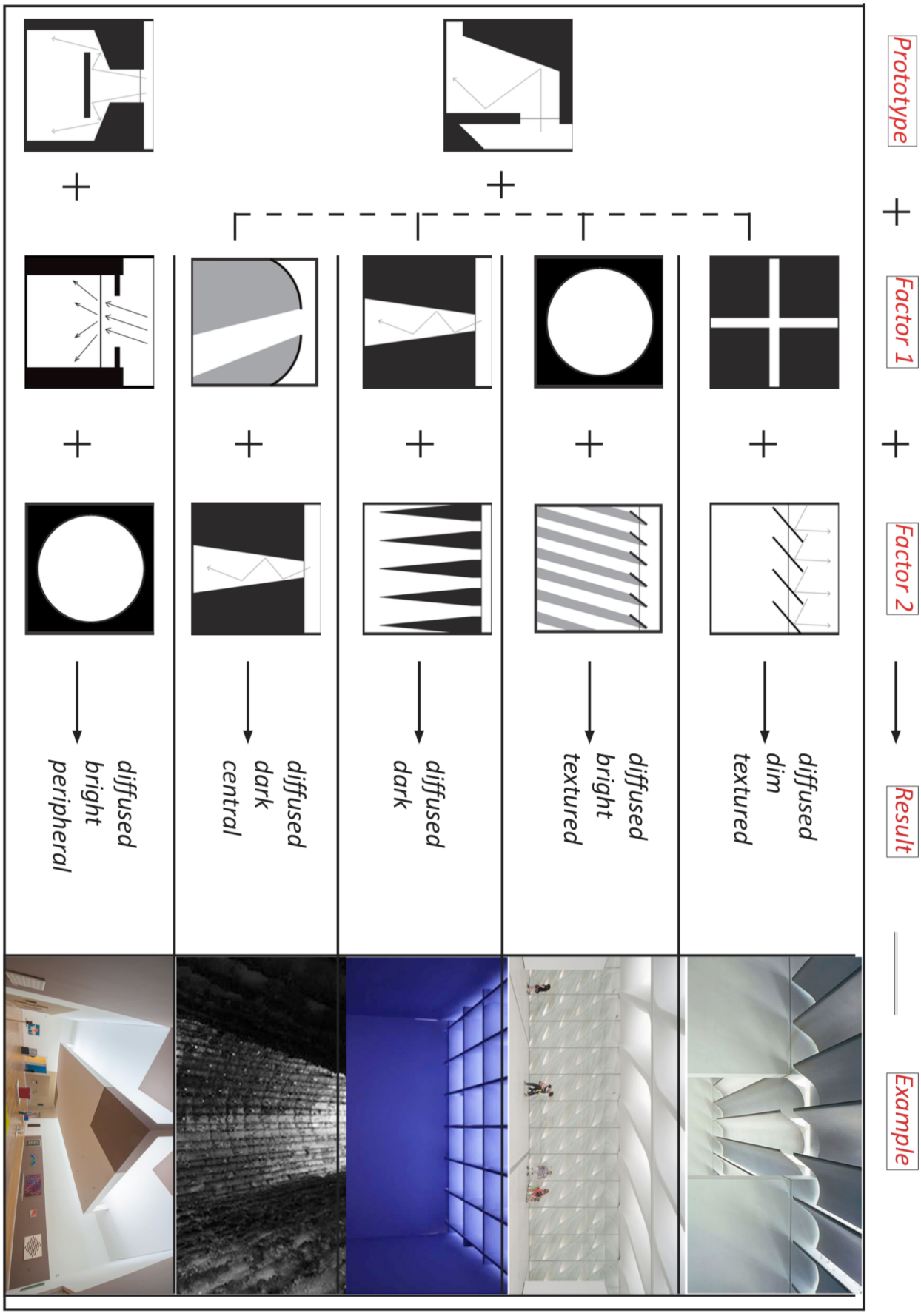
Synthetic skylight strategy



The strategy of shaping different ambient lights in the public space of AMC

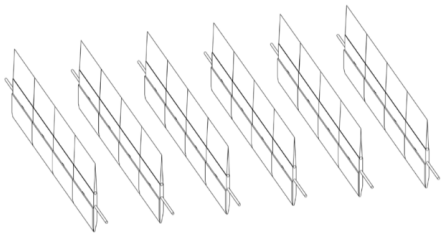
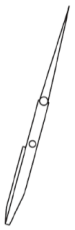
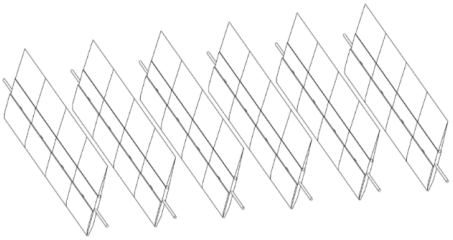
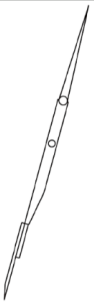
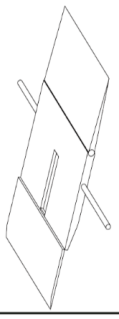
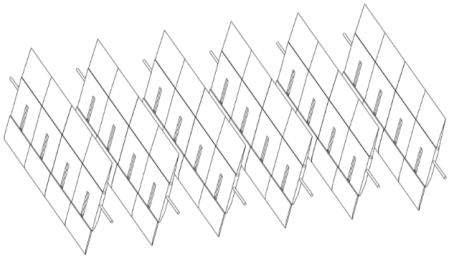
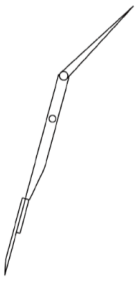
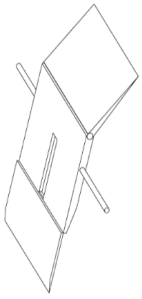
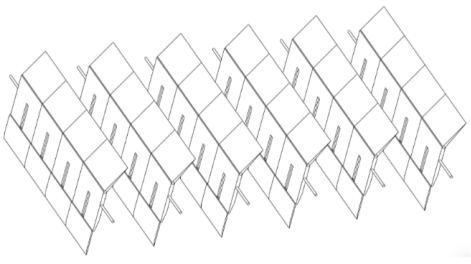
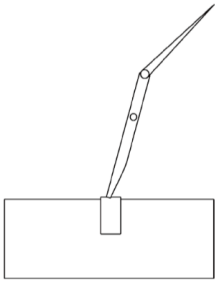
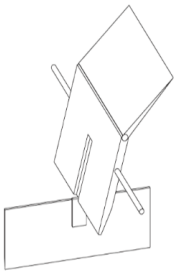
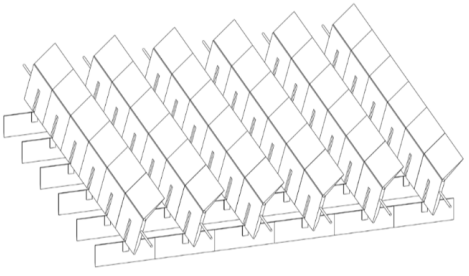
Appendix VI

The composition of roof unit and corresponding ambient lights



Appendix VII

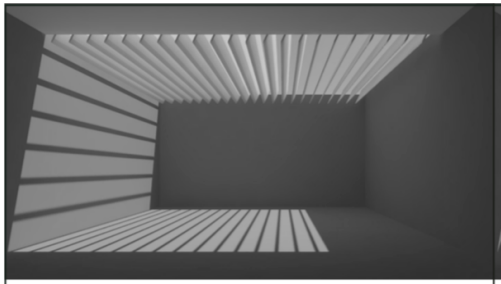
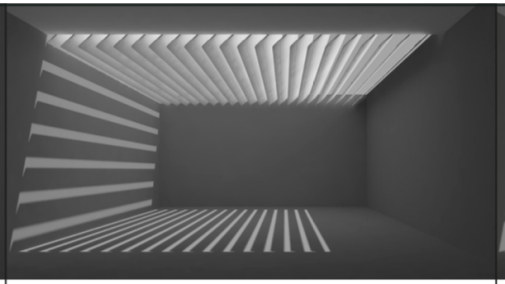
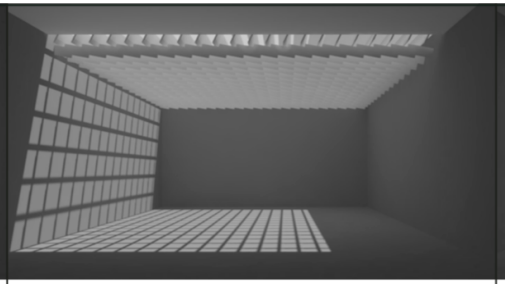
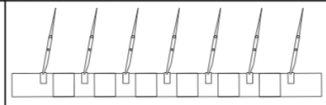
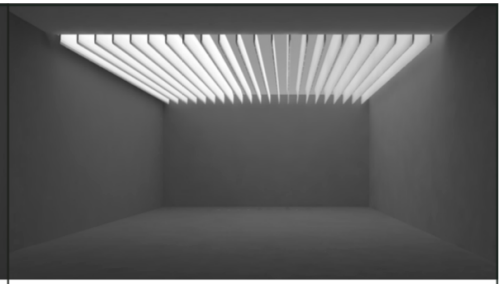
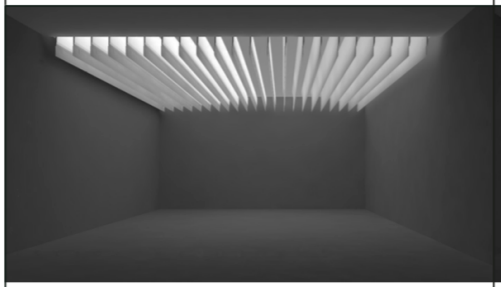
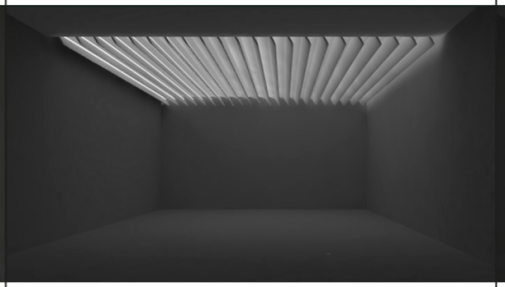
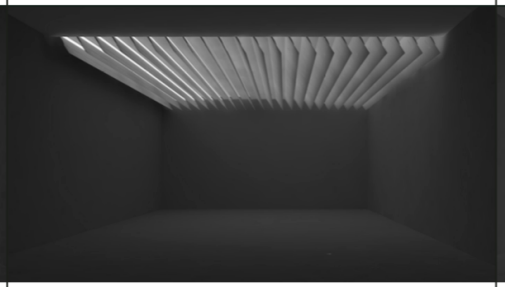
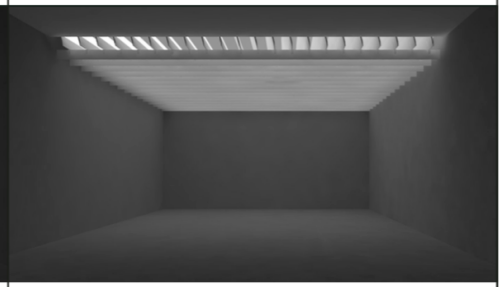
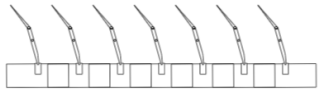
The initial design of the roof system

Form	Front view	Perspective view	Perspective view
1 Vertical			
Rotating ↓ 2 Slant			
Extending the back panel ↓ 3 Extented			
Rotating the top shield ↓ 4 Covered			
Turning the back panel sideway ↓ 5 Textured			

Appendix VIII

Performance test of the initial designed roof system

Software: Vray for SketchUp 2016

 	 	 	 
Skylight Test 01 Ambient Light: Bright / Direct	Skylight Test 02 Ambient Light: Dim / Direct	Skylight Test 03 Ambient Light: Bright / Direct / Textured	Skylight Test 04 Ambient Light: Bright / Diffused
 	 	 	 
Skylight Test 05 Ambient Light: Dim / Diffused (deep void)	Skylight Test 06 Ambient Light:Dim / Diffused(small opening)	Skylight Test 07 Ambient Light: Dim / Diffused (deep void + small opening)	Skylight Test 08 Ambient Light: Bright / Diffused / Textured