A STUDY OF THE CHARACTERISTICS OF NATURAL LIGHT IN SELECTED BUILDINGS DESIGNED BY LE CORBUSIER, LOUIS I. KAHN AND TADAO ANDO

A Thesis

by

SUKHTEJ SINGH GILL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2006

Major Subject: Architecture

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Approved by:

Chair of Committee,	Valerian Miranda
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ABSTRACT

A Study of the Characteristics of Natural Light in Selected Buildings Designed by Le Corbusier, Louis I. Kahn and Tadao Ando. (August 2006)

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The thesis discusses the characteristics of natural light that are visible inside concrete buildings designed in the late twentieth century. The study addresses three major objectives. First is to identify the characteristics of natural light visible inside these spaces. Second is to understand the use of natural light to illuminate different spaces. Third is to explore the relation between the characteristics of natural light and the overall perception of the space. With these objectives in mind, a comprehensive literature review was done to develop the hypotheses for this thesis.

The first hypothesis states that the overall perception of a space is affected by certain basic characteristics of natural light. The second hypothesis suggests that the overall character of a space can be enhanced by emphasizing the source of natural light as a visual element.

To test these hypotheses, this thesis studies the effect of natural light in three buildings made out of reinforced concrete in the late twentieth century. The three buildings are the Chapel of Notre Dame du Haut Ronchamp by Le Corbusier, the Kimbell Art Museum by Louis I. Kahn and the Church of the Light by Tadao Ando. The

method of analysis is based on the selection of a spatial envelope in each building that helps to provide an ideal framework for studying the effects of light. The method takes into consideration the principles of visual perception and the use of images depicting the varied effects of light inside the spatial envelope.

The results of the analysis show that the three projects employ similar design principles to achieve some of the common effects of light, and the listed characteristics of light in relation to the overall perception of the space do not vary to a great extent when moving from one project to another. The emphasis on the source of natural light is a common and recurring theme in all three buildings. The thesis concludes that the results support the hypotheses, and that the quality of a space is dependent upon the way a designer brings natural light into the space**.**

to my teacher …

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CHAPTER I

INTRODUCTION

With the rise of modernism in the early twentieth century, the design process in architecture went through a major transition, one that was to transform the character and ambiance of the everyday spaces. New materials were introduced and the improving technology provided innovative ways to use them in the construction of the buildings. Glass, steel and concrete became the abundantly used materials for construction. The 'open plan' and freeing of the outer skin from the inner structure made a strong impact on the internal layout and the expression of different spaces in each of the building types. The use of glass, as an external membrane to the building envelope, removed the need for traditional windows in most of the building facades. Concrete and steel brought in much needed freedom to the form and design of different spaces. Openings for light were no longer restricted to a horizontal plane, as the case was with the traditional windows, but would exist based on the relation between the exterior and the interior bringing in varied light from all different planes. Openings of different sizes and orientations were used to transform the natural light as it was brought inside the building that gave these spaces a unique character.

Reinforced concrete, as a material of construction, offered structural advantages that brought in a host of possibilities to the design of different spaces. The plasticity of concrete was used to mold it into different shapes thus bringing new forms to be seen in

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This thesis follows the style and format of *ASHRAE Transactions.*

modern architecture. In this homogeneous structural envelope, architects found new ways to carve out openings for light that could transform the quality of spaces inside a built form. Experimentation continued with architects such as Le Corbusier who came up with a well defined vocabulary in his 'Five Points of a New Architecture' in 1926 (Tzonis 2001). The ribbon windows demonstrated a conscious attempt, on the part of the architect, to control the quality of light inside the buildings by manipulating the size and proportions of the opening.

Curtis (1996) points out that the period from 1945 till the death of Le Corbusier in 1965 produced the kind of work which brought 'new patterns of form and meaning' to architecture. Dealing with the quality of light, he used 'brises-soleil' and 'Light Canons' to manipulate the effect of natural light once it underwent the transformation from the outside to the inside. The buildings he designed in this period served as leading examples to some of the most innovative work done with the use of natural light inside a space built in concrete.

Louis I. Kahn and later Tadao Ando are two of the master architects who continued to work primarily with reinforced concrete as a material of construction and expression, in the late 20th century. Their emphasis was on improving the quality of spaces inside the buildings through the use of natural light, as evident from most of the material published on their projects and their individual writings on the subject of architecture. Though the work of these three architects spans across different continents, their projects depict new ways of controlling various effects of natural light in a similar vocabulary of architecture.

1.1 SCOPE

An analysis into some of their well known projects can bring out underlying characteristics of natural light that these three architects share in their approach to the design of a built space. The present research will be unique in its attempt as the context of the study is based on the use of reinforced concrete as a common material of construction and expression which differs from the distinction based on a building type. The monochromatic surface provides a neutral ground to study the characteristics of natural light which are highlighted to an even greater degree as there is little deviation in the reflective properties of a built space while comparing different projects.

1.2 SIGNIFICANCE

Since there has not been much research regarding the quality of natural light by selecting buildings with similar material of construction and analyzing the space for different effects, this study provides an opportunity to address different issues related to light and expression of a space in a collective manner. The outcomes from this study could help designers in the use of natural light to design and articulate spaces. The methodology developed and tested in this study could form a basis for analyzing other architects use of natural light in public spaces. A similar approach could be used for instructing design students in the configuration and articulation of spaces using natural light.

1.3 OBJECTIVES

In pursuing this investigation, the study addresses three major objectives. First is to identify the characteristics of natural light visible inside these spaces. Second is to

understand the use of natural light to illuminate different spaces. Third is to explore the relation between the characteristics of natural light to the overall perception of the space.

1.4 RESEARCH QUESTIONS

What are the underlying characteristics of natural light in the buildings made of concrete in late twentieth century?

How do these relate to the overall perception of a space?

1.5 HYPOTHESES

The first hypothesis states that the overall perception of a space is affected by certain basic characteristics of natural light. The second hypothesis suggests that the overall character of a space can be enhanced by emphasizing the source of natural light as a visual element.

1.6 LAYOUT

The thesis is divided into six chapters including Introduction, Literature Review, Method, Analysis, Results, Summary and Conclusion.

The Literature Review covers four major topics. First, the historical context of natural light inside the buildings, and the way it relates to the present time frame of the thesis topic. Second, the quality of light inside the buildings designed by Corbusier, Kahn and Ando in the second half of the twentieth century. Third, descriptive interpretation of the role of natural light in terms of the character of a space in the present context of the study. Last, studies related to the scope of different methods in dealing with the role of natural light inside a built space.

Chapter III Method, describes the primary criteria for the analysis of different buildings based on the relation between the light and the space. This thesis draws on logical argumentation as an underlying research methodology in an attempt to investigate the basic characteristics of natural light in buildings made of reinforced concrete, and the way these relate to the overall perception of a space. Michel (1996) establishes criteria for the analysis of architectural space in relation to overall lighting. This criteria has been used to analyze the different effects of natural light in the spaces designed by Le Corbusier, Louis I. Kahn and Tadao Ando.

Chapter IV Analysis, is divided into three major sections. Each section deals with the analysis of a spatial envelope inside one of the selected buildings by each of the three master architects. The selected buildings are: Chapel of Notre Dame du Haut Ronchamp by Le Corbusier; Kimbell Art Museum by Louis I. Kahn and Church of the Light by Tadao Ando.

Chapter V Results, describes the underlying patterns observed in the analysis of these three buildings.

Chapter VI Summary and Conclusions, summarizes and discusses the results.

CHAPTER II

LITERATURE REVIEW

The literature review will cover four major topics: (a) Historical perspectives on natural light inside the buildings; (b) Light quality in concrete buildings of late 20th century; (c) Light in relation to the revealing character of a space; (d) Scope of different methods of investigation.

2.1 HISTORICAL PERSPECTIVES ON NATURAL LIGHT INSIDE THE BUILDINGS

The role of natural light inside a built space has seen a sea change starting with sunlight as the only source of light and slowly moving towards greater dependence on artificial sources of light. The last century has seen a tremendous shift with the advent of electrical lighting and its easy availability. The increasing need for control in the illumination levels inside a space has been emphasized through the use of static artificial lighting. The variation in the character and ambience of a space, with the movement of the sun across the sky and the changing seasons, has been sacrificed in the process. This shift while increasing the energy dependence has also made the interior devoid of a strong relation with the exterior.

Primitive accounts on the use of natural light can be traced back to the strong rays of sun penetrating through the extreme darkness of a cave. All through this time, natural light has been a primary source for illumination used, with varying degrees of control, in different kinds of shelters built by human beings in pursuit for survival and

comfort. The intuitive and artistic sense with which light openings have been carved of different surfaces has brought in a sense of place that is unique in so many different ways. Daylight has been associated with strong symbolic meanings in the way it was made to enter a space and cast shadows on different surfaces.

This part of the literature review will focus on the use of natural light in its different manifestations inside the built environment in the context of their historical period. It will deal with the symbolic meanings of natural light as well as the manner in which it was controlled to create different effects inside a built environment.

Phillips (2004) lays an emphasis on the history of windows and of daylighting, which he says is synonymous with the history of architecture. The nature of windows relate to the appearance of buildings. In mediaeval period, the shape and location of windows was related to the function and role they would perform in the overall daylighting of the interior spaces. This changed in the Renaissance period as windows became formal objects seen as part of the elevation thus loosing the connection with the interior spaces. For military needs, slit windows with splayed sides were used to reduce the overall contrast as the light would spread along the interior wall surface. Indirect lighting was used in the baroque churches of southern Germany from windows concealed of a direct view from the congregation. Vertical windows in the external façade had been used throughout, but it was the use of roof lights to allow daylight in the central part of the building that had an influence on the stately homes of the seventeenth and eighteenth centuries. This gave the architect freedom in the layout of the central areas in the plan that could receive daylight from different kinds of openings on the roof.

The modern movement in England in the 1930s saw the use of full walls of glass and wrap-around windows at corners. This was one of the earliest attempts aimed at expressing the freedom in the relation between the exterior and the interior. On the same note the growth of the workplace in the nineteenth century had seen a need for higher levels of illumination, thus forcing a greater dependence on a controlled environment where primary illumination was achieved through artificial lighting. The ever increasing use of artificial lighting led to windowless built environments by the middle of the 1960s, thus raising questions regarding the association of the interior with the natural environment and its importance.

Moore (1985) gives a brief summary on the historical response towards natural light inside the built environment. According to him, daylight has been associated by symbolic meanings of cleanliness, purity, knowledge and heaven apart from its main role to illuminate a space. He categorizes the use of natural light into three different sections – Preindustrial, Industrial and Postindustrial Architecture which have been discussed below with further subheadings.

2.1.1 PREINDUSTRIAL ARCHITECTURE

The ancient civilizations reveal some of the most interesting transitions in the way light is brought inside a space. The use of openings both large and small helped in creating different effects that revealed the intensity with which light was made to enter a building.

2.1.1.1 Egypt

In ancient Egypt, the openings of light were restricted by the limited freedom offered by the structure as well as the harsh climate. This brought in soft and diffused sunlight through the thick walls of masonry, as in the process of transformation the rays of sun would go through multiple side reflections. Clerestory openings with carved grills would bring in soft light deep inside the large temples thus reinforcing the geometrical sequence of spaces inside (Moore 1985).

According to Baker and Steemers (2002), the Egyptian temples depict innovative use of light on a grand scale that shows deep understanding of the effects of sunlight in the desert landscape. The intensity of the sunlight has been used to reveal the three dimensional forms by the contrast of light and shadow inside the built space. The building form and the sequence of spaces were planned in a manner that accentuates the processional movement from light to dark.

2.1.1.2 Greece

The mild climate of Greece made it possible to bring in strong narrow shafts of light. The temples oriented towards the east allowed the rays of the rising sun to enter through the doorway and shine brightly over the statues. Diffuse sky light and reflected ground light would reveal the decorated and ornamented forms of the structure. The planning principles revolved around the use of sundial so that winter sun could penetrate deep inside the spaces (Moore 1985).

Baker and Steemers (2002) point out the use of strong daylight in the Greek temples to reveal the depth of the façade. The shadows created by the layers of closely

spaced columns in the front of the stone walls further accentuate this effect. The sharply fluted channels on the column shafts are revealed in profile through the change in the light and shade patterns of the vertical lines.

2.1.1.3 Rome

The structural limitations of the post and beam construction made it impossible to have large openings so most of the interior spaces were dimly lit. This changed with the advancements made in Roman Period. Whereas the use of sunlight in the Egyptian and Greek monuments was to reveal the exterior form and surface modeling through the play of light and shade, the Roman and Gothic monuments depict the integrity of the structure and the way light is brought inside a space (Baker and Steemers 2002).

The architectural developments in Rome show a careful understanding of the principles involved in daylighting and solar passive heating. The structural advantages gave way to large uncolumned interiors and window openings that could bring in sheets of light deep inside a space. Skylight and concealed clearstory windows were used to make the path of light visible inside a space. The Pantheon stands as a strong example that illustrates this effect (Moore 1985).

2.1.1.4 Early Christian

The basilica building type during the Early Christian architecture was one of the prominent forms that came to be associated with a particular building type, religious in this case. It was an attempt at improvisation with the timber trusses replacing the roman concrete vaulting that resulted in reduced wall area for the clerestory windows. The low

levels of light inside the building served to enhance the mystical nature of the spatial layout by reinforcing the linear perspective towards the altar and religious functions, which were associated with the apse that received greater visual emphasis due to the windows surrounding its semi circular plan (Moore 1985).

2.1.1.5 Byzantine

The Byzantine architecture was characteristic of the use of dome supported at only four points covering a rectangular plan form. This allowed small stained-glass light openings at the base of the dome making it appear to float above the supporting structure. During the Romanesque period minor changes took place in the layout of the basilican church plan. Windows were relatively small thus keeping the mystical quality of the space intact (Moore 1985).

2.1.1.6 Gothic

Baker and Steemers (2002) provide a detailed account of how the symbolism and imagery of light and dark were used as ideal vehicles to express religious mysteries and to inspire devotion. They support this view by a quote from Watkin (2005, p.126), “The elimination of the massive wall structure and the frontality of Romanesque churches in favor of a lighter and more diaphanous structure with an emphasis on diagonal lines and views”. The use of stained glass to create a colored and mysterious quality of space can be seen as a predominant effect to achieve an association of God with light.

The Gothic period saw a tremendous improvement in the structural sophistication of stone masonry. The wall was freed of its traditional role of supporting the roof

allowing for large expanse of stained glass openings. The east west orientation of the gothic cathedrals resulted in higher levels of illumination with the light entering through the windowed façade on the south (Moore 1985).

2.1.1.7 Renaissance

The experimentation with light quality continued through the Renaissance period. The thick walls and ceilings allowed for deeply recessed light openings thus allowing for dramatic quality of light that was used to emphasize forms not previously seen. The dome structure was made of two different shells thus carving out a complex path for daylight to enter through the upper portion of the dome (Moore 1985).

The association of light was more in terms of a metaphysical link between the object and soul and as an enhancement of the sense of life. The symbolic association of light defining the eternal grew obsolete. The emphasis was on the qualities of nature that formed the basis for linking and evoking emotional response to light. There was a revival of interest in the visual harmony and proportion that resulted in the effective manipulation of daylight to emphasize form and dramatize space (Baker and Steemers 2002).

2.1.1.8 Baroque

The series of investigations beginning with the premises of Borromini had light as their central concern. The extremely refined technique of fusing incident and reflected light in the same spatial enclosure demonstrated the increasing control of light in relation to the achieved effect. In the last decades of the eighteenth century, light was brought into the

space from the openings that were regulated based on the modular proportioning of the façade (Portoghesi 1994).

The architecture in Baroque was characterized by a sculptural exuberance and dynamic spatial qualities. There was a considerable emphasis on the articulation of the form that provided greater control of light as it entered the space through the overlapping layers of enclosure. The mysterious quality of light introduced from the perforated vaults in an indefinite spatial enclosure was used to signify transcendence from the earth to the heaven. The use of large number of deeply recessed openings to diffusely illuminate the interior created an atmosphere of illusion and mystery. Most of the sculptural decorations were illuminated through the use of oblique light rays emphasizing the three dimensional forms through light and shade (Baker and Steemers 2002).

2.1.2 INDUSTRIAL ARCHITECTURE

The technological advancements of the industrial revolution changed the relation of the interior from the exterior of a building. The interdependence of the two was minimized to an extent where it was possible to ignore the environmental conditions. For the first time, architect had enough freedom from the constraints that had influenced the form of the building thus marking a definitive shift in the course architecture was to follow in the future. The use of steel as a structural member removed the need for traditional load bearing walls with a thin outer skin. This opened the possibility of using large sheets of glass in the exterior to bring in increased levels of illumination (Moore 1985).

Baker and Steemers (2002) point out the examples of the railway sheds in the 1830s and 1840s that used the strength of iron to provide a structural framework that

opened the indoor space by removing the need for load bearing walls. Space and light could merge with an even greater freedom. This was followed by the more refined greenhouses and arcades that were further transformed into the astonishing exhibition structure, the Crystal Palace by Joseph Paxton.

The advent of electrical lighting made it possible to have increased floor area far removed from the proximity to the exterior thus reducing the overall dependence upon the natural source of light. Ceiling heights came down and the operable windows became redundant with most of the building opting for a mechanical ventilation system. Mass production of the construction materials brought in a change in the overall vocabulary of the buildings clearly demarcating the start of a modern era that was to see the building soar to new vertical limits (Moore 1985).

For the first time, the design of a built environment could be done with a complete isolation from the outside environment – artificially lit, heated and cooled. The use of glass and steel could help in covering large spaces, both horizontally and vertically, thus leading to the construction of high rise, deep plan, tower blocks. The use of large sheets of glass in the perimeter brought in high levels of daylight around the perimeter at the cost of increased glare, excessive solar gains and heat losses, and a lack of privacy. The scientific progress in the measurement of light levels helped in achieving required lux levels on the work plane. But the analysis based on the illuminance levels was still not able to throw light on the emotional content of the luminous environment and in providing an explanation to the beauty of a space (Baker and Steemers 2002).

The modern movement saw the rise of some prominent architects who employed the new found freedom in the use of materials and structure to explore new building forms. Architects, such as Wright, Corbusier and Aalto, were pioneers in using the new building technology as a means to explore fresh dimensions while retaining the historical principles of site orientation, natural ventilation and daylight illumination. Others used it as an end to generate the building form while ignoring the climate. This brought in the international style that broke free from the use of localized elements that were characteristic of the traditional architecture. The simple geometric building forms were seen as a reaction to the over ornamentation of the classic revival architecture of the previous century (Moore 1985).

2.1.3 POSTINDUSTRIAL ARCHITECTURE

The use of technology for artificial lighting and mechanical ventilation had called for an ever increasing load on the energy costs of the building. The oil embargo of 1973 saw steep rise in the prices. The energy costs could no longer be ignored and thus saw an awakening while dealing with issues of lighting and ventilation. Around the same time there was another architectural moment that surfaced bringing in a postmodern style. It was a reaction to restore the visual interest, richness and variety through the use of color, ornamentation and spatial organization that were characteristic of the new style. However, some critics still regard all this as purely cosmetic thus not differentiating from the international style it sought to replace (Moore 1985).

2.2 LIGHT QUALITY IN CONCRETE BUILDINGS OF THE LATE 20TH CENTURY

The architectural research focused on light as the central theme in the period that is known as Expressionism that spanned before and after the First World War. The thought of building new cities with glass as the predominant material of expression saw some of the utopian ideas being put on paper before the actual reconstruction began.

"It is a light which plays on the subjectivity of perception, a light filtered, guided, and materialized, determining a kind of identification within the observer between light and space, extension and illumination" (Portoghesi 1994, p. 9).

Plummer (2003), talks about the change in the light quality of different spaces towards the start of the twentieth century. He associates this with a much broader understanding of the perceptual, physiological and psychic experience associated with the way light behaved in a space.

Until this point, light was associated of a dialectic nature, emerging from the shadows and having metaphysical connotations. This changed with the early works of Corbuiser and Gropius, as the efforts to build a new society were achieved by means of production. The theme of transparency and light became predominant in a vocabulary that followed from the reduction of architecture to a figurative art. "The rational and Cartesian light of the functionalists is not born from darkness, and has no need for its opposite in order to exist and assert itself; it lives autonomously, asserts itself as the natural and necessary condition of an architecture intending to prefigure a pacified society, free of contradictions and internal conflicts. Gropius' Bauhaus, Rietveld's

Schröder House, the Villa Savoye by Le Corbusier, three of the most celebrated models of functionalism, share the same conception of light, understood as 'universal light' that describes the geometric consistency of the architectural object: an ideal midday light, inclined at 45°, which penetrates the interior without changing quality, since all divisions between the interior and exterior are temporary and occasional, and do not 'separate' different worlds, but at most distinguish 'zones,' separate a 'microclimate' within the same environment" (Portoghesi 1994, p. 9-12).

Although there were a number of architects that made significant contributions, it is not possible to list each of their work individually. This section of the literature review attempts to delve deep into the works of Le Corbusier, Louis I. Kahn and Tadao Ando. It is aimed at providing a better understanding of the existing literature on the way these three master architects manipulated the effect of natural light inside their buildings. Also, the focus is on the use of concrete as a common material of expression, and the way it is manifested in the overall expression of the built form.

2.2.1 LE CORBUSIER

Pauly (1997) lists the work of Le Corbusier in a way that light becomes the language expressed in his architecture. He quotes Corbusier, 'As you can imagine, I use light freely; light for me is the fundamental basis of architecture. I compose with light.' The light sources have been used in a restrained manner, but Corbusier lays utmost importance to their placement that defines the interior volumes.

Transparency retained its symbolic value in the early projects by Corbusier such as Geneva Apartment building in which clarity of light has been used to provide

meanings of form to different objects. "Transparency and light in the functionalist code are, however, intellectual symbols that aim not at evoking impressions, sensations and emotions, but merely at confirming an affirmation of a principle that identifies light with hygiene and habitability, and with the moral call to the necessity that nothing remain mysterious and hidden in the development of social relationships, in the operation of great machine of human society" (Portoghesi 1994, p. 12).

The earlier work of Le Corbusier, that found a common expression with other architects working under the banner of International style, can be associated with the concept of luminosity and clarity of a space. This was in direct contrast to the dialectic nature of light that was aimed at expressing a space through contrast of light and shadow rather than a uniform blanket of white light impoverishing the effects of light. Portghesi (1994) lists art deco as one of the important movements in the 1920s that aimed at the improvisation of the traditional models to the current function and taste of modern society, which finally led to the revival of interest in the varied effects of light and shadow from the universal, technological and absolute light of the International style. The period after the Second World War saw some of the great examples that were to bring back all that was lost in the sole pursuit for achieving the transparent light effects. The four buildings, Le Corbusier's chapel at Ronchamp, Alto's church at Imatra, Eero Saarinen's chapel at M.I.T., and the first Unitarian Church in Madison by Frank Llyod Wright, all religious in character, were attempts at exploring the mystical character of the space through the light-shadow dialectic.

"At Ronchamp, Le Corbusier lets light enter from slits that seem carved out by the light itself, interpreted as a crystalline pyramidal block, or better, as beams of glass blades spread apart, which cut the wall, making its inertia and materiality stand out in contrast … If, with the perforated wall, Le Corbusier seems to have wanted to symbolize human light descending from on high but reaching us and describing the qualities of our world, another light, divine light, seems to be symbolic referent of the luminous flux channeled down from those sorts of hatches rising above the roofing. To the observer looking from below, the light, filtered through vertical slits, appears pearly and distant, coming from an unfathomable region: a transcendent, but not triumphant light and binding light, like that of Baroque 'glorie': a light projecting the divine within the confines of an existence lived in frustration and desire" (Portoghesi 1994, p. 13).

Plummer (2003) lists the chapel at Ronchamp as one of the greatest metaphysical work of the century which can be seen in light of Le Corbusier's famous dictum that 'architecture is the masterly, correct and magnificent play of forms in light.'

Another building that defines the new culture of light in which there exits a continuous relationship between the two dialectic factors, light and matter and light and space, is convent at La Tourette built by Corbusier in the year 1952-1960. The formwork on concrete becomes all the more evident in the presence of light-shadow dialectic. The surface thus is removed of the oneness of material as the light in its quest for luminosity reveals a hidden material that finds co-existence in the imprinted texture of wood on concrete. The building stands as a testimony to the principles of contemplation and a

permanence in the way of life that followed a precise ritual for which architecture is just the medium (Portoghesi 1994).

The Dominican monastery of La Tourette is more severe in its expression with the use of a single material, and the strength expressed by unfinished concrete coated at times with plaster. Each basic void is characterized by its own unique light and shadow that brings in atmospheric richness to a character of total poverty (Plummer 2003).

"Light and shadow are 'loud speakers' in the convent at La Tourette as well: they in fact amplify the character of an uninterrupted chain of different spaces tied to one another by a sort of complementarity, and underline its extraordinary metric and proportional qualities, realized through the subtle experience acquired in the theoretical toil of the Modulor" (Portoghesi 1994, p. 17).

2.2.2 LOUIS I. KAHN

For Louis Kahn light is at the base of every architectural effect. It is the very essence that provides character to a space.

"The 'meeting between light and silence' could be the most exact definition of Kahnian space, a space built from carved out volumes and put into function by the light which joins and blends the separate unities, drawn near each other as in an ideal inventory. Kahnian light is synonymous with unity, and with space, if this word is understood as the visible and traversable interior and exterior extension created by architecture, which like a boundary delimits and identifies it" (Portoghesi 1994, p. 20-21).

Brownee and Long (1991) provide an understanding into the works of Kahn, and in the way he treated light to achieve different effects, especially in the last decade of his life. Most of the buildings depict the way Kahn treated mass and space; two entities that he considered as fundamental and apparently antithetical elements out of which architecture was made. For Kahn, mass was related to the structure in ways similar to space and natural light. The way structure and light were dealt with in a space defined the basic compositional element of architecture – the room.

"The room is the beginning of architecture. It is the place of mind. You in the room with its dimensions, its structure, its light respond to its character, its spiritual aura, recognizing that whatever the human proposes and makes becomes a life. The structure of the room must be evident in the room itself. Structure, I believe, is the giver of light" (Kahn 1971, p. 33).

The integration between structure and light is evident from one of his earlier projects, Trenton Bathhouse, in which the light is washed into the building from the opening between the wooden pyramidal roofs and the concrete-block walls, though on a smaller scale. The experiments continued on larger buildings in an even more complex manner with the use of perforated screens and towering light rooms. The use of 'silver-lit barrel vaults in Kimbell Museum, the interfingering light patterns in the Exeter library, the luminous coffer of the Yale Center for Bristish Art, and the glowing pylons of the monument for the Jewish martyrs', are examples of ways in which Kahn brought the light inside a space (Brownee and Long 1991).

2.2.3 TADAO ANDO

"As we grow less aware of darkness, we forget spatial reverberations and the subtle patterns created by light and shade. When this happens, everything is uniformly illuminated and object and form are limited to simple relations. The remedy to this situation is a restoration of richness to space" (Ando 1995, p. 458).

The quote above suggests the struggle in the architecture of Tadao Ando, one which is aimed at restoring the delicate relation between the light and the dark to give meaning through depth perceived through the formation of shadows. Modern architecture reached a stage where the freedom of the form from the structural envelope made way for the use of structural glazing, thus creating a uniform blanket of light in the interior. Natural light lost its significance as it hardly differed from the artificial light, both comparable in terms of a uniform luminance pattern inside a spatial enclosure. Most of the projects done by Tadao Ando can be seen to serve as innovative design solutions in light of the present discussion. The perception of the tangible (concrete) and intangible (light) elements of design, as expressed in his works, can be done in a number of ways. But a more holistic approach is to understand the underlying design issues in relation to the overall perception of the built form. This is to analyze the play of form, geometry and the way light is made to interfere with the physical objects. Most of his projects offer a unique opportunity to study the realm of architectural lighting in a vocabulary that is pure to the core in terms of the material and the expression (Ando 1995).

"Among those architects today who are still in touch with their native skies and the muted traditions of the past, one comes first to Ando, whose work takes the grayish light of Japan at its point of departure. Hid buildings mirror the visual qualities of the national climate, but also express the way reality is transformed by that climate. Thus his architecture deprives the eye of easy sensory comfort, and pursues instead an art of vacancy, softening and distancing physical reality" (Plummer 1995, p. 18).

As in the traditional Japanese architecture, the role of light has always been kept the most sacred especially when it is made to enter the tea house. Paper partitions allow diffused light to enter the space in a way that reinforces the silence inside. This is the power of light that can transform an ordinary space into one that invokes strong response from the user. Tadao Ando's architecture restates this phenomenon though on a level where it seems all the more mystical, and the space is freed of its physical dimensions (Ando 1995).

2.3 LIGHT IN RELATION TO THE CHARACTER OF A SPACE

According to Millet (1996), "For all light sources, the luminous effect depends upon four factors: the source (its intensity, its directional characteristics, its color); the geometry (its relationship between the source and the receiver or receiving surface); the surfaces that receive and modify light, becoming secondary light sources in themselves by reflecting, redirecting, and coloring light; and the person who views the source and illuminated surfaces as he or she moves around. By observing how light behaves, we can work with it to reveal architecture."

This section of the literature review explores different meanings of character and character of a space as associated with the four factors: (1) The Source, (2) The Geometry, (3) Different Surfaces inside the Space and (4) Movement and Visual Perception of the Observer. These meanings are both particular and universal.

2.3.1 THE SOURCE

According to Millet (1996), "Each particular place has its light. Light expressing place encompasses two distinct aspects: the place itself, its physical feature and characteristics that determine how it differs at any given moment from any other place; and the particular set of changes that take place within it over time, creating distinctive patterns of diurnal and seasonal changes."

These meanings change the way light interacts with the built environment. The openings in an enclosure define a new source of light which acquires universal meanings of architectural expression from the distinct meanings associated with light of the place.

"The appearance of buildings of all periods reflects the nature of windows …" (Phillips 2004, p.4).

"The window is a major component of the 'spatial record' between inside and outside. With its size relative to the solid wall, it determines the sense of separation from or connection to the outside. With its placement, it determines the direction in which attention is focused. With its details, it defines the transition between the room and landscape" (Millet 1996, p. 96).

It is in the transition of the natural light, from the outside to the inside, that a space is transformed and its character is defined. Millet (1996) lists (a) intensity, (b)

Directional Characteristics and (c) Color as three important factors that relate to the source of natural light, and the way it affects the perception of a space.

2.3.1.1 Intensity

The intensity of the source of light is judged based on the perception of the objects it tends to highlight. Lam (1977, p. 52) states that "Perceptions of the luminous environment always include an affective component: an evaluative or emotional response to the perceived state of affairs." Judgments in a space, such as light or dark, bright or gloomy, interesting or dull, sparkle or glare, depend on whether or not the luminous environment meets our expectations and satisfies our needs for visual information by emphasizing what we want or need to see rather than the actual luminance levels in a space.

2.3.1.2 Directional Characteristics

The directional characteristics of natural light are defined out of the movement of the sun across the sky. The depth of shadows and the contrast between two surfaces are born out of the directional characteristics of the source of natural light once interrupted by a physical plane or boundary. These are associated with the character of a space and help to draw a meaningful relation with the source at all times of a day, month or season of a year.

Tannizaki (1977) talks about the character generated by shadows in the Japanese architecture, and the mystery associated with it.

"And so it has come to be that the beauty of a Japanese room depends on a variation of shadows, heavy shadows against light shadows-it has nothing else. Westerners are amazed at the simplicity of Japanese rooms, perceiving in them no more than ashen walls bereft of ornament. Their reaction is understandable, but it betrays a failure to comprehend the mystery of shadows. Out beyond the sitting room, which the rays of the sun can at best but barely reach, we extend the eaves or build on a verandah, putting the sunlight at a still greater a remove. The light from the garden steals in but dimly through paper-paneled doors, and it is precisely this indirect light that makes for us the charm of a room" (Tanizaki 1977, p.18).

Millet (1996) lists contrast as one of the essential characteristics that introduces variety in a space. The difference between the bright and the dark helps in understanding the overall depth of a scene.

"We see by contrast, we live by contrast, and we are aware of qualities only through their opposites. There is always light to counter darkness and vice versa. Variety in our environment stimulates us and keeps us aware. As René Dubos warns, 'We must shun uniformity of surroundings as much as absolute conformity in behavior and tastes. We must strive instead to create as many diversified environments as possible.' Part of the diversity is accomplished through lighting: the flames of a fire, a candlelight dinner, the suffused glow of colored light in a cathedral, sunlight filtering through leaves or reflected from a smooth surface of water, neon signs, and searchlight crossing the night sky at a grand opening. Light is an indelible part of our experience of life" (Millet 1996, p. 1).

2.3.1.3 Color

According to Solon (1922), “Color possesses an inherent property recognized in its scientific aspect as its radiant energy. This form of energy is capable of a control which enables it to attain results of an esthetic character; the phenomena which characterize it produce direct optical results in their decorative operation; but these results react indirectly upon certain vital properties in architectural design unless subjected to rigid regulation. It is necessary, therefore, to discover the nature and location of those reactions upon elements of architectural design which must not suffer depreciation through the presence of color, in order that the results proceeding from the use of color may be uniformly advantageous.”

The use of color can change the perception of a space. Lighter colors reflect more light, and the room appears to be of a greater size. When painted with dark colors that tend to absorb most of the light falling on the surface, the same room appears much smaller in size. The light that filters through a colored glass can change the hue of the base color of the surface on which it falls. Apart from this, the natural light changes in color as the case is when comparing the morning, afternoon or evening light from the sun, but this change is compensated by our expectation in the way we perceive the same space at different times of a day. According to Phillips (2004), “the experience of natural colour; for whilst the physical colour of our world as experienced in daylight changes from morning to night, the changes are part of our experience; we compensate automatically, a white wall appears a white wall even if in the evening it may be

warmer, or is coloured by sunlight, or altered by cloud formations … it is the colour we regard as natural."

2.3.2 THE GEOMETRY

The geometry of a space depends on the way structure shapes the overall form. Light is not perceptible without form and vice versa. The natural light that renders form visible is always changing, but we perceive the form as stable due to our perceptual processes. Light can be used to emphasize form depending upon the clarity with which we can distinguish one form from another. Shadows help in the perception of the form and the spatial depth. Forms are highlighted to a greater extent on a clear day as compared to a cloudy one. On the other hand, light can dematerialize a form if the reflecting surface becomes a secondary source of light obscuring a clear view of the form. Extreme brightness or darkness can dissolve a form as they tend to blur the details and obscure the firmness of a material. Silhouetting is one of the ways in which light from the roof glazing can reveal the structure. At other instances, light can conceal the structure when the pattern and rhythm of light contradicts to the pattern and rhythm of structure. These contradictions arise from our expectation of the structure, and the unexpected way light finds an expression (Millet 1996).

2.3.3 DIFFERENT SURFACES INSIDE THE SPACE

The surface properties of a material are responsible in the way it reflects, refracts and absorbs the light received from the source. Materials directly affect the quality and quantity of light present in a space. The finish and color of the material are two

important qualities in this regard. Glossy surfaces tend to reflect light as a mirror does, whereas matte surfaces reflect diffused light equally in all directions. With respect to color value is one of the three aspects (hue, value and intensity) that determines the amount of light absorbed or reflected. Light bouncing of a colored surface carries the hue of the material. Emphasis on materials can be achieved by three different kinds of interaction, i.e. highlights, revelation and dark shadows, between the light and the material. Highlights are born out of glazed materials. Revelation of the inner qualities of materials results from light passing through them and dark shadows arise from light being deflected from the surface and from the material absorbing light. Surface texture is defined by the grazing of light. Alternatively, materials can be chosen in a way to mute the effects of light. The surface properties of two dissimilar materials might make them look similar in the way they interact with natural light. Also materials can be used to make the light seem unchanging. A shoji screen in Japanese architecture stands as an example (Millet 1996).

2.3.4 MOVEMENT AND VISUAL PERCEPTION OF THE OBSERVER

According to Gibson (1986), “One sees the environment not with the eyes but with the eyes-in-the-head-on-the-body-resting-on-the-ground.”

The experience of a space is through our entire perceptual system. We explore the space not through a static perspective but by our movement from one point to another. Our perception of a space is based, in part, on experience and preconceptions.

“As we walk through a room, our visual perceptual system tells us both about the invariant structure of the environment and also our movement in relationship to it. The

light is structured both according to its source and also by the surfaces of the environment, so that the resulting illumination of the room surfaces informs us about the room. A change in the lighting conditions means a change in our perception of the room. We perceive the physical structure of the room as unchanging even as we react to changes in the patterns of light" (Millet 1996, p. 94-95).

2.4 SCOPE OF DIFFERENT METHODS OF INVESTIGATION

Methods dealing with analysis of daylighting can be grouped into two broad categories – quantitative and qualitative. The quantitative methods are based on the measurement of light levels in a space that can be further used to analyze the lighting design. On the other hand, qualitative methods are based on the perceived qualities of a space as related to the overall lighting scheme. The first method uses mathematical base for arriving at values that can be used as data to reach further conclusions. On the other hand second method is more graphic in the sense that it relies on visual information inferred through human perception.

Robbins (1986) discusses a number of ways to analyze a daylighting design namely performance characteristics analysis of lighting or lighting energy use; tradeoff analysis of lighting, heating, and cooling energy use; cost analysis; and human comfort analysis. He lists different methods for lighting performance and visual comfort analysis that can be used to determine the amount of light entering a space from one or more daylighting apertures, and the effect of this light on visual comfort. These are -

- The Lumen Input Method
- The Daylight Factor Method

- The Flux Transfer Method
- Physical Scale Modeling of Daylighting Systems
- Glare analysis

These methods are based on the measurement of luminance values in a given space and then comparing these with the prescribed values in the codes. Ralph Hopkinson, a psychophysicist, discusses the qualitative issues that these methods might overlook in their final analysis of a lighting design. He states that "whenever we treat lighting in purely physical, quantitative terms ... we must constantly sit back and think where our calculations are leading us. If they lead us to a design that common sense and experience tell us will be disliked, there is no choice but to examine the design on those grounds and to reject it if it is clearly at fault" (Hopkinson 1963, p.28).

Lam (1977) lists an alternative approach for the analysis and design of a lighting scheme based on the process of visual perception. He questions the validity of a lighting design based on the codes that attempt to define a good luminous environment in pure quantitative terms. He draws his arguments from the results of psychological experiments that state that there is no simple correlation between the measured strength of sensory stimuli and the importance of perceptions which they produce in the brain. He lists the information content of the incoming stimuli, rather than its absolute intensity, as the basis to evaluate the quality of an environment. The adaptability of human perception makes the quality to dominate over quantity when analyzing a lighting design. He advocates an approach that aims at a lighting design with an emphasis on character or atmosphere to modify the appearance of a space, one that complements the

structure and expresses intended use and not merely providing certain quantity of task illumination, the conventional objective of contemporary lighting design.

Jay (2002) lists different methods for the analysis of a lighting design, based on the calculation of luminous intensity like the 'designed appearance' by JM Waldram and 'Multiple Criteria Design Method' by C Cuttle. The author brings to light the inherent drawbacks that still exist in most of the methods based on the calculations of luminance values, thus making a case for a new approach to the subject. The main line of reasoning adopted by the author is that lighting is essentially a practical subject, and its design can be effectively guided by rational application of criteria that are expressed as visual concepts rather than being mathematically defined. The paper lends in a new perspective to look at the subject of natural light, acknowledging the importance of visual parameters that cannot be measured. It emphasizes the need to investigate the underlying characteristics of natural light in relation to the varied characters and expressions of a space.

"Vision is the primary sense through which we experience architecture, and light is the medium that reveals space, form, texture and colour to our eyes … light can be manipulated through design to evoke an emotional response – to heighten sensibilities. Thus architecture and light are intimately bounded" (Baker and Steemers 2002, p. 4).

Jay (2002) makes a broad distinction between two different kinds of lighting installation – 'Functional' and 'Subjective'. The former, he defines as one "whose *primary* function is to enable people to see accurately, quickly and with minimum effort." The latter is defined to be in which "subjective and aesthetic considerations are

of *equal* significance." The systematic differences in the two calls for a different approach in their analysis, which are summarized below-

- Functional Installations call for an even distribution of light whereas subjective installations will emphasize a particular zone of interest by concentrated light.
- Luminaries, for the former, are designed to be plain and simple whereas in the latter any visible luminaries are designed to attract attention.
- 'Order' and 'coherence' are important conditions for subjective installations, that too with a special significance whereas functional installations may or may not be coherent.
- Functional installations will generally have a low contrast in the foreground and the background, not greater than 5 so that in all circumstances brightness constancy will hold. In subjective installations, there is a high contrast often exceeding 10 so that the brightness constancy starts to break. This can introduce dramatic effects with certain objects attracting the eye more than others.

Jay (2002) lays emphasis on a different approach towards subjective installations as their purpose of design is different. He calls for a rational analysis of the lighting design, one in which the visual process may be exploited.

The present research is aimed at analyzing spaces where aesthetic issues are of utmost importance. In other words, these spaces could be categorized under 'subjective installations' that cannot be dealt with the conventional methods that are based on luminance values. These spaces have been designed to create a character by experimenting with different effects of natural light. To analyze the lighting design in

these spaces, one needs to approach the subject based on the visual perception of the observer. The lighting design cannot be treated in isolation from the architecture of the space.

CHAPTER III

METHOD

This thesis draws on logical argumentation as the underlying research methodology in an attempt to investigate the basic characteristics of natural light in the buildings made of reinforced concrete, and the way these relate to the overall perception of a space. Specifically, the study deals with the buildings made in the late twentieth century - a time period in which three of the master architects (Le Corbusier, Louis I. Kahn and Tadao Ando) exhibited their artistic skills in the treatment of natural light inside the built space, working primarily with concrete. The literature review helped in defining a strong context to work in, while exploring the role of natural light inside the built environment. With clear objectives in mind and a comprehensive survey of the relevant literature, it was possible to develop the hypotheses for this thesis.

3.1 RESEARCH QUESTIONS

What are the underlying characteristics of natural light in the buildings made of concrete in late twentieth century?

How do these relate to the overall perception of a space?

3.2 RESEARCH MODEL

The review of the existing literature shows that there exists a very close and definite relationship between the quality of natural light and the revealing character of space. Each period in the history of architecture has been associated with new and innovative

ways for designing different openings that brought in a unique quality of light inside the building. These examples provide opportunities to get a better understanding of the way in which natural light has been used to achieve different effects inside a built environment.

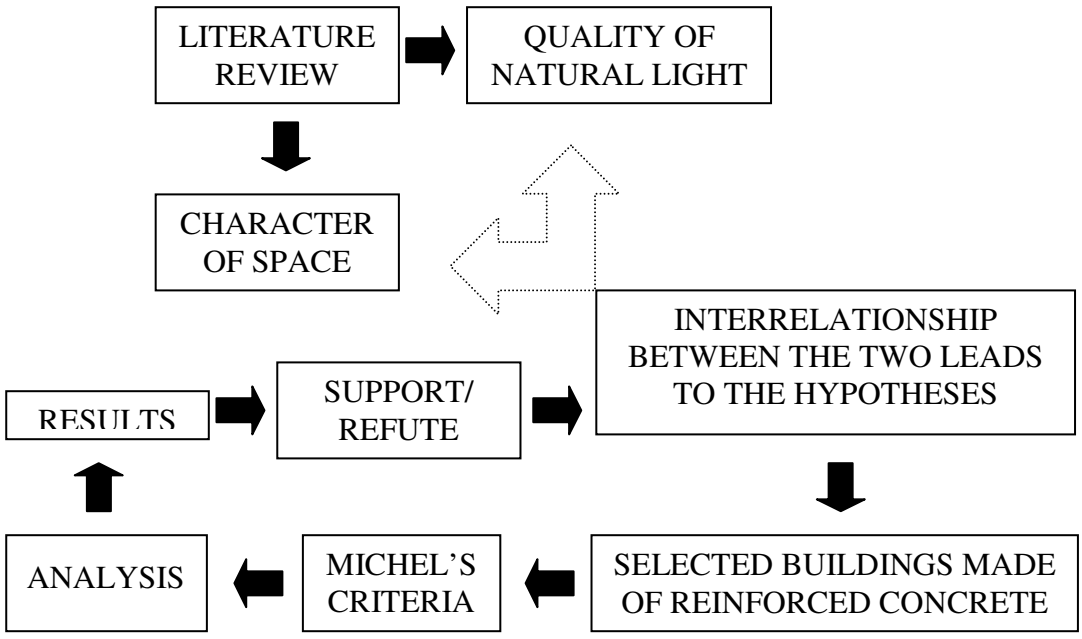

Figure 1: The study's conceptual model

This study is aimed at exploring this relationship in even greater depth so that the analysis of different buildings can help in listing the underlying characteristics which in turn (should/could) affect the overall perception of a space (see Figure 1). Most of these buildings stand as examples in which the role of natural light is much more visible in the way it affects the space. There is an emphasis on the source of natural light and the way light is brought inside a space. Both these aspects have been the predominant recurring themes in the literature review, however the exact nature of their relation has not been

explored. This provides the necessary material for developing the hypothesis for this study that can be tested in the later analysis in some of the selected buildings.

3.3 HYPOTHESES

The first hypothesis states that the overall perception of a space is affected by certain basic characteristics of natural light. The second hypothesis suggests that the overall character of a space can be enhanced by emphasizing the source of natural light as a visual element.

3.4 CRITERIA FOR ANALYSIS

To test the hypotheses, the research relies on the analysis of three of the selected buildings designed by Le Corbusier, Louis I. Kahn and Tadao Ando. These three master architects worked with concrete as a common material of building construction and expression. The plasticity of the material provides the necessary freedom in the placement and design of the openings for natural light. Thus, it provides greater scope for experimentation with the building envelope and with the placement of the openings to achieve different effects of natural light inside a space. The work of these architects has an underlying emphasis on the experimentation with the light quality inside a built space and provides the opportunity to get a deeper understanding in the way it has been achieved.

The selected buildings, Chapel of Notre Dame du Haut Ronchamp by Le Corbusier, Kimbell Art Museum by Louis I. Kahn and Church of the Light by Tadao Ando, are projects that have been widely published in recognition for the achieved

quality of natural light that can be appreciated with respect to the design of a space. The emphasis of this study is to explore the different effects of natural light, and the way these have been achieved.

To understand and analyze the effect of natural light in relation to the overall perception of a space, it is important that there is an underlying criterion that takes into consideration all the different parameters that have a major bearing on the design of the built environment. The analysis of these buildings cannot be done in isolation by differentiating the lighting design from the overall design of a space. The underlying criteria should be one that takes into account the principles of visual perception that help in the analysis of the achieved effect of natural light in relation to the overall design of a space. The visual nature of the analysis will require images from different projects that can serve as useful source of data and will provide greater information in a more concise format.

Michel (1996) lays down the criteria for the analysis of architectural space as related to its overall lighting. The criterion analyzes the design of a space with respect to the effect of light rather than the light itself. This has been done with an underlying emphasis on the way a space is perceived by the human vision. The method of analysis is based on the principles of visual perception that closely relates to the emotional response, which is a determining factor in the overall perception of a space in terms of the revealing character and ambiance. The focus is not in generating mathematical values of luminance but in understanding the aspects of natural light that help in the humanization of architecture. This approach is based on the use of a space taking into

consideration the movement pattern as it relates to the observed effects of light along a circulation path. It varies from the conventional methods of analysis based on a stationary position of the observer which is not the way a space is perceived in reality. The criterion is based on the concept of spatial envelope as a convenient tool for the analysis of an architectural space in relation to its lighting design. The criteria has been summarized below-

1. THE SPATIAL ENVELOPE

a) Boundaries for Spatial Definition

b) Visual Perception of the Envelope

c) The Character of Space

d) Distortion of the Spatial Envelope

e) Clarity of the Spatial Envelope

f) Proportioning of the Spatial Envelope

g) The Color of Architectural Space

2. ARTICULATION OF THE SPATIAL ENVELOPE

a) Patterning the Dominant Boundaries

b) Penetration of the Spatial Envelope

c) Articulation with Subspaces

d) Spatial Banding

e) Curvature and Level Change

3. ROLE OF THE STRUCTURAL SYSTEM

a) Prominence of Building Form

b) Structure Patterning the Spatial Envelope

c) The Sources of Light

d) Structural Synthesis for Architectural Beauty

4. MOVEMENT THROUGH SPACE

a) Stimulus for Movement

b) People Move Toward Light

c) The Zones of Transition

d) Brightness Changes as a Function of Movement

The explanation for each of the above steps follows below.

3.4.1 THE SPATIAL ENVELOPE

According to Michel (1996), "A composite set of those [walls, floors, ceilings, and other major surfaces] boundaries at any one place comprises the *spatial envelope*, a working mechanism for the design, analysis, and lighting of architectural space. The envelope is a conceptualization of a space, stripped of movable or temporary furnishings. This theoretical segregation of shell and contents facilitates control of the color and brightness relationships created by all reflected light in the total environment once the furnishings are added."

The visualization of the space as an envelope provides a strong conceptual framework to work with a three dimensional analysis of a built environment. The boundaries, as defined by the physical planes, help to isolate the spatial envelope from its surroundings and, in the process, provide a nice setting to analyze the effects of light. The number of physical parameters affecting the space can be controlled to study the

quality of light in a space. A similar approach has been used by Thibaud in the analysis of the public spaces that have been categorized on the basis of different light levels. This approach was aimed at exploring the overall relationship between different objects present in a scene.

"A frame of visibility is a methodological device that helps describe the various luminous contexts in which interpersonal observation occurs … Each frame of visibility stands between two extreme cases that prevent any form of vision: complete brightness and complete darkness. The five frames of visibility that occur most frequently in the visual experience of the city dwellers are overexposure, enclosure, filtering blurring, and silhouetting" (Thibaud 2001, p. 43).

The concept of devising a frame of visibility is to understand a space in terms of the light levels that control the overall visibility of different objects, and the way in which they relate to one another. Each frame of visibility throws light on the way different individuals observe space. The idea is to explore deep into the relation between light and sight.

Whereas the frame of visibility characterizes a setting based on the light levels and then analyzes the way people observe a space, the spatial envelope defines a space based on the physical parameters that demarcate its boundary and then analyzes the effect of light in the way it is made visible in a space. The idea is to start with a limited number of parameters that might include the major boundaries and surfaces in the beginning and slowly move towards a complete representation of the space.

"Putting freestanding objects or furnishings inside the envelope sets up figure-ground relationships, brightness ratio, and color relationships. The spatial envelope then provides a vantage ground for evaluating perceptual simplicity, complexity, Gestalt Patterns[1], character, and, most important, the locations of light sources and their resulting luminance effects" (Michel 1996, p. 103).

The envelope forms the zone of stimuli for visual perception as defined by the physical planes. The spatial envelope in terms of its characteristics is categorized into –

- Enclosed Space (Confining and Static)
- Contiguous Space (Partially Confining, Dynamic or Ambiguous)

The spatial quality of the envelope has many advantages over the planar organization of the boundaries. It brings together the isolated elements of design that can then be used to analyze the character and character of a space under the overall effect of light. It also acts as a convenient and practical tool for discussion among designers and users of a space, and a way of evaluating a space in terms of its lighting design.

3.4.1.1 Boundaries for Spatial Definition

According to Michel (1996), "A spatial envelope is best defined by the *dominant*[2] boundaries that shape a clearly defined volume functioning as a full or partial enclosure."

The first step in defining a spatial envelope is to recognize the major boundaries and surfaces that demarcate the limits of human vision in a space. A spatial envelope

[1] Grouped perceptual stimuli by spontaneous organization.
[2] The major surfaces and the edges that build up the volume for a given space act as the dominant boundaries.

functions as a full enclosure when the space is completely enclosed and well defined from it surroundings. But in some cases, the space might seem to flow from one envelope to another depending upon the way one relates to another and on the use of materials that define the physical boundaries. This will be an example of a partial enclosure where most of the edges are loosely defined and the surfaces seem permeable.

The boundaries of the spatial envelope define some of the important characteristics of the enclosed space like the overall size, human scale, and material of expression. These further define the predominant visual vocabulary of the built environment thus providing a background to study the effect of light and then arriving at the overall perception of a space. This is the starting framework in the overall perception of the spatial envelope. It can be explored in terms of the underlying concepts such as unity, clarity and scale that relate to the character and ambience of a built environment. Thibaud (2001) lists 'Enclosure' as one of the five frames of visibility that affect the overall unity of a space and sets up a background-foreground relation to most of the spatial parameters.

"Enclosure involves the delimitation and fragmentation of what can be seen in the built environment. Its function is to structure and direct the visual field of passersby, to shroud a portion of the place while revealing otherparts and unifying what is visible. Enclosure both reveals and hides, depending on the spatial position of the observer. This phenomenon introduces a differentiation between areas that could be considered upstage and backstage" (Thibaud 2001, p. 43).

3.4.1.2 Visual Perception of the Envelope

According to Millet (1996), “The definition of architectural space is the definition of enclosure, in which light plays a major role. Our sense of space is dependent upon the way light reveals the enclosure to us.”

This concerns the role of different surfaces on the perceptual stimuli, and the way these physical boundaries come together to form a spatial envelope. The visual perception of the boundaries is defined by the visible limits of the envelope. The dominant edges and surface boundaries provide information for the spatial depth and the values of a surface’s color, texture, and brightness. The edges and contours act as strong activators of the photoreceptors in the retina by breaking the flow of surface gradients and giving a sense of overall depth. The floor, walls, and the ceiling with the overall pattern, material, and reflectance have a major bearing on the perception of the spatial envelope. The concern for size and human scale of the space can be dealt in a more realistic manner while visualizing volumetric proportions of the spatial envelope without any major articulation of surface details (Michel 1996).

Gärling (1970) studied the role of dominant edges for surfaces in an architectural setting to understand the way people perceive spatial depth. Subjects responded to two different set of drawings, one with the surface details and another with just the dominant edges. The results showed that the drawings with just the edges provided enough information to make reliable judgments regarding the spatial depth. The need for organization of major boundaries depicting the edge relationship is important when dealing with some of the basic characteristics of space.

3.4.1.3 The Character of Space

According to Michel (1996), “The spatial envelope is a principal conveyor of the character of a space. The freestanding contents in a room further describe its individualism, but the intent here is to continue to isolate the spatial envelope to facilitate analysis of the space it defines. Furniture can be replaced or rearranged and litter picked up, but the surface complexion of the boundaries of a room remains more stable and in prominent view, influencing our feelings.”

The character of a space deals with the underlying character that is conveyed by the collective imagery of the spatial envelope. This could range from satisfying and peaceful to the stressful and depressing. Surfaces of walls can convey the variation (harsh or soft, tattered or trim, upright or leaning, monotone or colorful, bright or shadowed) in the character of two different spatial envelopes. Age of boundary surfaces and its familiarity are factors that count in the determination of the character of the space. Common use of materials, textures, colors and the overall architectural vocabulary might provide similarity, proximity, and good continuity to the spatial envelope and, in some cases, prove to be dominant enough to negate the effects of an incongruous element of design.

The minimalist architecture and postmodernism offers two extreme poles in the overall variation of the character of an architectural space. The former lays emphasis on developing a restrained spatial envelope through pure and well proportioned cubic volumes that conveys a muted and a serene character. The latter banks upon the use of

sensuous color, decorative use of materials, and unusual forms and spaces and, at times, crosses the limits of visual simplicity and spatial clarity.

According to Michel (1996) size, shape and proportions of the spatial envelope can dominate on the effect of the surface properties of an enclosure. These parameters can be used to enliven a space where a single monochromatic surface has been used throughout the building. Such a vocabulary can bring out interesting spaces through the overall richness and clarity of the spatial envelope as it distinguishes from another, while still maintaining required interconnectivity.

3.4.1.4 Distortion of the Spatial Envelope

According to Michel (1996), "The spatial envelope can be conceived in any shape, proportion, or character to produce ergonomic architecture, but it can also be responsible for the distortion of space, which can be physically upsetting to the human nervous system when the shapes and organization of the dominant boundaries deprive people of the basic human need for equilibrium."

The spatial envelope can be designed in ways that the different surfaces unite to create a form that has a compositional and psychological imbalance. This breakdown occurs when an unusually sloped or twisted boundary forms a discordant part in the spatial envelope. It could also be in a case where the ergonomics have been violated in designing a space. These distortions can obscure the actual boundaries of the space that might prove to be disorienting and unsettling. These mostly result from excessive detailing in the visual field that makes for a poor backdrop for the perception of form-space relationships.

"Unexpected bright elements in the visual field, particularly if they are distorted, demand the attention of the focus selector, causing distraction. The uneven illumination of the planar structural surfaces … distorts their apparent form, commanding attention and forcing viewers to make sure the structure is not in fact the irregular shape which patterns and gradients of incident illumination seem to suggest it is. This sort of distracting distortion is annoying and should be avoided whenever possible" (Lam 1977, p. 38).

3.4.1.5 Clarity of the Spatial Envelope

According to Michel (1996), "Organizing the dominant boundaries of space for perceptual clarity is an essential step toward achieving visual order and architectural beauty … To enrich a space, a major surface may deviate from the others as a designated accent, but the more the individual boundaries are differentiated by dissimilar surface pattern, color, or appendages, the more the clarity of the overall space is weakened."

The clarity of the spatial envelope is dependent on a minimal number of dominant boundaries and similar surface elements used in a space. The more similarities that different surfaces share, the easier it is to achieve overall visual order. The effect of reflected light and shadow may then be used to enliven the boundaries of a spatial envelope if it retains the overall integrity.

3.4.1.6 Proportioning of the Spatial Envelope

According to Michel (1996), "The composition of the dominant boundaries and the distance between them establish the basic proportions for space."

The manner, in which different boundaries combine together with specified distances separating one from another, generates the basic proportions of a space. The controlled volume that is defined in the process becomes a determinant of spatial perception. The height to width ratio is an important measure of the way a space is perceived to emphasize a major axial line. The proportions of a spatial layout are less significant in terms of their overall effect on the perception of the observer who is moving. The visual relationship with different surfaces is continuously changing and is dependent on a host of other factors like color, materials, light, exits and entrances. A linear perspective of the same space will count on the boundary edges of walls, floor, and ceiling to bring in a perception of depth.

3.4.1.7 The Color of Architectural Space

According to Michel (1996), "The predominant surfacing materials of the spatial envelope determine the prevailing color of an environment … The color of the spatial envelope will serve as the greater field against which all other colors will be perceived after wall appendages and interior furnishings are added … The amount of surface area of the total envelope is significant for the way various hues influence the quality of spaciousness." The shift in the value and saturation of hue, due to the variations of reflectance and texture, do not affect the overall dominance of the base hue, more so when there is a single color. Brighter colors will have a positive influence on the size of a room whereas darker colors will tend to make the room appear smaller. A space with more than one color will need a further analysis on the amount of color that is present depending on the surface area on which it is applied.

Controlled spatial and chromatic design can add interest and enliven a space while maintaining the overall stability and clarity of the spatial envelope. Visual order is thus restored without an overload of stimuli that can take place in the presence of multiple colors and surfaces. The clarity and character of an environment will depend on the shape and color of the spatial envelope (Michel 1996).

"Filtering involves the quality and the propagation of light in the built environment. By passing through a physical milieu (such as glass or foliage), natural light can be refracted, absorbed or reflected. Filtering produces an ambiguous relationship between the inside and the outside … the lighting of the place is neither completely bright nor totally obscure; instead, the light produces a mottled atmosphere. Such an impressionistic surrounding enhances and transfigures the shapes and the colors of the place. This frame of visibility creates the sensation of bathlight or a luminous envelope shared by everybody. Such a diffuse light increases the coherence and the unity of the place. People located in this kind of surrounding feel physically bonded with the environment and can also sense the time passing by" (Thibaud 2001, p. 43-46).

3.4.2 ARTICULATION OF THE SPATIAL ENVELOPE

According to Michel (1996), "As buildings are put together by a process of assembling fabricated parts, the patterns formed on the singular boundaries can activate the surfaces, but need to be joined together into a good composition for the whole. This is the *articulation* of space, and to make the process successful, we need to reiterate this principle: *Clarity of architectural space depends on the distinctness and intelligible order of the entire spatial envelope.*"

The articulation of space is the organization of different boundaries with surface patterns so that they form a cohesive envelope. Clarity is the measure of success for the articulation of a spatial envelope, which should be visually comprehensible and must be expressed through the overall design integrity. Over detailing and lack of uniformity can lead to the break down of the envelope. Perceptual simplicity should be the controlling condition while attempting to enrich and enliven the space.

3.4.2.1 Patterning the Dominant Boundaries

According to Michel (1996), "As a perceptual phenomenon, *pattern* belongs to the 'hierarchy of focal accents' and attracts the eye scanning the visual world. This is what makes it an effective means for animating architectural space… As pattern draws attention to one surface in a visual field, it also draws the eye to another, and becomes effective for uniting the boundaries of space."

The spatial articulation can be used to enhance the perceptual response to a surface boundary through the use of a detailed pattern that forms an interesting part in the overall composition. The manner in which different patterns draw attention will determine the hierarchy of focal accents and establish the dominant visual boundary.

"Pattern is an easily perceptible form of order, and triggers expectations of completeness and consistency" (Lam 1977, p. 41).

3.4.2.2 Penetration of the Spatial Envelope

According to Michel (1996), "Articulating such [self-confining] spaces by animated detailing of their boundaries begins to break up the static quality, but that technique is

not nearly as effective as actual penetration of the greater spatial envelope by windows, doorways, grilles, or other openings that connect adjacent spaces or subspaces."

Spatial articulation is aimed at breaking the static quality of the space and is best achieved by different openings that allow penetration between two or more spatial envelopes. Penetration of the spatial envelope dramatizes the depth perception as the space flows through the opening diminishing the power of enclosure. The lighting of the architectural space will depend on the penetration that can be seen in terms of the brightness ratio of the reflected light on the surface against the view from the opening. The relatively bright surface seen against a dark opening enhances the articulation and animation of the spatial envelope. The proportion of the envelope that is penetrated compared against that of the opening, will decide the overall dominance of the building mass in a space.

3.4.2.3 Articulation with Subspaces

According to Michel (1996), "One of the most reliable design devices for generating visual interest and creating a stimulating quality of architectural space is the controlled use of subspaces working in harmony with a primary spatial envelope… a *subspace* is one of only partial enclosure, identified by its own spatial envelope, but opening freely to join with the primary space to which it clearly relates. It can be a spatial inset or an element protruding from the boundaries of its parent space."

A subspace is a partial enclosure that has its own spatial envelope but can be seen as an extension to the primary space merging freely at one of the boundary edges. It affects the overall spatial composition of the parent space depending on the way it has

been articulated. The visual framing of the subspaces on the primary envelope should be controlled in terms of its detailing. The two spaces should not compete with one another for attention of the visitor. At all times the primary spatial envelope must remain intact maintaining its own identity and clarity. Color difference can be used to differentiate the primary spatial envelope from the surroundings, so that the articulation by subspacing is not weakened. Lighting levels can vary to mark a gradual transition from one space to another.

3.4.2.4 Spatial Banding

Spatial banding is a design pattern created by the linear strips of structural members. Fascias of floors, as seen through an atrium, are an example of horizontal banding whereas piers and columns would depict vertical banding. It is a way of articulating a space through an integration of the structural and mechanical systems with the overall spatial composition. Different views to the subspaces might be framed in the process while keeping with the integrity of the parent space (Michel 1996).

3.4.2.5 Curvature and Level Change

According to Michel (1996), "Curved spaces and those that involve changing from one level to another provide the opportunity for creating dynamic architectural space due to the continuously unfolding views for people walking around them. Good articulation of the spatial envelope is especially important for those environments because design continuity is required along the path of movement."

Spatial articulation can be achieved by planning circulation patterns along a major curve or by joining two different levels, while maintaining the overall continuity in the design. Changes in curvature can bring in interesting views that change dramatically from one point to another. Stairs or series of steps can been used in connecting two or more partial spatial envelopes while providing a zone of interaction. The alternate play of light and shade along a path with well planned start and end points can help in the articulation of these spaces.

3.4.3 ROLE OF THE STRUCTURAL SYSTEM

Concrete and stone masonry has been used in the construction of the chapel in a manner that the structure is concealed in the external envelope. The plasticity of the form has been achieved by using concrete.

The structural system has to be integrated with the overall lighting design if the space has to be perceived as visually comfortable. The conflict between the two could lead to overloading of the visual stimuli without any meaningful information being conveyed in the process. The use of uneven illumination should have a definite purpose like an emphasis on one of the design elements that creates a point of interest against a restrained background.

3.4.3.1 Prominence of Building Form

Structure is the generator of form and space. The structural form needs to be conceived in a manner that it takes into consideration the internal layout and spatial configuration rather than just dominating the building design. The outer wall, or the structural

membrane, needs to be planned from the interior as well as the exterior in terms of shaping space and bringing in daylight (Michel 1996).

3.4.3.2 Structure Patterning the Spatial Envelope

According to Michel (1996), "A dominant boundary of space can be designed with structural members organized as aesthetic pattern."

The structural members can be themselves articulated to create surface patterns for dominant boundaries in a spatial envelope. Individual units in a structure can be grouped in a manner that creates an interesting design pattern. The pattern of light and shadow can further articulate the spatial envelope by animating the surface under changing effects of daylight. All this should be done while maintaining an overall integrity with the design of the spatial envelope.

"Strong patterns of visual information can also dominate the visual field, demanding the attention of the focus selector. The problems of visual noise … can be eliminated by the use of indirect lighting systems, which deliver light to the room by reflection from room surfaces, which are intrinsically interesting to look at. These bright room surfaces satisfy biological needs for structural clarity and for a bright, cheerful environment" (Lam 1977, p. 39).

3.4.3.3 The Sources of Light

According to Michel (1996), "the design of the structural system determines where, how much, and what shape of penetrations can be made. When structural design and building

design are coordinated, the outcome makes possible engaging dialogue between architectural space and light."

The size and type of openings for the entry of daylight are determined by the design of the structural system and the overall orientation of the building. The interaction between the spatial envelope and light that fills in the space is best achieved through close coordination between the structure and the building form. The use of contrast or even soft illumination should depend on the kind of function and the need for visual emphasis inside a space.

3.4.3.4 Structural Synthesis for Architectural Beauty

According to Michel (1996), "The appropriateness and correctness of the structural system fitting the concept and program requirements of a building is a standard for the achievement of quality architectural design."

The beauty of an architectural design, as it relates to the structure, is achieved through the integration of the exterior form with the internal arrangement of the functional components. The structural synthesis should bring in integrity of different spaces rather than an isolated dominance of form. This further relates to the idea of visual harmony inside a space that will depend on the coordination between the structure and the source of light.

"… the perceptual distortion of structure resulting from sharp brightness gradients … will be diminished if the designer can locate a color change or a prominent joint line where a drastic rate change in brightness gradients is unavoidable due to the geometry of the situation. Flat, uniform surfaces are expected to appear that way; uneven

gradients are much more noticeable on a flat ceiling than on an articulated (three-dimensional) one where the shape of the ceiling itself helps to justify the gradients to the mind's eye as long as the relation between shape and gradient is consistent throughout the visual field. One of the disturbing aspects of the lighting scheme … is the inconsistency and incompatibility of the relationship between structural form and luminance gradients" (Lam 1977, p. 50-51).

The luminance gradients should be used in a manner that helps to highlight the basic geometry used to achieve a particular form. The ambiguity in revealing the structure might lead to an overall distortion of the way a spatial envelope is perceived.

3.4.4 MOVEMENT THROUGH SPACE

According to Michel (1996), "Spatial organization and the lighting of certain features of the built environment prompt people's movement patterns, and those features can be manipulated to make architectural design more comprehendible and meaningful."

The movement pattern in a space relates to what people see, and the way they see different elements of a spatial envelope. There might be some design elements that attract greater visual attention and thus define a strong path for movement in a space. The use of contrast through controlled use of light can help to highlight certain objects more than others.

"If the building is familiar territory, he moves through it in a *habitual* manner, scarcely aware of his architectural environment; if it is unfamiliar, he moves in an exploratory manner, looking in all directions, hesitating, and sometimes retracing his steps. Exploratory locomotion usually occurs in public buildings such as museums and

art galleries. Habitual motion is far more common and generally occurs in homes and office buildings" (Bechtel 1967, p. 53-54).

The movement of the visitors inside a building depends on their familiarity with the built environment. Hence what becomes important is the path defining a sequential arrangement of spaces that creates visual interest and minimizes confusion as people find their way around a building. Spatial organization and the lighting of certain features in the built environment do define the movement pattern.

3.4.4.1 Stimulus for Movement

According to Michel (1996), "Focal accents are helpful for creating nodes of special interest in a building, especially when the intention is to attract people to certain locations. A center of attention is stronger when it is carefully integrated with the design of the spatial envelope(s) through which the pedestrian circulation is routed."

The use of focal accents to create nodes of special interest along a certain path of movement can be integrated with the overall design of a spatial envelope. This can help in creating zones that will demand the attention of people while highlighting certain design features more than others. Perceptual simplicity of the space should not be broken down with too much of visual stimuli at one point. So a controlled amount of focal accenting should be done, more so when the nearby space is framed by the opening in the immediate spatial envelope. The incomplete information that is read through such an opening prompts the observer to explore the next space. The way this transition takes place depends on the quality of the focal accent that lies ahead in relation to the design of the immediate spatial envelope. Pattern detailing can be used as a way of connecting

two spaces while keeping with the integrity and clarity of design and maintaining an overall continuity in the experience. Strong visual patterns as those of light and shadow can be used as centers of focal attention while integrating different spaces.

"Overexposure involves creating a differentiation between and a hierarchy among objects in the visual world. It consists increasing the visibility of a specific object, such as a monument or an individual. This frame of visibility displays passerby, attracts their visual attention, and points out what can or should be seen by anybody … Such a phenomenon can be produced in two different ways: either by making use of contrast between lit space and obscure space …, or by offering a view from above of what is happening underneath …" (Thibaud 2001, p. 43).

3.4.4.2 People Move toward Light

The relative brightness in certain portions of the spatial envelope acts as focal accents. The movement of a visitor to a building is directed towards light. The higher the ratio of the brightness or contrast between two surface the greater attention it demands. This becomes an important factor in the sequential layout of the spaces inside a building as the challenge is to combine the functional necessities with the artistic play of light levels (Michel 1996).

Taylor and Socov (1974) did an experimental study that would answer their research question: Will light or bright surfaces and objects actually stimulate a person to move towards them when there are alternate choices to move in directions where light is not a dominant feature. What they found out was that higher the ratio of brightness between the two end walls, the higher the percentage of subjects who moved towards the

brighter wall. There was clear evidence that people choose the brighter way whenever they had more than one option to move from a point to another.

"Silhouetting emphasizes the contour of objects or individuals instead of the details of their surfaces. This frame involves a particularly pronounced figure-ground relationship; it produces a clear differentiation between several juxtaposed planes or visual elements … The transition from a dark, artificially lit place to a bright, naturally lit place, such as the exit from an underground place into the daylight, is the most common context for experiencing silhouetting … From an architectural point of view; silhouetting makes it possible to strongly accentuate the transition between two places and clearly differentiate the foreground from the middleground and background" (Thibaud 2001, p. 46).

3.4.4.3 The Zone of Transition

According to Michel (1996), "the human retina undergoes light or dark adaptation when human vision is subjected to changes of brightness levels surrounding the eye. Movement through the architectural environment strongly influences that adaptation, particularly between two adjacent spaces of significant brightness-contrast… The retina needs time to adjust during the move from one extreme of lighted environment to another, and to promote the humanization of architecture, a spatial *zone of transition* is needed."

The human eye takes time to adjust to significant changes of brightness and contrast. The movement between zones of high brightness-contrast should provide suitable buffer for adaptation. A spatial zone of transition is required that provides the

necessary time for the adjustment of the photoreceptors in the retina. Shadow patterns and similar effects of light can be used to bring in the necessary amount of adjustment between two extreme conditions of brightness and contrast.

"Blurring involves the reducing of visibility of people, making it difficult to perceive the contours and the shapes of objects and bodies … Blurring emphasizes the dilution of the visible forms and limits the perception of depth … A feeling of insecurity, mystery or surprise can result from this luminous context: the pedestrian cannot really anticipate what will be in his path. Such a frame may also be interpreted as a means to enhance the secretive character of a place and dramatize the experience of urban space" (Thibaud 2001, p. 46).

3.4.4.4 Brightness Changes as a Function of Movement

According to Michel (1996), "to the eye, the colors and textures of surfacing materials change in brightness as seen by a person walking through the architectural environment ... The concept of the spatial envelope is effective for observing and analyzing the influence of the dominant spatial boundaries surrounding the vision of a person walking through successive spaces of alternating luminance contrasts … Spaces need to be connected in such a way as to facilitate a pleasant transition between them, which depends on the brightness levels of what precedes and what follows."

Different surfaces appear to change in overall brightness with the movement of the observer. This is caused by light and dark adaptation of the eye that is continuously trying to adjust and compensate for the variation of light levels at any given point in time. The luminance of the dominant surfaces will have a greater affect as compared to

the rest, in a way that affects the connection and transition between different spaces. Thus the shape, dimension and the material of the dominant boundary tend to be important parameters in the overall play of changing light levels.

"The perception of brightness, as well as color, is influenced by simultaneous contrast. Objects of the same surface luminance will be perceived as brighter or darker depending on the relative luminance of their context" (Lam 1977, p. 49).

The visual perception of the space relies on the contextual information to make judgments on the brightness of a surface. There is a strong relation between the foreground and the background that helps to decide on the perception of a space in terms of the existing light levels. The context might change with the movement through a space, for example, the surface that looked bright against a much darker background might seem the opposite when seen against a well illuminated light color material. This might shift the visual interest from the foreground to the background depending on the information that the two surfaces provide.

CHAPTER IV

ANALYSIS

This chapter deals with the analysis of the spatial envelope inside three different buildings. The selected buildings are (a) Chapel of Notre Dame du Haut Ronchamp by Le Corbusier, (b) Kimbell Art Museum by Louis I. Kahn, and (c) Church of the Light by Tadao Ando.

The main space that houses the primary function of the building program has been selected as the spatial envelope to be analyzed using the criteria as listed in the previous chapter. The headings and subheadings have been retained to provide an in depth explanation to each of the parameter that affects the light quality inside a space.

The use of a common criterion based on the principles of visual perception helps in the study of the effect of natural light in these three buildings that are spread across different continents. Also, the variation in the shape, size and the organization based on the functional requirements of the spatial envelope can be dealt in the final analysis as it provides an opportunity to study the underlying patterns in relation to the quality of light inside a space with a common material of expression across different projects.

The analysis is aimed at providing a rich content of descriptive explanation in the way different effects of light have been achieved in a spatial envelope. The approach takes into consideration the variables that influence the way natural light illuminates a space. The isolation of a spatial envelope from its surrounding helps to control the analysis of a space.

4.1 CHAPEL OF NOTRE DAME DU HAUT RONCHAMP BY LE CORBUSIER

Le Corbusier started with the design for the Chapel of Notre Dame du Haut in 1950 and the construction of the building was completed in 1955. It stands as the first of only two religious buildings designed by Le Corbusier, the other building being the Monastery of La Tourette. In the Chapel at Ronchamp, Le Corbusier made use of curved surfaces of reinforced concrete to generate a form that is bold and organic (see Figure 2). Since its construction, the building has evoked poetic notions in the mind of the visitor observing the play of light and shadow on different surfaces (Pauly 1997).

Figure 2: Exterior view from the southwest. (Photo courtesy of M. Salas, 2004)

4.1.1 THE SPATIAL ENVELOPE

The selected spatial envelope in the case of Chapel of Notre Dame du Haut is the main space of worship used inside the building (see Figure 3). The use of curved surfaces gives an unusual form to the building envelope that is made possible by exploiting the plasticity offered by concrete as a construction material. The spatial envelope is an example of enclosed space clearly demarcated from its surroundings by thick walls with small openings that bring in a controlled amount of light making the interior boundaries appear confined and static.

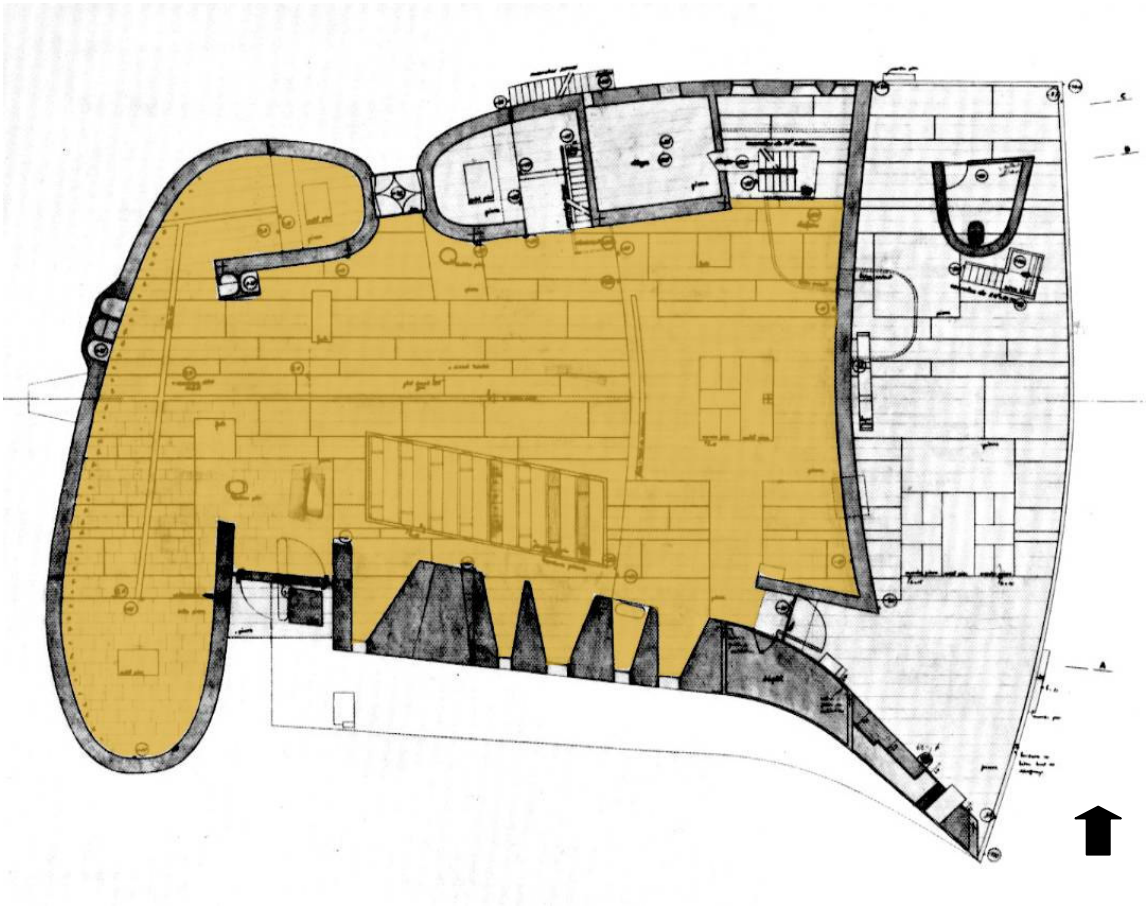

Figure 3: Plan of Notre-Dame-du-Haut Church. (Adapted from Le Corbusier, 1975)

4.1.1.1 Boundaries for Spatial Definition

This spatial envelope functions as a full enclosure, and all the dominant boundaries are clearly marked from their surroundings. These have been listed below.

a) South Wall – In plan, this wall bends in from the outside (convex shape, see Figure 3). Vertical triangular frames embedded in the thickness of the south wall are revealed only at the top where it supports the roof shell. The south side has one vertical tower along the west end that brings in light from the clerestory opening (see Figure 4).

Figure 4: Interior view of the chapel looking towards the south entrance. (Lai, J. Y. C., http:// www.0super.net/upload/edited/ronchamp06.jpg, accessed April 20, 2006)

On the east side, the south wall has a number of small thick splayed openings that provide a uniform spread of light to the inside (see Figure 5). The size and layout of the windows are based on the modulor. Also, there is a 10 cm gap between the walls and the roof which brings in washed light along the ceiling. The main sculptural door separates the vertical tower from the east end of the wall. The cast concrete wall has a rough white finish (see Figure 4).

Figure 5: View of the south window wall. (Archive Colour Slides Ltd., 1984, Slide 10 L 24,046)

b) East Wall – This wall bends in from the outside (convex shape, see Figure 3). The altar is placed in the middle with a cross next to it. There are a number of small openings behind the altar. The main source of light is the window opening on the top of the altar

door that has been placed towards the south end of the wall. Also, there is a square opening just behind the altar with a statue of the Virgin Mary, which appears as a silhouette against the intense rays of light from the morning sun. The 10 cm gap between the wall and the ceiling continues on this side that makes the mass of ceiling disappear. The ceiling appears to be floating in mid air as the supports are hardly noticeable (see Figure 6). It reaches its maximum height at the southeast corner. The stone and concrete wall has a rough white finish.

Figure 6: View of the east wall facing towards the altar. (Simon, G., 2003, http://www.galinsky.com/buildings/ronchamp)

c) North Wall – The profile of this wall bulges out from the inside (concave shape, see Figure 3). It has two vertical towers that bring in light from the clerestory openings

and are facing each other. The towers are made of stone masonry and are capped by cement domes on the top. Also, there are a number of small openings on the east side of the wall that light up the freestanding elements in the choir (see Figure 7).

Figure 7: Close-up view of area behind altar from south. (Archive Colour Slides Ltd., 1984, Slide 10 L 24,056)

The stone and concrete wall has a rough white finish. The concrete, as a surface material, is covered with gunnite which further strengthens the walls made of old Vosges stone. The finish for the walls has been achieved by spraying mortar on the vertical surfaces by the use of a cement gun. Both the interior as well as the exterior have been white-washed with lime to achieve the final finish.

Figure 8: General view of interior looking west. (Archive Colour Slides Ltd., 1984, Slide 10 L 24,050)

d) West Wall – This wall also curves out from the inside (concave shape, see Figure 3) with a confessional contained in the bulge that comes out from the mass of the wall. It

is a stone and concrete wall that has a rough white finish and is the only side without any openings to the exterior (see Figure 8).

Figure 9: View towards the east depicting the slope gradient in the floor. (Lai, J. Y. C., http://www.0super.net/upload/edited/ronchamp07.jpg, accessed April 20, 2006)

e) Floor – The floor has a downward slope towards the altar. The construction material is cement paved and poured in place between the battens, giving the floor a tiled pattern; the design of which is dictated by the modulor (see Figure 9). The change in the

flooring material takes place where the interior and exterior altars rest and is done in white stone matching with the material used for the altar.

f) Ceiling – The roof consists of two concrete membranes 6 cm thick and separated by a space of 2.26 m. The idea of this roof represents the shell of a crab that inspired Corbusier in the design of the final form for the roof. This roof is supported by short struts, protruding from the vertical surfaces at the south and the east end of the chapel. The grey ceiling has been left unfinished and rough with the impression of the formwork visible from the inside (see Figure 8).

4.1.1.2 Visual Perception of the Envelope

The use of curves for all the major surfaces and dominant boundary edges has a strong impact on the visual perception of the spatial envelope inside the chapel. The sculptural beauty of the overall form is less predominant inside when compared to the exterior. This is due to the low light levels inside the space with the emphasis being more on hiding than revealing the interiors of the chapel. The sources of light become all the more prominent in the dark interiors because of the strong visual contrast that is generated by the openings particularly on the south and east walls (see Figure 9).

The rough finish on the vertical surfaces provides greater surface area for the scattering of natural light inside the chapel thus creating a soft and diffused interior space. The contrast between the light and shadow is further enhanced by the white painted surfaces seen against the dark floor and the ceiling. Also, the use of the convex and concave shapes for the adjacent walls, to support the curved roof, creates a strong outward thrust from within the building. This effect is further strengthened as the light

washes through the small gap between the vertical walls and the ceiling on the south and east side of the chapel (see Figure 8).

4.1.1.3 The Character of Space

The religious character of the space is defined by the mystery of the shadows, and the way light reveals the overall form of the chapel. The softness in the light, as it reflects from the textured surfaces, gives a muted expression to the space. The light, as it is seen entering from the different openings in the south wall, helps in removing the bulkiness in the mass of the building and, combined with the curvilinear roof, contributes to a light and free floating form of the chapel (see Figure 9).

The small size of the chapel, seen enclosed by thick walls as it isolates the spatial envelope from the exterior, creates a static and silent character that is broken on the periphery by the placement of major openings of light. The sacred nature of the space is embedded in the closed quality of the space and the peaceful interaction with the exterior through the entry of the natural light into the dark interiors (see Figure 9).

The form has been generated out of simple curves that give the spatial envelope a free flowing geometry and highlights the continuity between different surfaces and boundary edges. The curvilinear profile generates an organic form that leaves an artistic impression in the mind of the observer. The space between the wall and the roof helps to liberate the building of its mass and opens the space to the exterior in a way that creates a strong relation between the sacred and the profane. The interior space is bathed in white lime that acts to purify the space and create a contrast with the dark colors on the floor and the ceiling. The light filtering through the colored glass, in the small

openings on the south wall, introduces an element of color that creates visual interest against a white background (see Figure 10).

Figure 10: Detail of the openings on the south wall (Weinel, E. F., http://arch.ou.edu/arch/2423/Chapter%2028/Ronchamp%20Int.jpg, accessed April 20, 2006)

4.1.1.4 Distortion of the Spatial Envelope

The use of convex and concave surfaces along the adjacent walls creates a curved outline to the spatial envelope that sits in harmony with the overall form. The curvilinear roof form unites all the four surface boundaries in a manner that emphasizes the underlying unity of the spatial envelope. The perspective towards the ceiling is distorted as the space tends to open out rather than close especially at the southeast corner where

the south wall extends away from the east wall creating a visual tension as the two boundaries meet (see Figures 2, 3 and 9). But this does not create an imbalance as the light from the gap between the vertical surface and the ceiling and the window opening on the top of the altar door highlights this repulsion as a design element. This creates a vertical thrust and breaks the static nature of the space. The curvilinear roof form further helps in accentuating the organic nature of the chapel and extends the space out to the exterior.

4.1.1.5 Clarity of the Spatial Envelope

The different surface boundaries have an underlying uniformity of expression. All the vertical surfaces are painted white with a rough finish that continues in the ceiling. The ceiling is in grey concrete and differentiates from the vertical surfaces, and the small gap for the entry of daylight, placed at the intersection of the two surfaces, further highlights this change. The floor has a tile pattern that differentiates it from the rest of the surfaces and, due to its dark color, demands the least visual attention. This contrast, in terms of the color, helps the building achieve the vertical thrust and combined with the careful planning, of different openings for daylight, brings clarity to the overall design of the spatial envelope.

4.1.1.6 Proportioning of the Spatial Envelope

The proportioning of the spatial envelope, and all the openings, is in accordance with the modulor that is based on the golden section, as is the case with the lowest point of the roof which is 4.52 m high. This number can be seen as 2 X 2.26 m, which fits in the

proportioning system controlled by the modulor. Different elements of design in the interior are in conformity with the same proportioning system. This generates a highly ordered and controlled space; one that can be related to the human scale, the scale on which the modulor is based.

4.1.1.7 The Color of Architectural Space

The color inside the chapel varies from the lightest to the darkest. White is the predominant color used on the vertical surfaces with a rough finish. This creates a space that is bathed in purity by the natural daylight and provides a clean and clear background to observe the play of light and shadow cast in shades of grey. The grainy texture on the wall generates a pattern of light and shadow at a very small scale. This creates an interesting surface pattern that changes continuously with the movement of the sun across the sky. The shadows that are cast on different surfaces make the white appear dark at times. This enhances the feeling of darkness inside the spatial envelope. The ceiling and floor create a strong contrast to the vertical surfaces that seem to be bathed in light trying to liberate the space from the dark shadows. Most of the openings have been placed in the vertical surfaces that bring light with even greater intensity due to the white color reflecting more light than the grey concrete of the ceiling or the dark colored flooring (see Figures 8 and 9).

The openings on the south window have a clear, colored, and painted glass that brings in, an additional element of color, through the interesting shadows that light casts after it passes through a colored film. The use of bright colors creates greater visual interest when seen against the white wall in the south (see Figures 5 and 11).

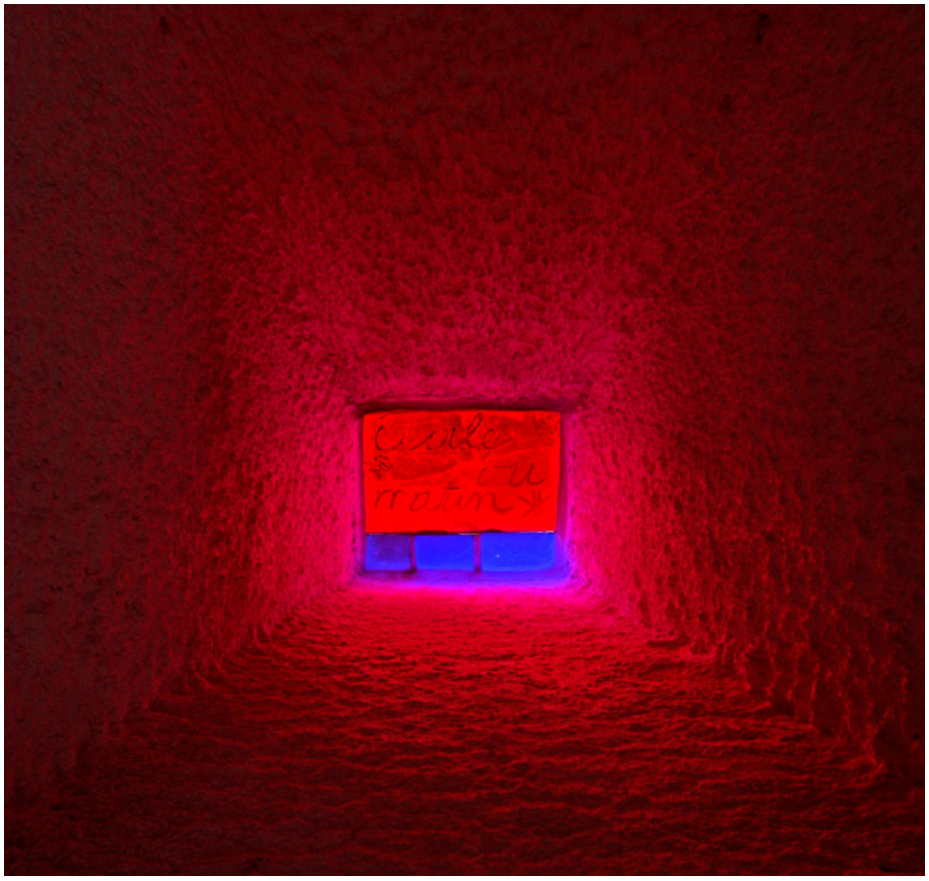

Figure 11: View of the window opening on the south wall. (Schmier, H., 2005, http:// www.myfourthirds.com/ document.php?id=13695&full=1)

4.1.2 ARTICULATION OF THE SPATIAL ENVELOPE

The spatial envelope has been articulated through the use of surface texture that affects the quality of light being reflected inside the chapel. The effect is to create a strong contrast between the light as it enters through the periphery of the envelope and the dark, that is, the result of long shadows being cast by the boundary surfaces. The three chapels placed inside the vertical towers help in articulating the spatial envelope through the use of subspaces.

4.1.2.1 Patterning the Dominant Boundaries

The underlying pattern in the spatial envelope is through the visible roughness in the final finish of the vertical surfaces and the concrete in the ceiling. The grainy and uneven texture helps in the unsymmetrical spread of natural light creating surface shadows. This highlights the underlying tension of the materials, and the way it has been applied on the surface boundaries to define a sacred enclosure far removed from its environment.

Figure 12: General view of interior looking east. (Archive Colour Slides Ltd., 1984, Slide 10 L 24,042)

4.1.2.2 Penetration of the Spatial Envelope

There is a strong emphasis on achieving a sense of penetration into the closed spatial envelope through the effect of natural light in different ways as light makes its presence felt inside the dark interiors of the chapel. The placement of the statue of the Virgin Mary in one of the recessed openings in the east wall is an attempt at animating a surface boundary through silhouetting.

The window openings on the south wall are made up of clear, colored, and painted glass to bring in colored shadows (see Figures 5 and 11). The splayed openings help in the spread of light creating a sparkle effect as light enters the chapel. Then, there are hidden openings in the north wall that help to highlight the free standing elements in the choir. But the most visible attempt of penetration is through the light washing along the ceiling as it enters from the small gap between the roof and the walls on the south and east end of the chapel. This heavy mass of the roof is set free and the static nature of the enclosed space broken through the light penetrating deep into the space (see Figure 12). A similar sense of penetration can be felt when standing near one of three altars places in the vertical towers. The light from the clerestory floods the small chapel and illuminates the altar to create a highlight that attracts visual attention in terms of contrast it generates against the dark interiors (see Figure 13).

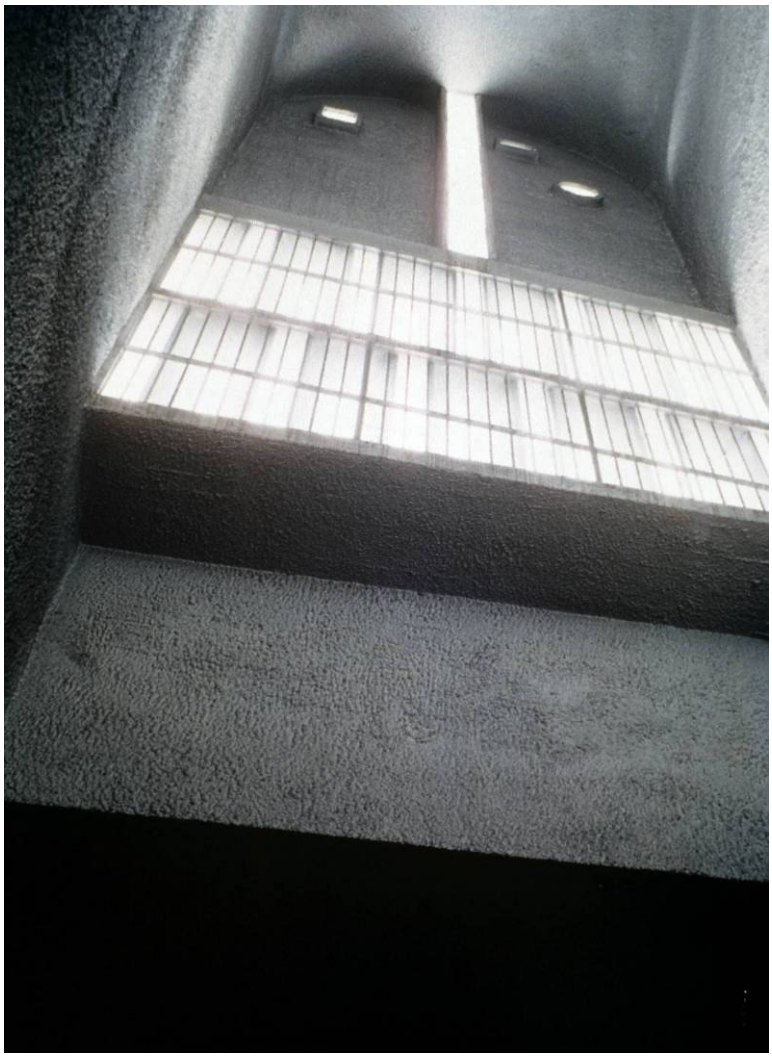

Figure 13: View up into main tower from the south. (Archive Colour Slides Ltd., 1984, Slide 10 L 24,064)

4.1.2.3 Articulation with Subspaces

The spatial envelope has been articulated by the placement of three small chapels in the vertical towers that become visible as they protrude out of the roof. The elongated cylindrical tower on the west end of the south wall is the tallest when compared to the towers placed on the north end of the chapel that are equal in height. All the three towers

bring in a different kind of light that is made to enter from the clerestory openings at the top and reflected down of the vertical surfaces of the tower. The absence of any sharp edges and the presence of the grainy texture on the vertical surface bring in a soft and diffused quality of light as it falls on the altars placed beneath the domical cap on the top of the tower (see Figure 14). The continuous use of curves from the walls enclosing the towers to the way they close and define the boundaries of the smaller chapels helps in maintaining a strong relation with the main spatial envelope. The clerestory openings in each of the towers face in a different direction, namely north, east, and west thus maintaining an individual character based on the kind of light it filters through the space. The tower on the south side brings in a light from the north that remains unchanged throughout the day (see Figure 13). The tower on the west end of the north wall brings light from the setting sun, and the one on the east side brings light from the rising sun. The unity of the form and underlying continuity is not made to look monotonous by the variety of spaces bringing in different kinds of light to achieve multiple effects in the spatial envelope.

The confessional, as it bulges out from the west wall, is another subspace inside the main spatial envelope. This is in strong contrast to the other three subspaces and relates to the exterior with the placement of the gargoyle on the top and the rain water collection tank placed next to it. The subspace is placed in the dead wall on the west side and signifies the darkest corner inside the spatial envelope.

Figure 14: Interior: Northwest side altar. (Archive Colour Slides Ltd., 1984, Slide 10 L 24,062)

4.1.2.4 Spatial Banding

There is no spatial banding inside the chapel. The grainy texture on different surfaces helps in the spread of a diffused quality of light. This removes the possibility of any

sharp patterns being created through the path of light as it stands in contrast to the dark shadows.

4.1.2.5 Curvature and Level Change

The use of curved surfaces inside the chapel varies from the concave to the convex on the vertical surfaces and gets all the more complicated in the roof. The east and south walls bend inward and act as receivers of natural light from these two orientations. The north and west walls bend outward and are more of containers that help in the distribution of reflected light inside the chapel (see Figures 3, 8 and 9). The generating curve for the roof sags in the middle and rises towards the periphery of the envelope. It reaches the pinnacle at the southeast corner of the chapel, and this is highlighted by the light entering from the gap between the wall and the ceiling. The roof defines the axis of the space that seems to move from the west end of the chapel, that has no openings, to the exterior, and the roof is at its lowest point to the southeast corner where the difference in the height level is made all the more pronounced by light entering from three different directions (see Figure 12).

The floor inside the spatial envelope slopes downward towards the altar directing the movement pattern of the visitors. This helps in achieving a gradual and smooth transition from the point of entry to the center of the worship (see Figure 9).

4.1.3 ROLE OF THE STRUCTURAL SYSTEM

The main structural system in the chapel is composed of reinforced concrete that has been used to construct the required framework for the building. It has been filled with

stone recovered from the ruins of the old chapel. The roof is composed of two membranes, each of which acts as a thin shell separated by a gap of 2.26 m conforming to the modulor proportion.

4.1.3.1 Prominence of Building Form

The building form in the chapel can be seen as a stretched envelope on the minimalist framework made of reinforced concrete. The various elements in the chapel, like the walls, roof, and towers, have a curvilinear profile that is further accentuated by the gradients generated by the light and shadow patterns. The building opens out to the four horizons through the well proportioned geometry of the external boundaries. The north and west walls bulge out to contain the sacred space from the surroundings, whereas the east and south walls open outwards to bring natural light inside the building. The controlled amount of light reveals the inside of the chapel in a mystical manner. The asymmetric arrangement of the inside relates to the way different surfaces and boundary edges contribute to the organic form of the chapel as seen from the outside.

4.1.3.2 Structure Patterning the Spatial Envelope

The rough texture visible on the surfaces depicts the tension in the material that confronts the plastic nature of concrete, and the way different forms have been held together by the structure. The texture forms the pattern that is seen repeated in the integration of the structure with the plasticity of the sprayed mortar. The outer covering can be seen as a stretched envelope wrapped around the reinforced concrete frame. The concrete, with the impression of the formwork (planks of wood) inscribed in the grey

roof, sets up a nice contrast to the vertical surfaces that have concrete sprayed by a machine gun and then covered in gunite and white washed (see Figure 15). This contrast further highlights the building form and its integration with the structure while playing down the duality of the material (stone and concrete).

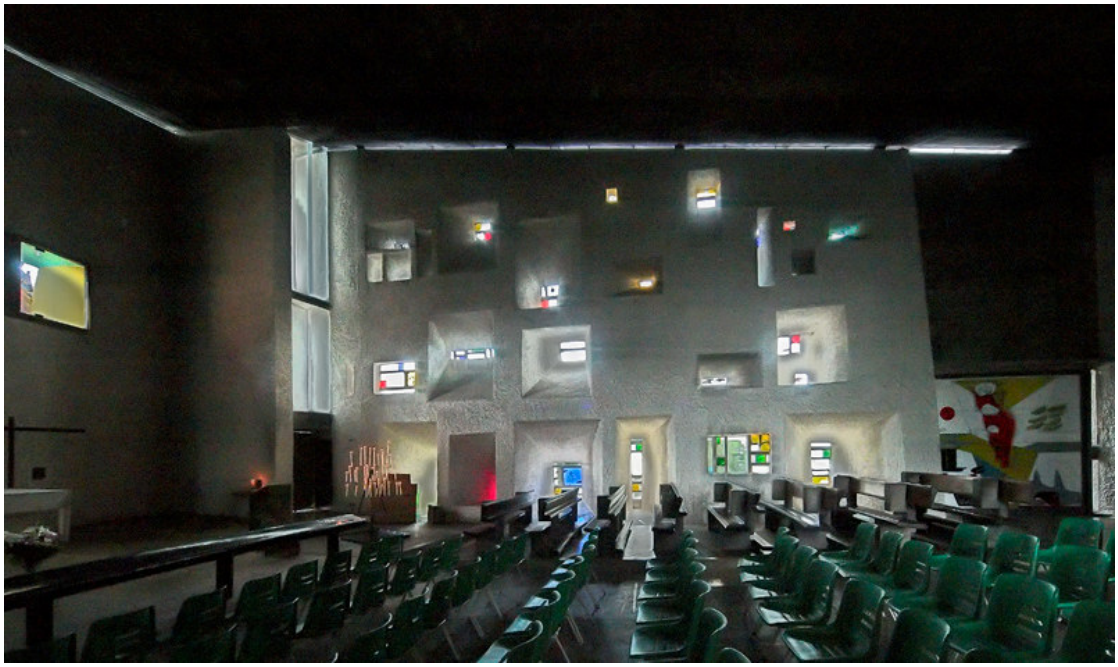

Figure 15: View towards the south wall. (Schmier, H., 2005, http://www.myfourthirds.com/ document.php? id=13552&full=1)

4.1.3.3 The Sources of Light

The structural envelope inside the chapel opens out to four horizons that the building overlooks sitting on the summit of the hill, to bring in varied light. The subspaces have been used to bring light from all possible directions that serve as an important feature in the design of the chapel. These subspaces are seen as prominent design elements in the structure and form of the building. The way light is brought inside the chapel helps in the

complete integration of the form, function, and structure of the spatial envelope (see Figures 16 and 17). The three parallelepiped vertical towers that extrude from the building envelope have clerestory openings that face north, east, and west directions. Rising above the roof line, these curvilinear forms have a domical shaped cap on the top that creates an interesting structural composition. The clerestory openings bring in soft, diffused, and colored light to the altar highlighting these subspaces (see Figure 13). The source of light from the three cardinal directions, i.e. north, east, and west, is hidden from the spatial envelope, and all one can see is soft light falling on the altar placed below the clerestory openings creating a contrast with the dark interiors (see Figure 14).

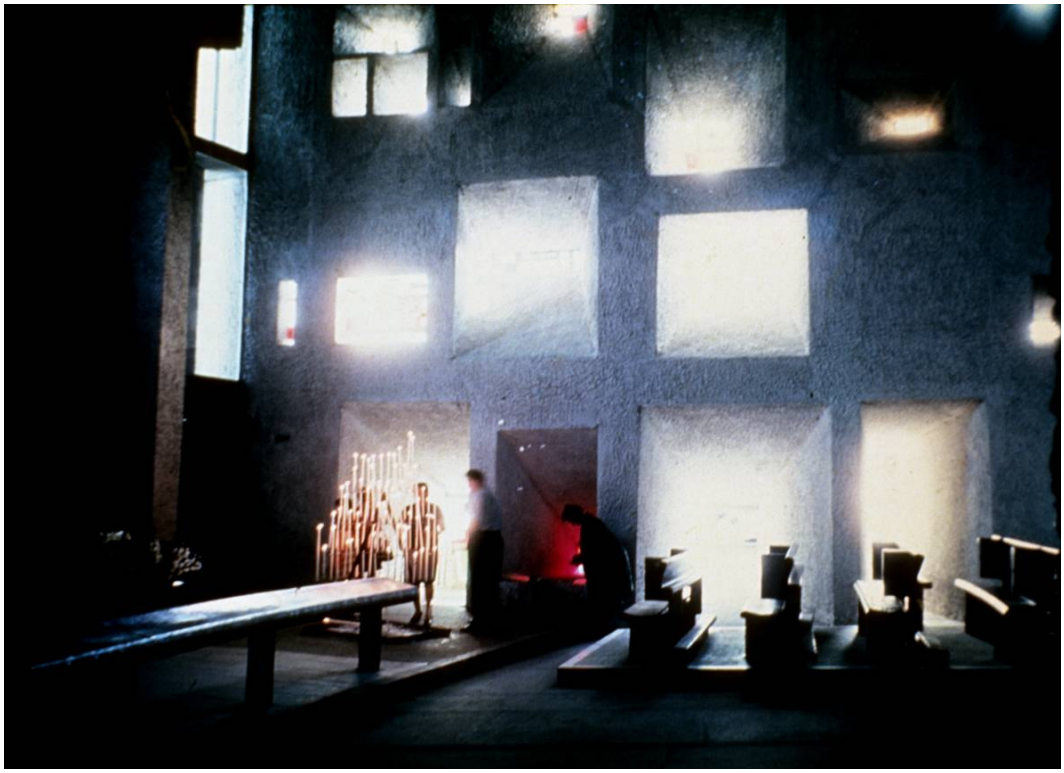

Figure 16: Close-up view of area behind altar from the south. (Archive Colour Slides Ltd., 1984, Slide 10 L 24,056)

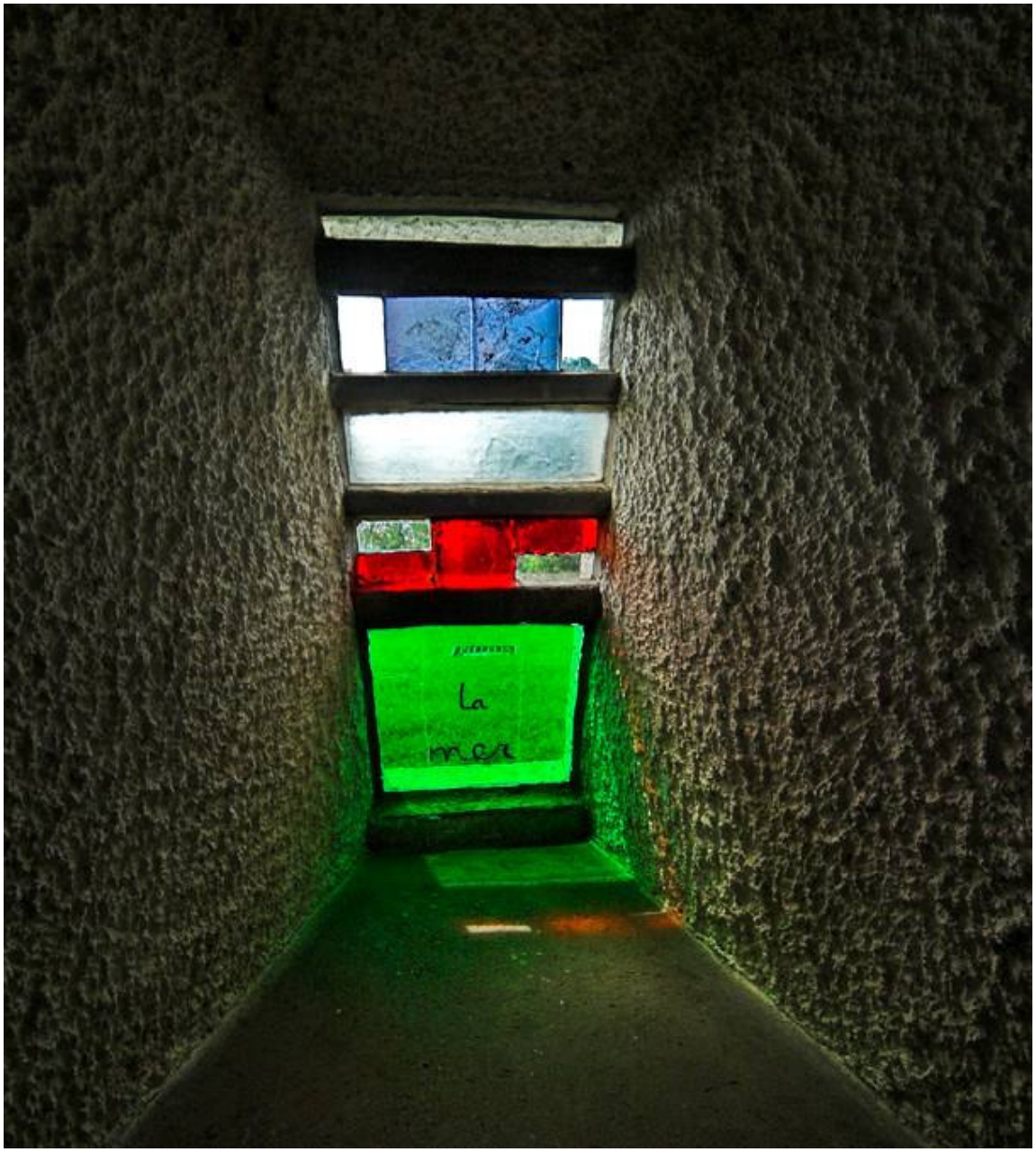

Figure 17: Close-up view of the window opening on the south wall. (Schmier, H., 2005, http:// www.myfourthirds.com/document.php?id=13601&full=1)

The fourth cardinal direction, i.e. south, brings in daylight with an emphasis on the way light enters the chapel rather than the object it illuminates. The splayed window

openings bring in direct intense light and help it spread from the narrow opening to the point where it is about to enter and illuminate the chapel. This creates an effect of sparkle, which highlights the south wall creating a strong design emphasis based on the transformation of natural light through the design of a window opening. This effect of natural light clearly distinguishes the south wall from the surface treatment of the other three walls (Figures 16 and 17).

4.1.3.4 Structural Synthesis for Architectural Beauty

The building can be seen as a continuous curvilinear skin wrapped around the structure which forms the basic skeleton. The fluidity in the envelope, as it moves from one surface boundary to another, gives a sense of visual harmony to the structure both inside and outside. The south wall is composed of a reinforced concrete frame that is hidden and partially revealed at the top where it supports the roof. The width of this wall varies from 3.70 m in the west (where the slant is maximum and the height minimum) to 1.4m in the east (where the wall gets vertical and reaches its maximum height) and 0.5 m at its top. This way, the wall achieves its shape in terms of the curve and thickness. This reinforces the harmony between the strength of the structure and the beauty of the form.

The three vertical towers stand independent from the walls. This is due to the differential settlement that could result from the pressure exerted by their massing which would exceed that of the walls. Although the curves from the wall surfaces merge with those of the towers to achieve the unity of form (see Figure 3), but a small void separates the two and highlights the difference as they extend out in the vertical direction to achieve different heights.

This structural synthesis is made visible in the way light renders the inside of the chapel creating a unanimous whole. The light is not allowed to enter from an opening and merge with the space but is guided along a surface boundary that forms an extension to the outer edge of the opening. This can be seen in the light that enters from the gap between the roof and the vertical walls and flows along the curve of the lower most shell, thus making the mass in the roof disappear as if it was floating on the top of the chapel.

4.1.4 MOVEMENT THROUGH SPACE

On the exterior of the chapel is a well laid out promenade that guides visitors' movement. The steep path to the hilltop brings about interesting views that reveal the structure through the foliage leaving the visitor amazed at the sculptural quality the chapel has to offer in the exterior. The three entrances on the south, east, and north side of the chapel invite the visitor to explore the building form by walking all around it. Once the visitor enters the chapel, the physical movement is replaced by the movement of the eye that tries to read the space in the way light enters and renders the spatial envelope. The form becomes less predominant in the dark interior space and what can be felt are sensations generated by the play of light and shadow (see Figures 8 and 12).

4.1.4.1 Stimulus for Movement

Upon entering the chapel from the north or the south door, one is faced with a dark space and, once the eye adjusts to the low light levels inside the chapel, the space opens out towards the south east corner of the chapel. The effect is more pronounced in the way

light renders the roof form which achieves its pinnacle at the intersection of the south and east walls (see Figure 12). Light from the gap between the vertical wall and the horizontal roof creates an opening for the space to merge with the exterior in a way that the tension between the inside and outside is relieved to some extent. The light from the south, east, and north openings highlight the elements in the choir that further demand greater visual attention of the visitor (see Figure 7). The visitor is forced to follow the path towards this corner of the chapel and finally exit from the recessed door in the east wall. In between, there are other focal accents that create visual interest while following this path. The different openings on the south wall have clear, colored, and painted glass that brings in natural light with varied effects. The three small chapels placed inside the vertical towers are bathed in different kinds of light based on the orientation of the clerestory openings. The hidden source of light creates mystery in the mind of the observer, and the incomplete information that is read in the process prompts the movement of the observer away from the path that connects the entrance doors on the north and south with the exit door on the east (see Figure 14).

4.1.4.2 People Move toward Light

The movement of the visitor is controlled by the strong contrast created by the shadows seen against a white background bathed in light. The south side of the chapel is silhouetted with the splayed openings being highlighted defining the path of light into the chapel. The effect is more of a sparkle rather than a glare due to the splayed edges and the grainy texture reflecting light in different directions. The seating arrangement is placed next to the south wall in an asymmetric manner that further reinforces the

movement pattern inside the chapel. The light leaking from the gap between the roof and the vertical surfaces on the south and east walls creates an emphasis on the southeast corner of the chapel. This is where the exit door has been placed with light, from the opening on the top of the frame, guiding the movement from the dark interiors of the chapel to the bright exterior (see Figure 12).

4.1.4.3 The Zone of Transition

The point of entry on the south wall is a revolving door hinged at its centre. The door is recessed between the south wall and the vertical tower on the southwest corner. The wall surface is sloped to adjust for the low height of roof at this point. The sloped surface is at its maximum deviation from the vertical. The buttressing inside allows room for a transition space from the bright exteriors to the dark interiors (see Figure 4).

The entrance door on the north wall is placed between the two vertical towers making a deep and recessed point of entry. The zone of transition provides breathing space for the eyes to adjust to the low levels of light inside the chapel and, in the process, makes the impact of small sources of light more strong and dramatic. As the visitor moves out from the east door, the wall on the south side extends outwards to provide natural shading from the direct sun and creating another smooth transition to the bright exterior.

The vertical towers containing the altar have a hidden source of light which can be seen once the person moves into the small chapel and looks towards the top (see Figure 13). From the initial view of soft light falling on the altar to the final appreciation

of the manner in which the light enters the space, there is a gradual change in the intensity of light being reflected of the surface (see Figure 14).

4.1.4.4 Brightness Changes as a Function of Movement

The brightness changes inside the chapel are perceived against a white background which creates a significant contrast with the foreground objects. Upon entering the chapel, light openings on the south and east walls are perceived as the brightest elements as seen inside the spatial envelope (see Figure 9). Once the eye adjusts to the inside light levels, the white lime on the vertical surfaces appears to be the brightest surface seen against the grey concrete on the ceiling and the dark flooring. The light filtering through the colored glass creates a variety of reflections on the white background that changes with the movement of the observer (see Figure 17). The light entering through the south, east and north side of the chapel makes the choir bathe in light and provides a strong visual emphasis towards the southeast corner (see Figure 12). Looking back towards the west end of the chapel, the space appears dark, and the absence of any openings makes the inside of the chapel appear all the more dark and shadowed (see Figure 8).

4.2 KIMBELL ART MUSEUM BY LOUIS I. KAHN

Louis I. Kahn was commissioned to design Kimbell Art Museum in 1966 and was one of the last buildings for which he witnessed completion. The museum building was designed as a series of narrow rectangular vaulted elements (see Figure 18) with light and simplicity of enclosure as key design issues. The emphasis was on providing natural day lighting to the viewing galleried in a manner that the artwork in display was not affected. For this, aluminum reflectors were designed to bring in soft and controlled amounts of light from the slit at the vertex of the vault.

Figure 18: Exterior view from the northwest. (Photo by S. Gill, 2004)

4.2.1 THE SPATIAL ENVELOPE

The spatial envelope selected for the analysis is the west entrance lobby at the gallery level (see Figure 19). This is an example of Contiguous Space (Partially Confining, Dynamic or Ambiguous). The space opens out to the spatial envelopes on the north and south sides which contain the viewing galleries. The spatial envelope is defined by a vaulted roof, and four columns supporting at the corner act as the basic modular unit in the museum. This central clear span cycloid shell is surrounded by three similar shells on the east and six shells on the north as well as the south. The low height partitions define the exhibition space in each of the viewing galleries.

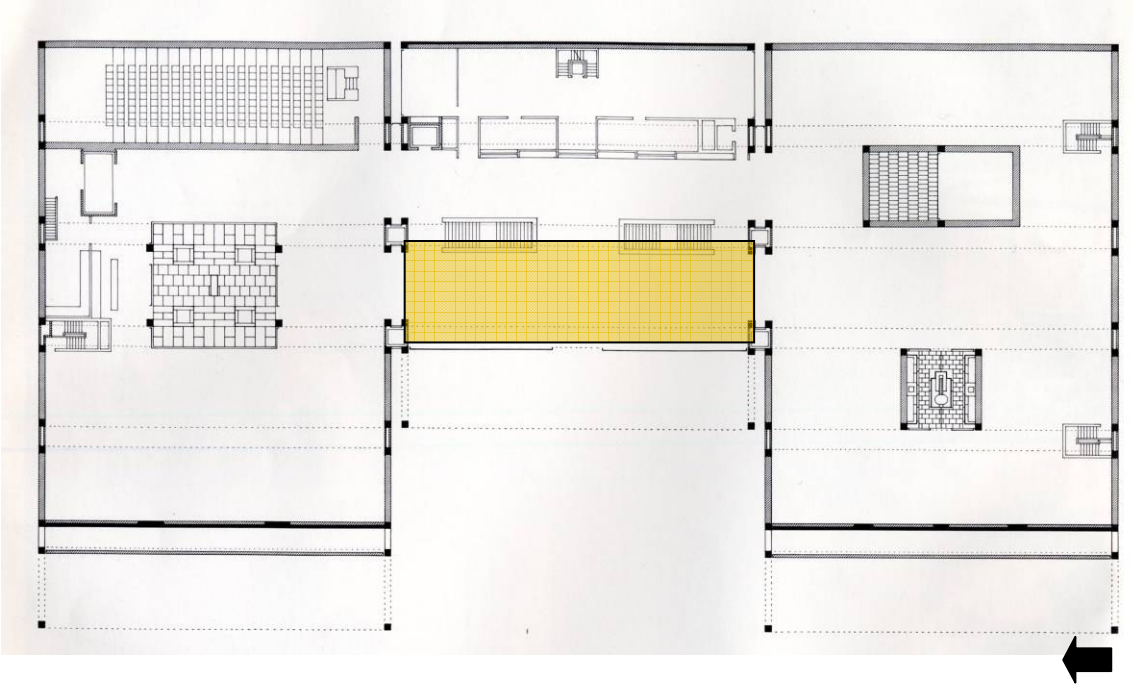

Figure 19: Plan of Kimbell Art Museum, upper level. (Adapted from L. I. Kahn, 1975)

4.2.1.1 Boundaries for Spatial Definition

The dominant boundary is the vaulted roof that spans along a north-south axis and gives the sense of partial enclosure to a spatial envelope (see Figure 20). The repetition of this modular unit along two perpendicular axes generates the overall form for the museum.

Figure 20: Interior view of the entrance lobby looking towards the south. (Photo by S. Gill, 2004)

The dominant boundaries of the selected spatial envelope are:

a) West Side **-** A full height glazing in aluminum framing with operable doors for west access of the visitors defines this boundary. This is further shaded by an open porch that cuts most of the direct rays from the setting sun (see Figures 20 and 21).

Figure 21: View from the entrance lobby looking towards the west porch. (Photo courtesy of M.M.H. Alnuaimi, 2005)

Figure 22: Interior view of the entrance lobby looking towards the north. (Photo by S. Gill, 2004)

b) East Side – The two staircases and the 7 feet reinforced concrete channels, with aluminum soffits that house the air and electrical distribution systems, define the partial boundary that merges with the adjacent subspace (see Figure 22).

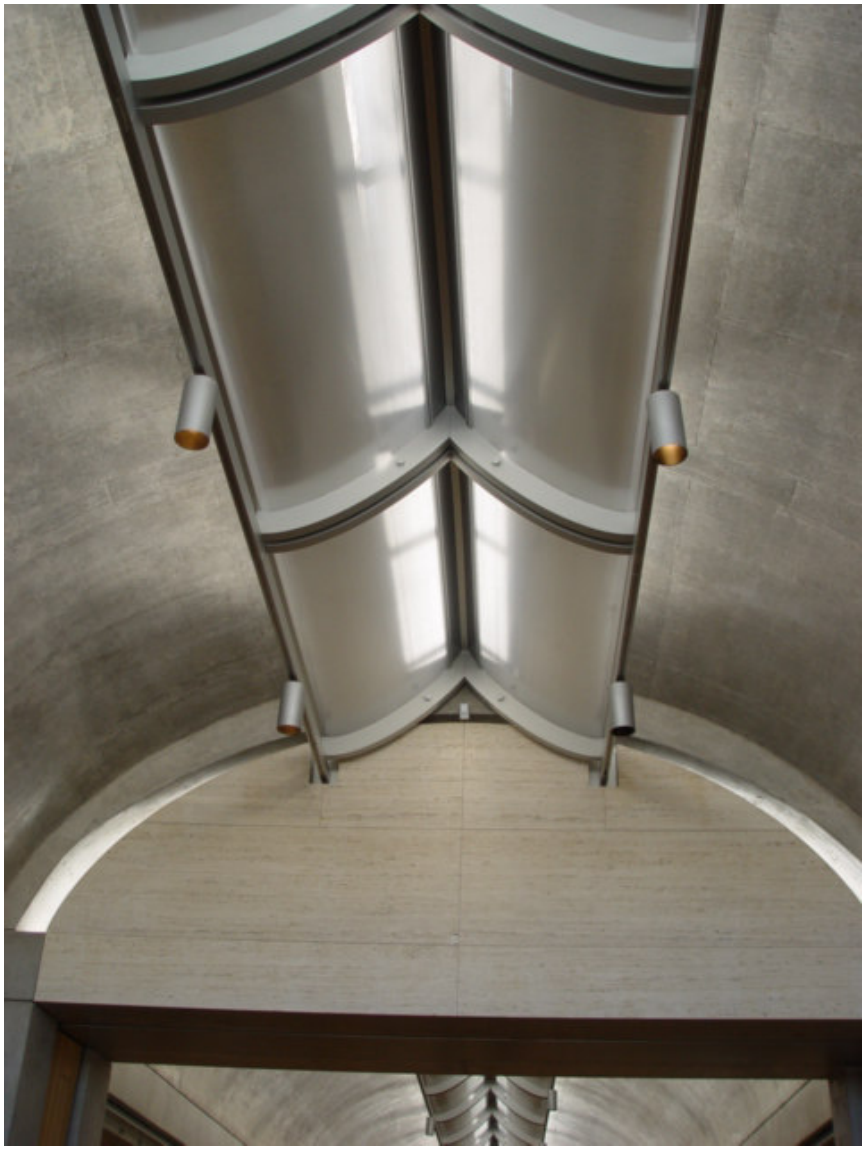

Figure 23: Detail at the gable end of the vault. (Photo courtesy of M.M.H. Alnuaimi, 2005)

c) North and South Side - The gable end of the vault is defined by a rectangular void that is capped by a semicircular vertical concrete section clad with travertine (see Figure 23). The section hangs in mid air and spans between the two edge columns. This forms a small glazed opening with the cycloidal vault and gable end of the circle thereby defining the two ends of the linear axis. This brings in direct light that creates a contrast with the soft diffused silvery light that spreads along the entire length of the ceiling.

Figure 24: Detail of the perforated aluminum reflector and the slit at the apex of the vault. (Photo courtesy of M.M.H. Alnuaimi, 2005)

d) Ceiling – The vault is made up of 23' x 100' clear span cycloid shells of post tensioned reinforced concrete (see Figure 22). This is supported by 2' x 2' corner columns. The placement of the daylight fixture at the apex of the vaulted ceiling, helps in the even illumination of the space. The fixture has a 2½' glazed slit that is controlled by perforated aluminum reflectors that are partially opaque to increase the amount of reflected light and remove direct penetration of the sun rays (see Figure 24). The convex shaped wings reflect the light onto the concave curve of the ceiling thereby achieving a much more uniform spread of natural light inside the spatial envelope. The soft diffused light from the opening helps in achieving a controlled level of illumination for the display of artwork.

e) Floor – The floor is made of quarter-sawn white oak that is golden brown in color and covers the middle section along the entire length of the spatial envelope. On the periphery, there is travertine flooring with the border of grey concrete (see Figures 20 and 22).

4.2.1.2 Visual Perception of the Envelope

The spatial envelope is perceived with a vault that covers the clear span cycloid shell and defines the visual boundary of the space along the vertical axis. The horizontal axis is loosely defined both in the north-south as well as the east-west axis. The spatial envelope merges with the boundaries of the surroundings thereby creating a much more open environment that facilitates the movement of the visitors between different objects of art. The spatial depth along the north south axis is defined by the concave curve of the vaulted ceiling and the perforated aluminum reflector that projects outward from the top

in two convex sections spread along the two curves that define the dominant boundary on the top. The light from the slit, on the top of the vaulted roof, helps in defining the curved profile of the spatial envelope (see Figure 25).

Figure 25: Interior view of the ceiling with the daylight fixture. (Photo courtesy of M.M.H. Alnuaimi, 2005)

4.2.1.3 The Character of Space

The major surfaces in the spatial envelope depict a soft and monotone imagery. The underlying character can be said to be satisfying and peaceful as the displayed objects of art are being appreciated by the visitor. The use of similar materials with common texture helps in providing good continuity throughout the space. This helps the visitor to

concentrate on the objects being displayed, which provide the necessary visual accent in the overall movement in the space (see Figure 26).

Figure 26: Interior view of the artwork on display. (Photo courtesy of M.M.H. Alnuaimi, 2005)

The soft and diffused light further supplements the restrained nature of the materials while highlighting the pure and simple geometry that is based on a strong sense of proportions. The volume conveys a muted and serene character as the surfaces are minimalistic in their expression and do not overload the visual stimuli of the visitor at any point. The controlled repetition of the cycloid shell helps in maintaining visual

clarity with the displayed artwork differentiating one space from another. The soft transitions from one spatial envelope to another help in achieving the interconnectivity between different functions while maintaining the underlying continuity in the overall experience of the museum (see Figures 20 and 22).

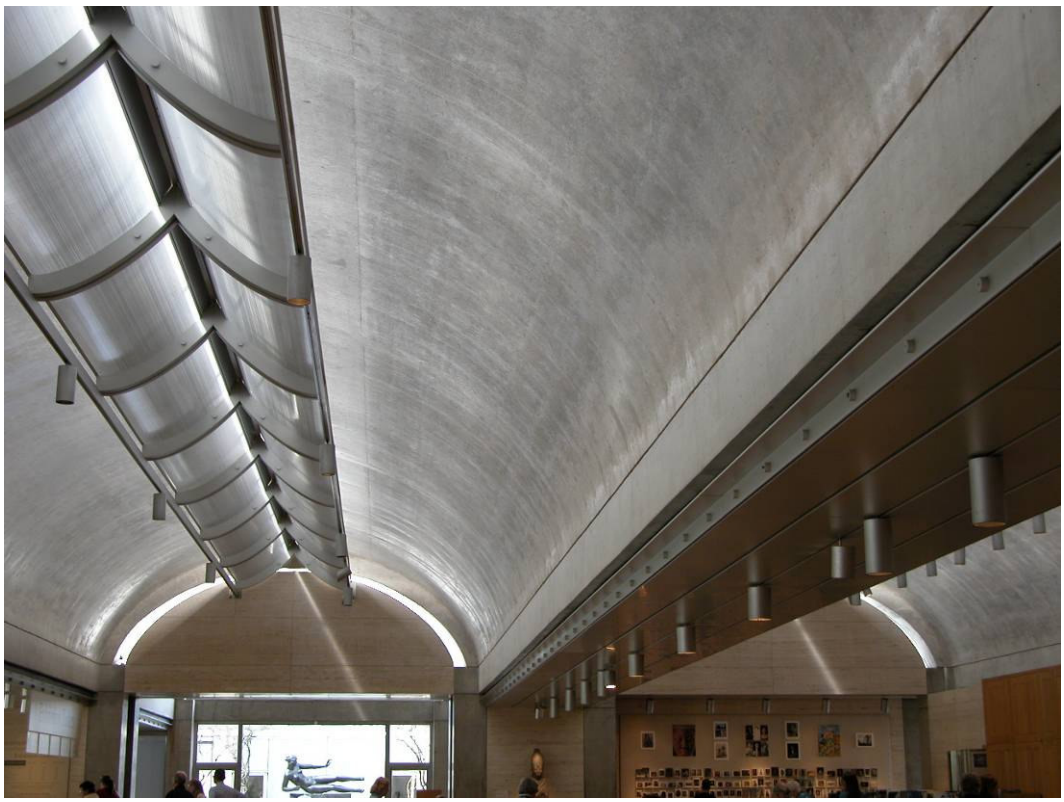

Figure 27: Interior view showing the even distribution of light from the daylight fixture. (Photo courtesy of M.M.H. Alnuaimi, 2005)

4.2.1.4 Distortion of the Spatial Envelope

There is no visible distortion inside the space as the integration of the light with the form of the spatial envelope depicts visual harmony. Natural light is made to enter from the

top of the cycloid shell thereby spreading along the two curved wings of the ceiling. This further helps in the even reflection of natural light inside the space thereby rendering each surface in relation to its apparent form. The distortion of the space is negated by the even gradient of natural light that is visible inside the spatial envelope (see Figure 27).

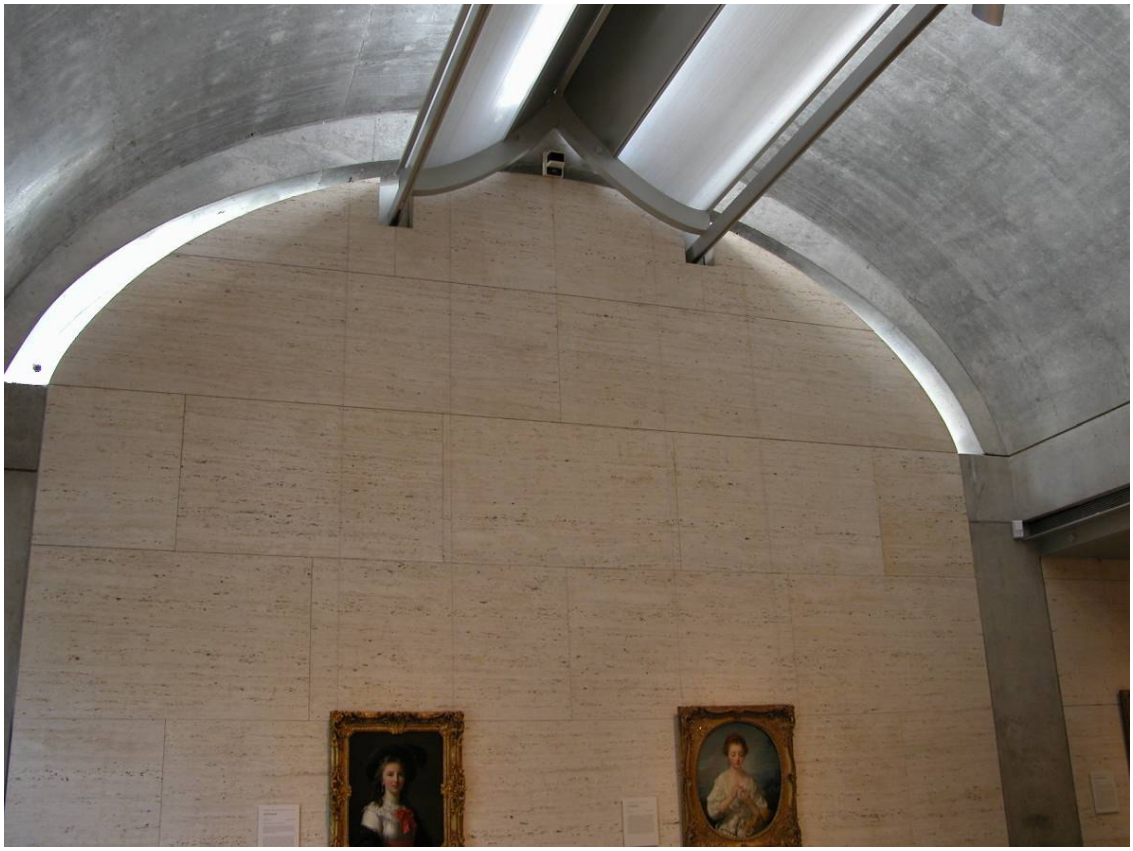

Figure 28: The materials of expression – concrete and travertine. (Photo courtesy of M.M.H. Alnuaimi, 2005)

4.2.1.5 Clarity of the Spatial Envelope

The clarity of spatial envelope is reinforced by the similar surface properties of the two predominant materials used in the expression of the space – concrete and travertine.

Although there is a slight color difference that helps to differentiate between the two materials, the irregularities present on the surface help in achieving visual order inside the space. The vertical and horizontal lines of the grooves, used in the cladding with travertine, resemble the left over impressions of the formwork on concrete. This helps in bringing together different boundaries of space to achieve perceptual simplicity. (see Figure 28).

4.2.1.6 Proportioning of the Spatial Envelope

The spatial envelope has a 23' x 100' clear span with the maximum height of the cycloid shell reaching 20'. This converts to a basic ratio of 1:5:1 with the emphasis on developing a strong linear axis along the north south direction. The height to width ratio is almost 1:1 and, with the articulation of the ceiling with the perforated aluminum reflector on the top, provides a strong sense of depth inside the spatial envelope. The square section is visualized in a rectangular shape as the edges on the east and west side merge freely with the surroundings (see Figures 20 and 22). The proportioning system is made all the more visible through the placement of cycloid shell at regular intervals in the space.

4.2.1.7 The Color of Architectural Space

The color inside the spatial envelope varies from the silvery grey of concrete on the vaulted ceiling to the beige color tone of travertine on the vertical wall surfaces and periphery of the floor and finally to the golden brown of oak wood flooring. The overall effect of this controlled variation is the monochromatic picture of the space. The light, as

it enters from the top of the cycloid shell, is made to flow along the grey concrete surface that renders each material in the soft silvery tone of natural light. This controlled and muted expression of the space provides a nice and neutral background to appreciate the works of art as they stand out in the foreground (see Figure 29).

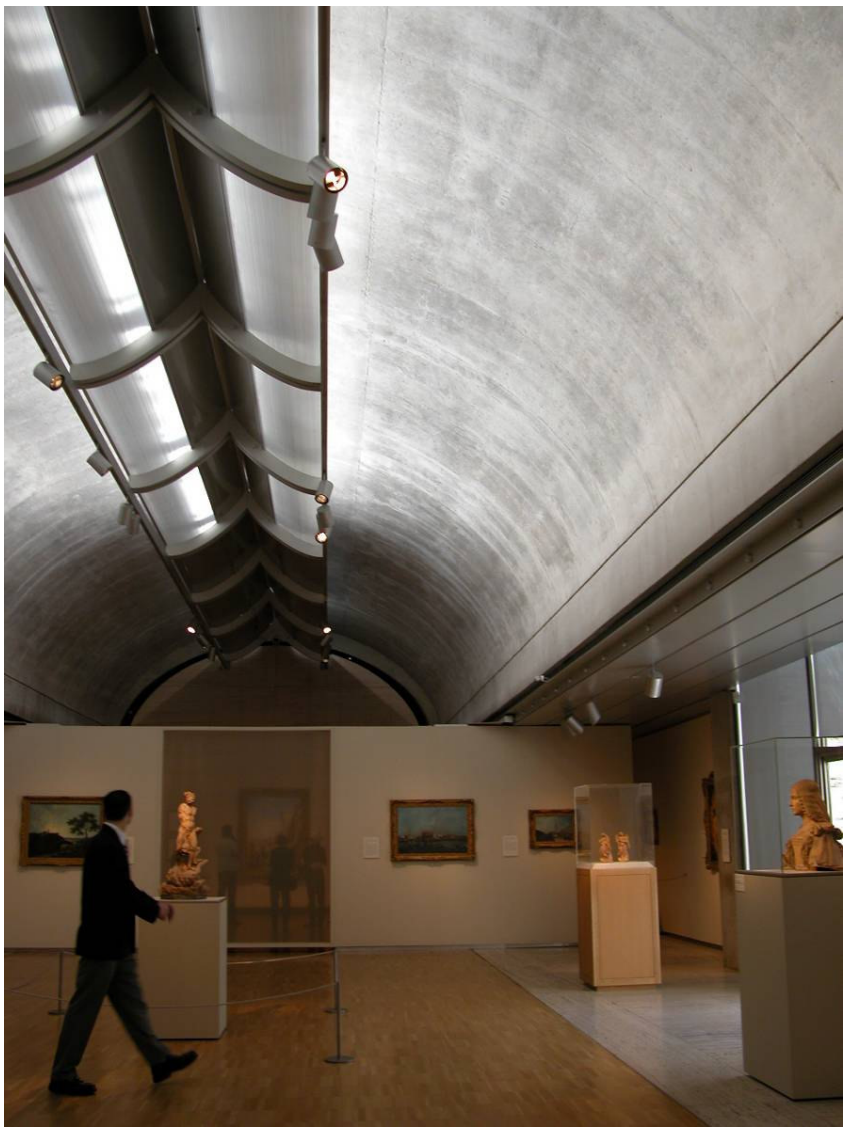

Figure 29: Interior view showing the different surface colors visible inside the gallery. (Photo courtesy of M.M.H. Alnuaimi, 2005)

4.2.2 ARTICULATION OF THE SPATIAL ENVELOPE

The articulation in the spatial envelope has been achieved by animating the dominant boundaries through surface textures and patterns while keeping a restricted and monochromatic vocabulary of material. This helps in achieving perceptual simplicity with the objects of art that are displayed acting as the main focal accents. The articulation through different openings helps in achieving a sense of penetration with soft, diffused light that creates a subdued character inside the spatial envelope. The visual clarity is visible with the focus on the objects of art that are in the foreground and are not disturbed by over articulation of the background that is made up of the dominant boundary and surfacing material.

4.2.2.1 Patterning the Dominant Boundaries

There is a strong sense in which the dominant boundaries have been patterned to achieve overall order inside the spatial envelope. From the small patterns on the brown colored oak flooring to the much larger modules on the bordering travertine, there is a well directed hierarch of focal accents that connects different surfaces and is aimed at animating the space. Then, on the vertical surfaces travertine is divided into the same modules that are visible on the floor in the shape of vertical and horizontal grooves. The rough textured finish on the travertine is continued to the irregularities in the concrete that forms the vaulted ceiling. The whole pattern continues throughout the longer axis of the spatial envelope thereby maintaining visual clarity throughout the space (see Figure 30).

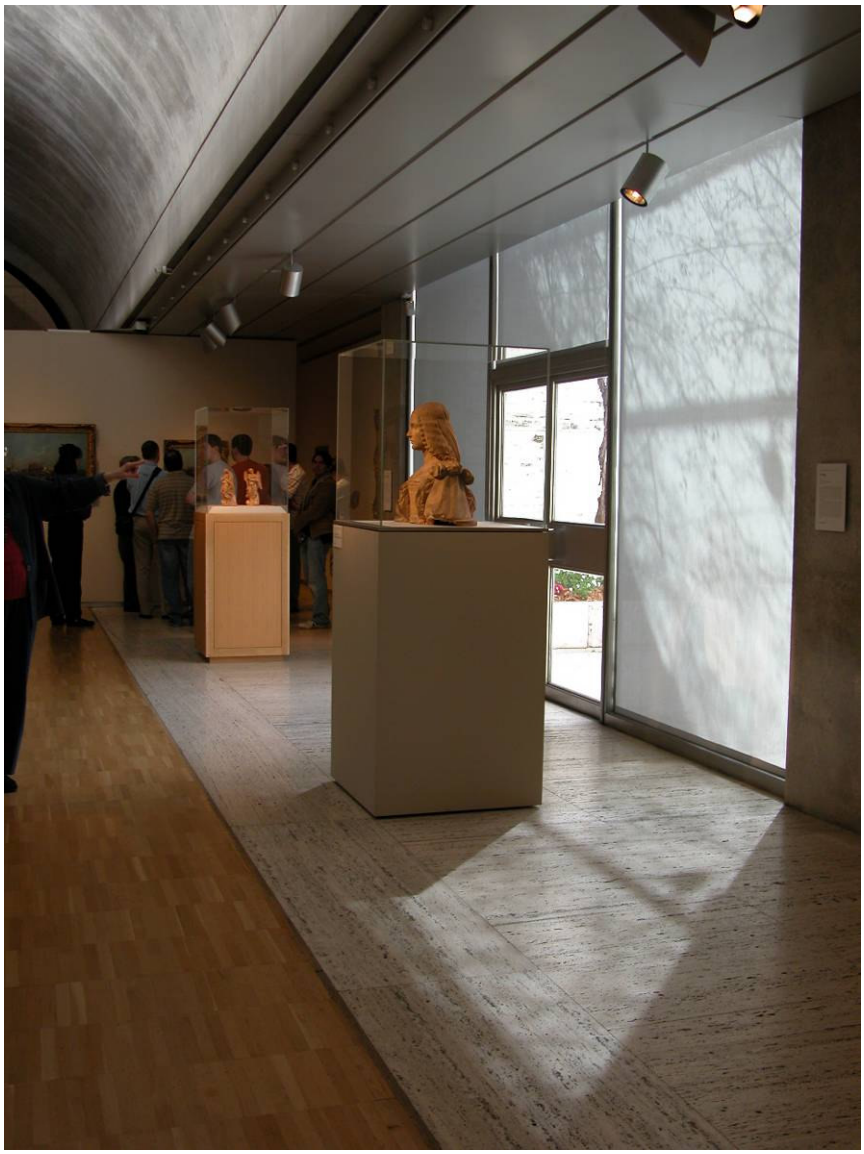

Figure 30: The visible patterns inside the spatial envelope. (Photo courtesy of M.M.H. Alnuaimi, 2005)

4.2.2.2 Penetration of the Spatial Envelope

The penetration inside the spatial envelope is achieved through three different kinds of openings. First is the full height glazing on the west side that opens the view to the

exterior. The contained space inside the museum merges in a free and organic manner as the open porch replicates the profile of the spatial envelope (see Figure 20).

Figure 31: The penetration of the spatial envelope towards the gable end. (Photo courtesy of M.M.H. Alnuaimi, 2005)

The use of a slit opening at the apex of the cycloid shell does not give a real sense of penetration and appears to be an animated detail of the dominant boundary (see Figures 24 and 25). The articulation is effective in increasing the depth of the linear

perspective that closes down with a small bright patch of light against the grey shades of the ceiling. This is the small gap, between the vault and the gable end of the circle, that creates a strong contrast with the intensity of light filtering in as seen against the soft diffused light inside the spatial envelope. The careful proportioning of this opening does not dominate over the building mass but helps to make the ceiling float towards the two ends on the north south axis of the vaulted roof (see Figure 31).

Figure 32: The 7' reinforced concrete channels with the aluminum soffits. (Photo courtesy of M.M.H. Alnuaimi, 2005)

4.2.2.3 Articulation with Subspaces

The lowering of the ceiling, along the east and west side of the spatial envelope, is aimed at articulating through the subspace (see Figure 32). The transition is made visible by the

change in flooring material from the quarter-sawn white oak to the travertine. The subspace marks the transition from one spatial envelope to another (see Figures 20 and 22). The 3' expansion joint on the north and south end of the spatial envelope is another example of articulation through the subspace. The gap between the cycloid shell and the gable end of the circle marks this transition through the entry of natural light that appears intense and powerful (see Figure 33).

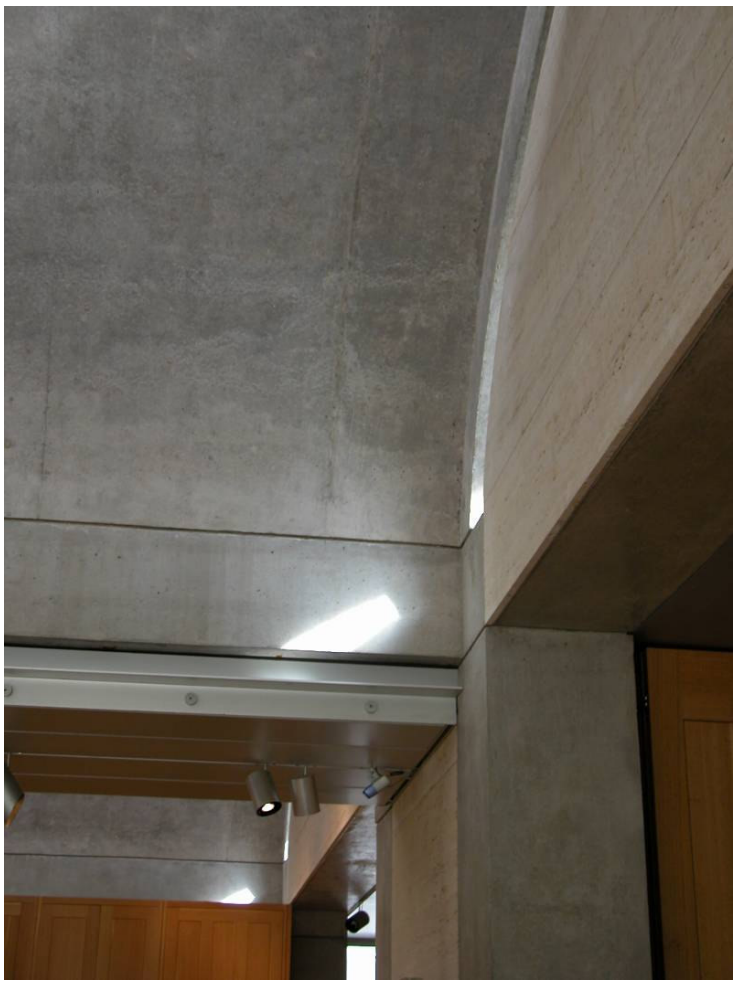

Figure 33: The 3' expansion joint on the south end of the spatial envelope. (Photo courtesy of M.M.H. Alnuaimi, 2005)

4.2.2.4 Spatial Banding

The spatial banding visible inside the spatial envelope is aimed at emphasizing the north-south axis. The 7' reinforced concrete channels with the aluminum soffits, which house the air and electrical distribution systems placed on either side of the vaulted ceiling, create a strong linear pattern that is further reinforced by the perforated aluminum reflector running along the entire length of the spatial envelope, although on a much higher level. This is aimed at the articulation of the space by integrating structural and mechanical systems with the overall spatial composition (see Figure 32).

4.2.2.5 Curvature and Level Change

The use of curved surfaces is restricted to the ceiling where the vault helps in bouncing soft diffused light in all different directions thereby creating a uniformly lit space. The concave profile of the ceiling is balanced by the two convex shaped aluminum reflectors that create an interest along the entire length of the ceiling while emphasizing on their function of bringing in the soft and controlled quality of natural light (see Figure 31).

The level change takes place as one makes the transition from the lower level to the upper level through one of the two staircases placed on the east side of the entrance lobby. The narrow staircase opens out under the aluminum soffit, which acts as connector between the two sections of the cycloid shells. The space opens out vertically with an increase in the ceiling height with the vaults and horizontally connecting the interiors with the exteriors through the full height glazed wall on the west end of the spatial envelope. The design continuity is maintained through the smooth transition along the path of movement connecting two different levels (see Figure 34).

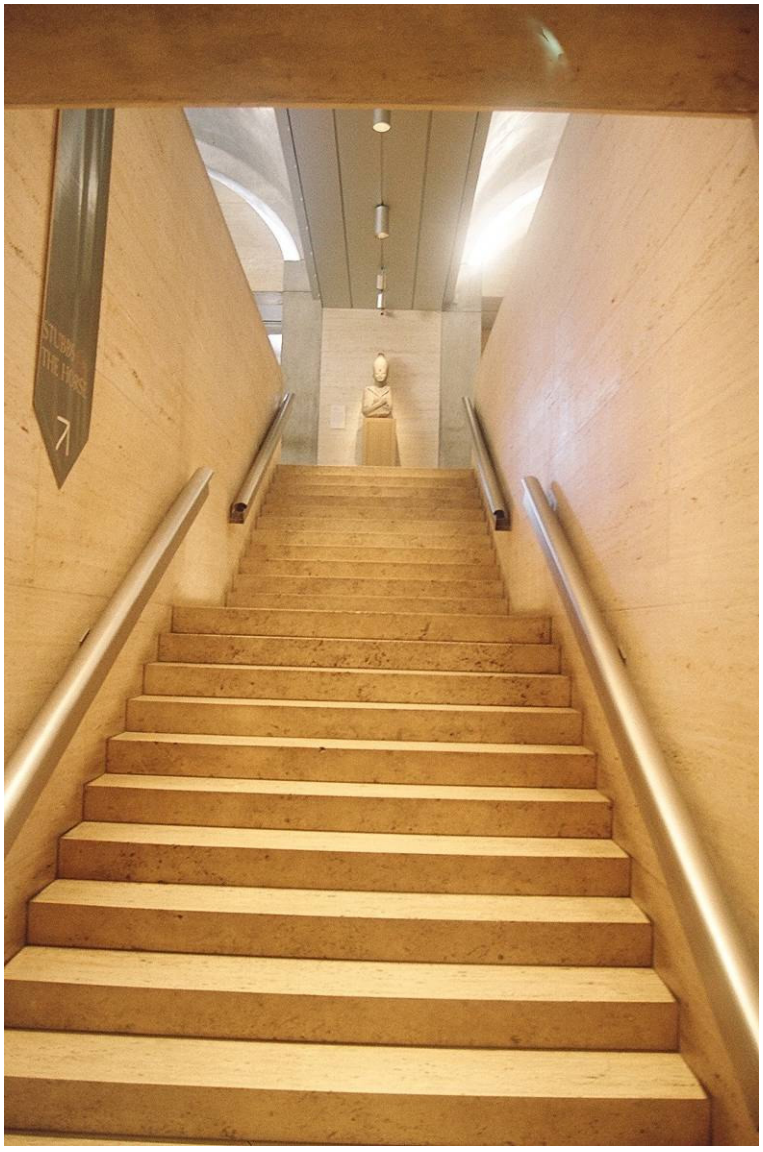

Figure 34: View from the staircase looking upwards to the entrance lobby. (Photo by S. Gill, 2004)

4.2.3 ROLE OF THE STRUCTURAL SYSTEM

The structure system in the museum is composed of post tensioned reinforced concrete vaults supported on four square columns on the corner. The slab on the lower level is made out of poured-in-place concrete whereas that on the upper level is made by two

way post tensioning. The exterior travertine infill walls have a reinforced concrete core between the columns. The continuity of the vaulted roof from one spatial envelope to another creates a smooth transition with the horizontal limits being defined by the three feet expansion joint towards the gable end that marks the boundary of one section from another.

4.2.3.1 Prominence of Building Form

The building form is made out of controlled repetition of the vault which stands as the main structural member defining the spatial layout inside the museum. The slit, at the apex of this vault, brings in a soft diffused light controlled by the perforated aluminum reflector that guides the sunlight to flow along the curved ceiling that brings in uniform light to the interior (see Figures 20 and 22).

4.2.3.2 Structure Patterning the Spatial Envelope

The structural patterning inside the spatial envelope can be seen in the irregularities in the surface properties of the two main materials – concrete and travertine. The shuttered concrete with the left over impression of the formwork and the surface pores on travertine bring out a similar expression creating a play of light and shadow on the surface at a microscopic level (see Figure 35). The vertical and horizontal grooves that divide the material into smaller modules help in establishing the human scale inside the spatial envelope. The monochromatic vocabulary of these two materials along with the soft and diffuse lighting help in controlling the visual noise that can result from a strong sense of surface pattern inside a space.

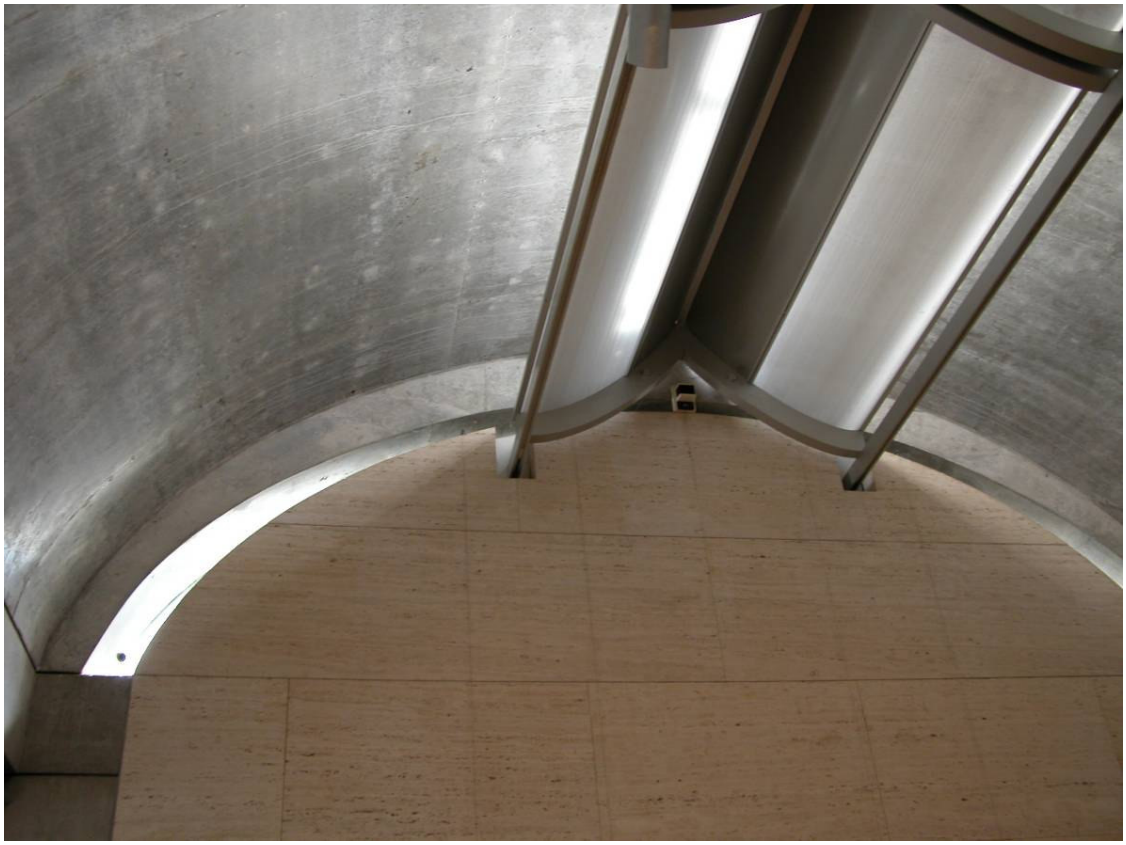

Figure 35: The effect of light on the irregularities of two similar surfaces. (Photo courtesy of M.M.H. Alnuaimi, 2005)

4.2.3.3 The Sources of Light

The main source of light inside the spatial envelope is through the slit opening at the apex of the vault and through the full height glazed wall on the west side of the entrance lobby. The daylight fixture is made out of a 2½' slit that runs along the north south axis all along the length of the cycloid shell and is further controlled by the perforated aluminum reflector that is partly opaque to increase reflections and avoid sun penetration that could harm the artwork on display. As the sun moves across the sky in the east west axis, the perpendicular layout of the spatial envelope helps in achieving a much more

uniform quality of light inside the space. Also, the curved profile of the ceiling helps in reflecting the light in an even manner to all the different corners across the width of the gallery (see Figure 36).

Figure 36: The uniform spread of daylight inside the gallery. (Photo courtesy of M.M.H. Alnuaimi, 2005)

The west side glazing opens out the view to the exterior while restricting the direct penetration of the setting sun through the extended open porch on the west side of the gallery and the green foliage at the entrance. The filtering of light from these trees brings in a soft light as it is reflected into the interior by bouncing off the hard paved open porch (see Figure 37).

Figure 37: Exterior view of the west porch. (Photo courtesy of M.M.H. Alnuaimi, 2005)

The visible source of light is the small gap between the cycloid shell and the gable end of the curve (see Figure 36). The bright light from the small opening seems to

enter with full intensity creating a silhouette of the vaulted ceiling. The strong sense of penetration helps in breaking the soft and subdued character of the space towards the two ends marking a strong transition from one spatial envelope to another (see Figure 38).

Figure 38: Effect of light as it enters from the gap between the cycloid shell and gable end of the circle. (Photo courtesy of M.M.H. Alnuaimi, 2005)

4.2.3.4 Structural Synthesis for Architectural Beauty

The integrity between the form, structure, and the source of light brings out a well designed space for the exhibition and display of artwork. The division between the lower

and upper levels brings down the scale of the space and the form does not dominate inside the spatial envelope. The controlled repetition also helps in regulating the overall form of the building that emphasizes the unity and structural clarity in the overall expression.

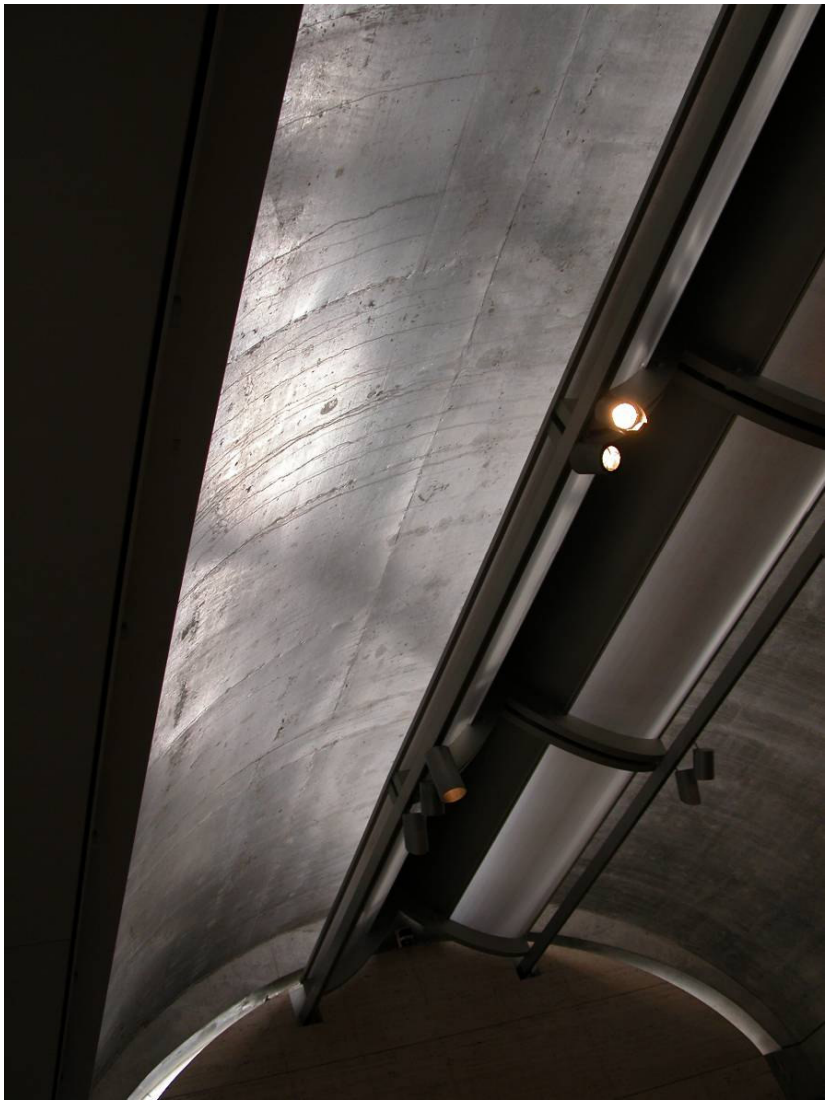

Figure 39: The combined effect of soft diffused natural light with the spotlight focusing on the displayed artwork. (Photo courtesy of M.M.H. Alnuaimi, 2005)

The spatial envelope offers freedom in the layout of the partition used for the display of artwork as well as the placement of the free standing installation. The uniform lighting levels, achieved by the natural daylighting, provide the flexibility to combine the artificial lighting systems for the required emphasis on the displayed objects (see Figure 39).

The soft lighting and the monochromatic expression of materials help in achieving visual harmony inside the space. The flow of light is regulated by the structural form of the vaulted roof depicting the achieved unity that negates the visual distortion of the spatial envelope.

4.2.4 MOVEMENT THROUGH SPACE

The movement pattern inside the museum is exploratory with the objects of art being displayed acting as the visual stimuli for movement. The space acts to provide a nice setting with controlled lighting that highlights these objects against a simple background. The layout of the spatial envelope with the long vaulted roof reinforces a linear movement pattern. The lobby connects to the viewing galleries on both ends of this axis, and the linear perspective focuses on the art being displayed in those subspaces.

4.2.4.1 Stimulus for Movement

The focal accents are the displayed objects that act as the foreground material for creating the stimuli for movement from one point to another. The background becomes an important surface that needs a restrained expression so that the contrast highlights the foreground. The use of materials with a similar texture on the surface, concrete and

travertine, along with subdued colors of expression, creates a monochromatic and neutral background for the display of art. The natural lighting is diffused and uniform throughout the space with artificial lighting creating the focused illumination on the objects on display. The colored paintings attract greater visual attention in the space thereby directing the visual movement based on the points of display (see Figure 26).

4.2.4.2 People Move toward Light

In the spatial envelope, the movement of visitors is directed towards the different paintings, and the lighting in the space is aimed at highlighting the objects of art. So, the movement inside the museum is not directed towards the light source but more towards the objects being illuminated by the light source. The amount of variation in the light levels is not to an extent where visitors can choose between different movement patterns based on the difference.

The spatial envelope does provide focal accents towards the ends with direct light piercing through the small gap between the vaulted roof and the gable end. The controlled light from this opening enables the visitors to orient themselves inside a viewing gallery and creating a strong sense of distinction between different spatial envelopes (see Figure 36). This is all the more important to break the repetition of the basic unit that otherwise can create a monotonous environment inside a museum.

4.2.4.3 The Zone of Transition

The entry into the viewing gallery could be made through the staircase that connects it to the lower level or through the entrance porch on the west side of the museum. In both

cases, there is an emphasis on achieving a zone of transition, although the entrance lobby itself serves as one. The porch on the west side with the vaulted roof sits as an emptied space, which helps the visitor appreciate the simplicity of the structure and the ingenuity in the material of expression before he enters the museum. This sets up a nice transition to the museum where the emphasis is not on understanding the geometry of the spatial envelope, but what is being displayed inside. Also, the shaded porch provides a gradual transition to the low lit interior space (see Figure 37).

The second entry through the staircase reveals the spatial envelope in a much more dramatic manner. Rising through the steps from the lower level of the museum, the narrow confined staircase opens out in a much more dynamic space that appears to merge freely with the surrounding spaces (see Figure 34).

Once inside the spatial envelope, one has to walk along the north south axis with a glazed view on the west side of the green space towards the exterior. Once inside the viewing gallery, the character of the space gets intrinsic with the closing down of the view to the exterior and the focus shifting to the art at display. The transition is back to a closed and confined space with the light filtering through the perforated aluminum reflector being visible in the clarity between the art in the foreground and the material of architectural expression in the background. The emphasis on art is stronger in such a quiet setting (see Figure 26).

4.2.4.4 Brightness Changes as a Function of Movement

The main source of light inside the Kimbell museum is through the slit opening on the top of the vault that is further controlled by a perforated aluminum reflector, the general lighting levels do not vary to a significant amount as we move inside the spatial envelope. The only variation is from the light entering through the gap between the cycloid vault and the gable end which is part of a circle. The intensity of light from this narrow opening stands in contrast to the diffused light entering from the daylight fixture on the top of the ceiling. The brightness of the opening defines the ends of the two axes by highlighting a curve similar in profile to the vaulted shell (see Figures 31 and 36).

4.3 CHURCH OF THE LIGHT BY TADAO ANDO

The Church of Light (1989) was one of the early projects that won International recognition for Tadao Ando including the Pritzker Prize in 1995. The minimalist building is composed of basic architectural elements with few openings that create a space that is born out of light. The interiors are dark and mystical with the entry of light from different openings becoming a dramatic event in itself. The intensity with which light enters from the cruciform opening in the south wall (see Figure 40) makes the space sacred and powerful.

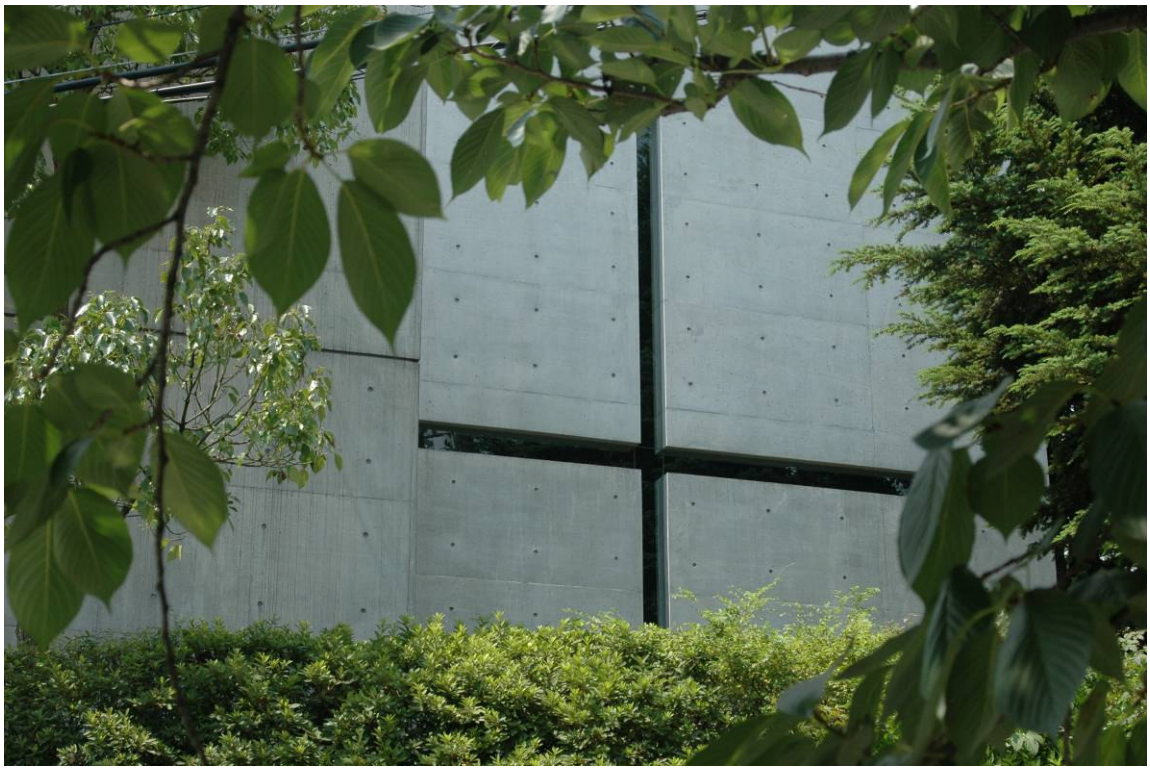

Figure 40: Exterior view of the Church of the Light showing the cross cut in the concrete wall. (Photo by S. Gill, 2005)

4.3.1 THE SPATIAL ENVELOPE

The spatial envelope chosen for the final analysis is the main chapel in the Church of the Light. In plan, it is a rectangular shape that is pierced by an angled wall through the west wall at 15 degrees (see Figure 41). It is an example of Enclosed Space (Confining and Static) in which different surfaces and boundary edges close down to form a full enclosure.

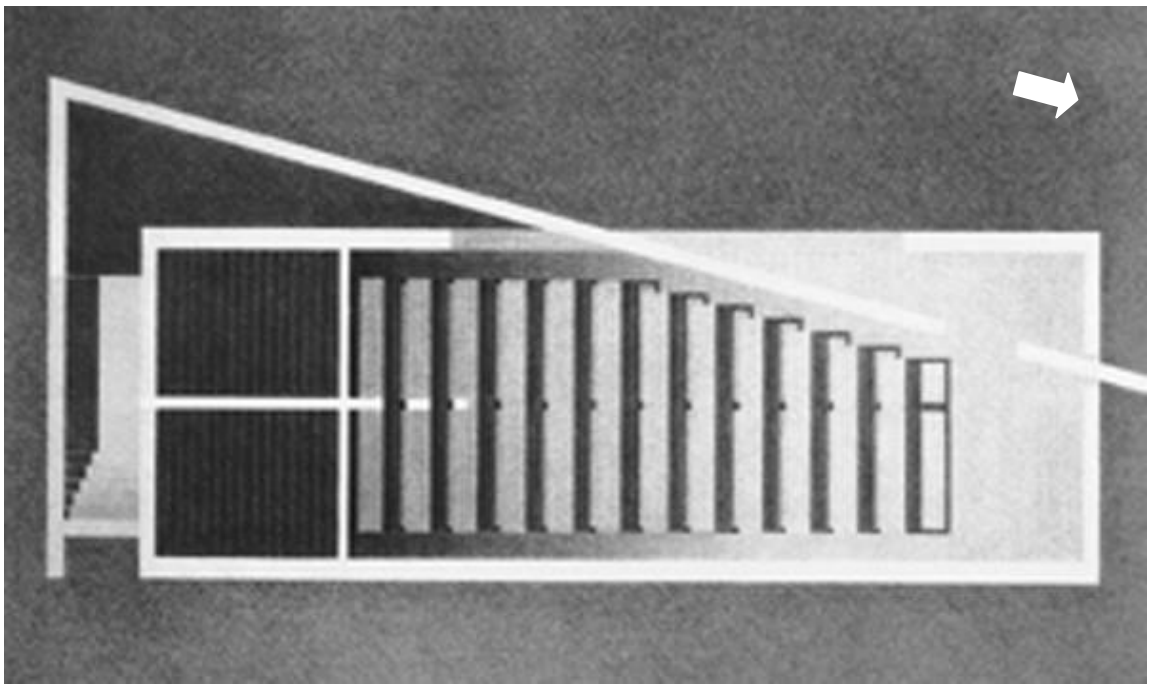

Figure 41: Plan- Church of the Light. (Barandon, J., 2001, http://architecture.mit.edu/~barandon/ 4.203/images/ jpegs/litho%20plan.jpg)

4.3.1.1 Boundaries for Spatial Definition

The different boundary edges of the chapel are oriented to the four main cardinal directions. The dominant boundaries that define the spatial enclosure are-

a) South wall - The exposed concrete wall has a slit opening (with fixed float glass) in the shape of a cross placed just behind the altar (see Figure 42). The direct rays of light from the sun silhouette the entire wall as the cross is bathed in bright white light.

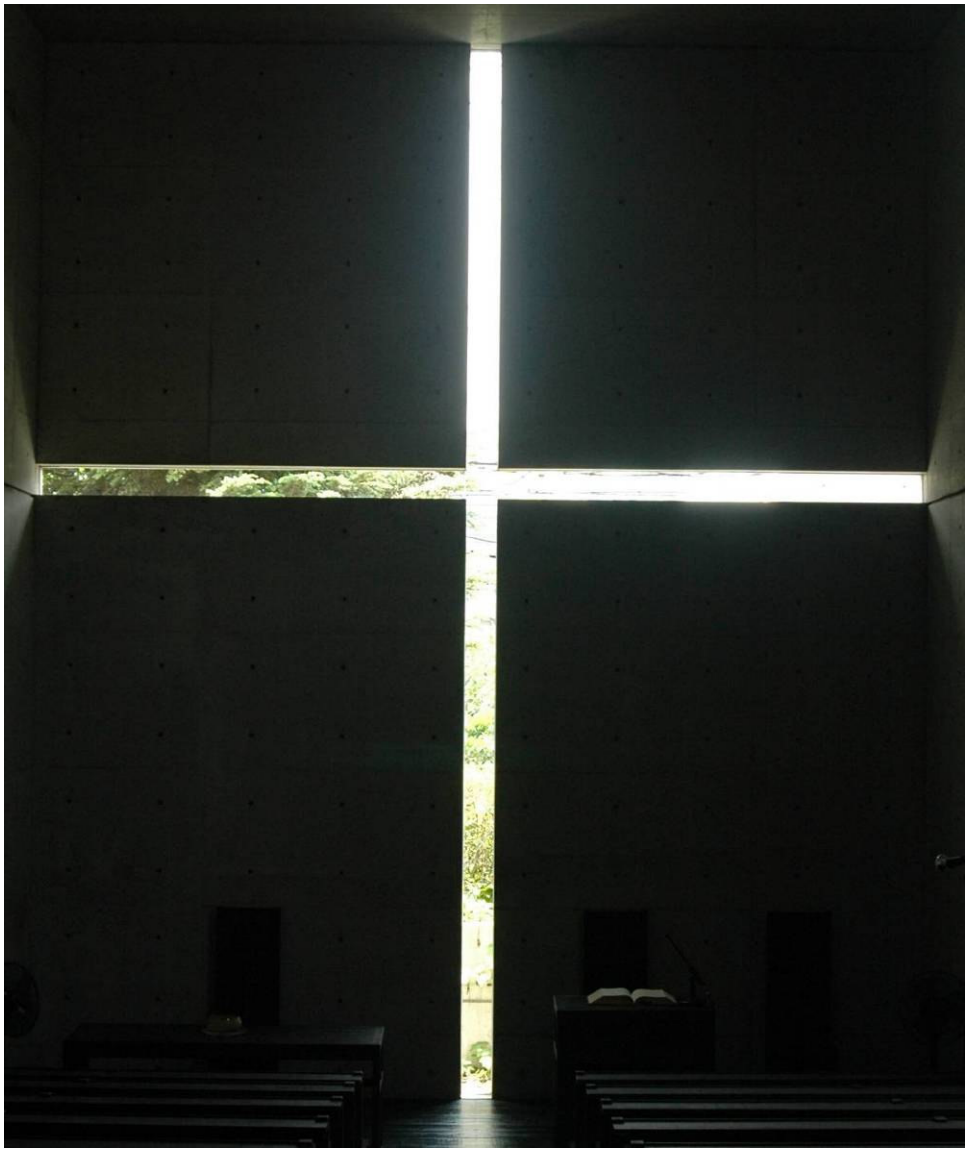

Figure 42: South wall with a cross shaped slit opening. (Photo by S. Gill, 2005)

b) East wall - This is a plain exposed concrete wall with no opening towards the exterior. There is a horizontal groove line that runs flushed along the lower arm of the cross on the south wall at a height of 7m (see Figure 43).

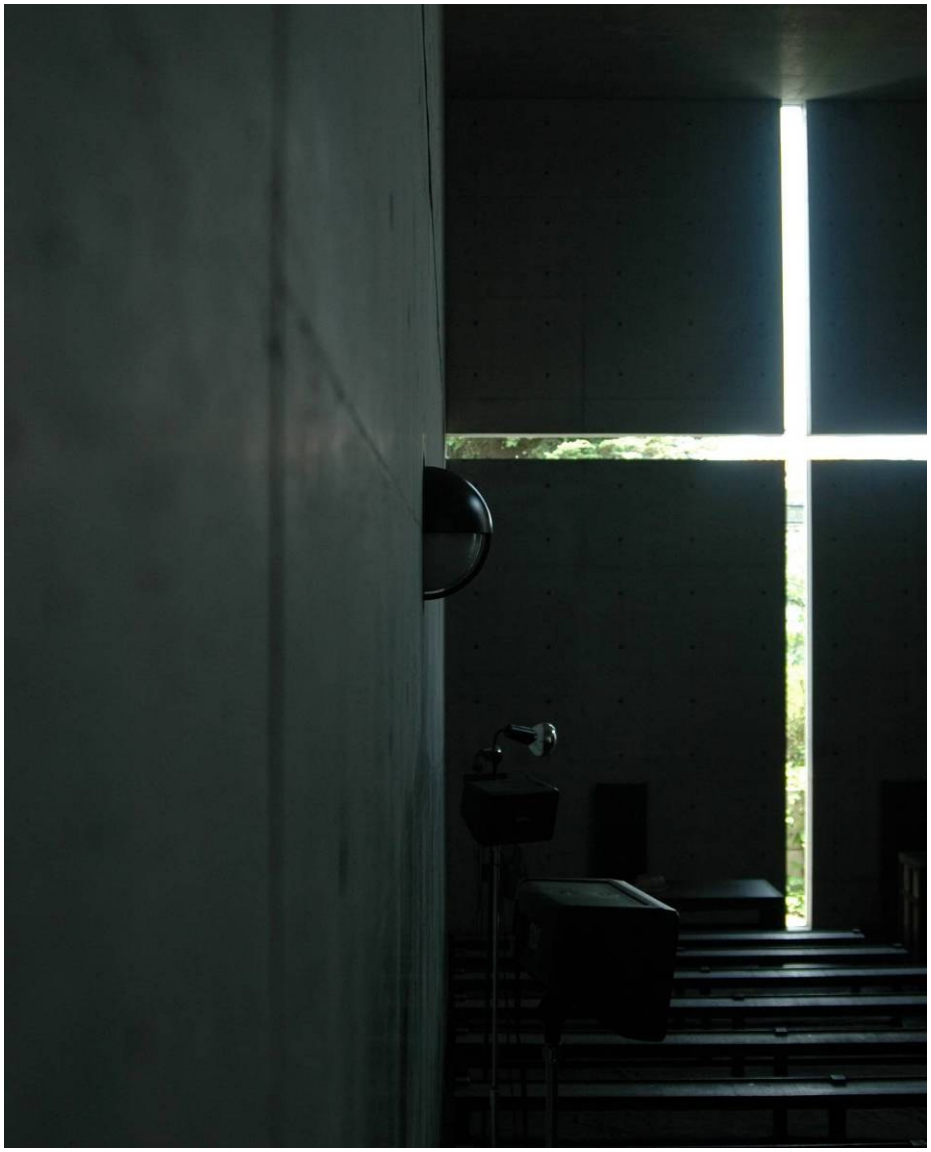

Figure 43: East wall on the left side of the image without any opening. (Photo by S. Gill, 2005)

c) North wall - The exposed concrete wall is cut through by the splay-wall on the west side. The two walls intersect in a manner that they do not appear to touch one another, making two small slit openings for light that run through the full height of the north wall and help in guiding the visitor to make the entry into the chapel (see Figure 44).

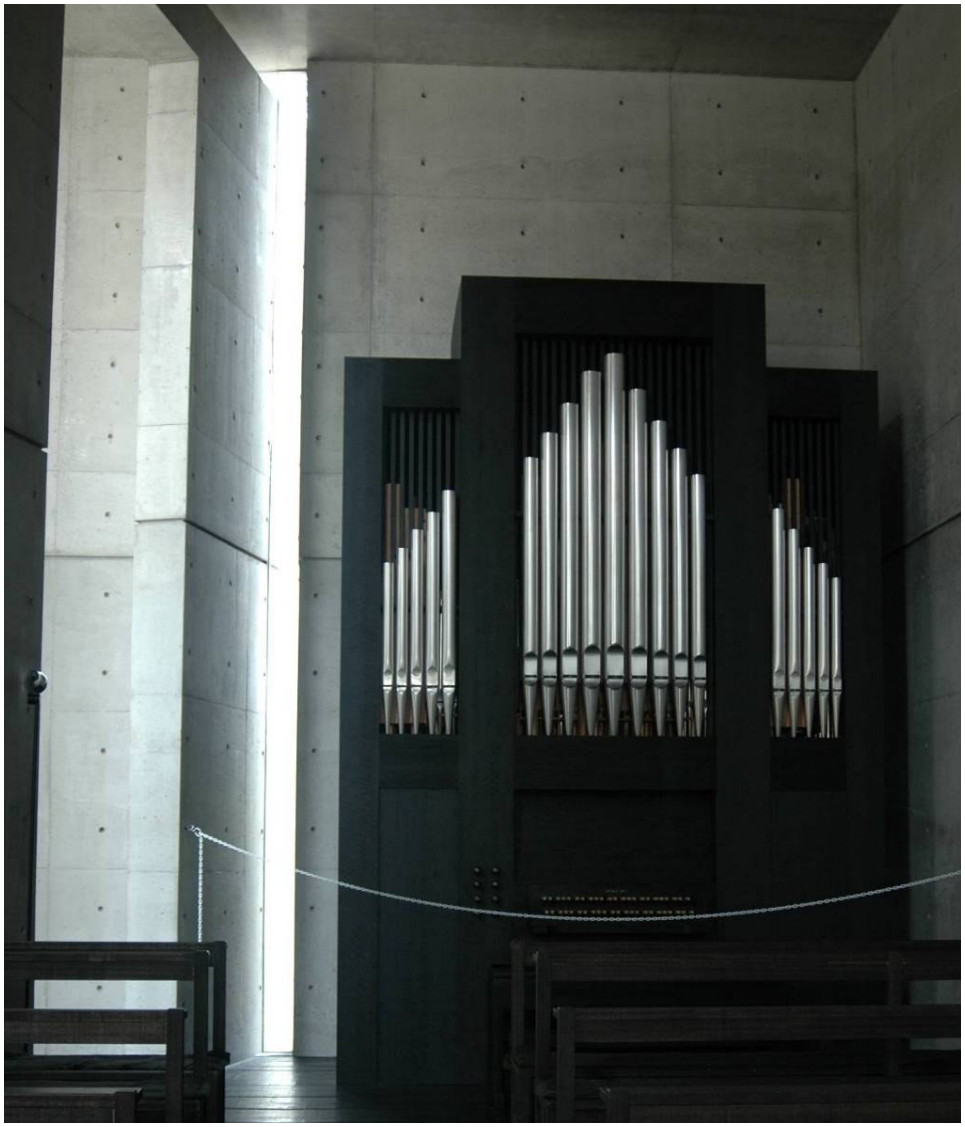

Figure 44: North wall with the full height slit opening. (Photo by S. Gill, 2005)

d) West wall – The west side of the chapel is made up of two intersecting exposed concrete walls. The splay-wall on the west side cuts through the rectangular space in a way that an L shaped entrance sequence is formed on the northwest side of the chapel. The openings on the west side include a full height glazed opening of a considerable size that is cut through the splay-wall. The splay-wall does not touch the ceiling of the chapel thus making a small opening for light on the top as it breaks through the west wall. The main entry to the chapel is through a large rectangular opening on the north side of the splay-wall (see Figures 45 and 46).

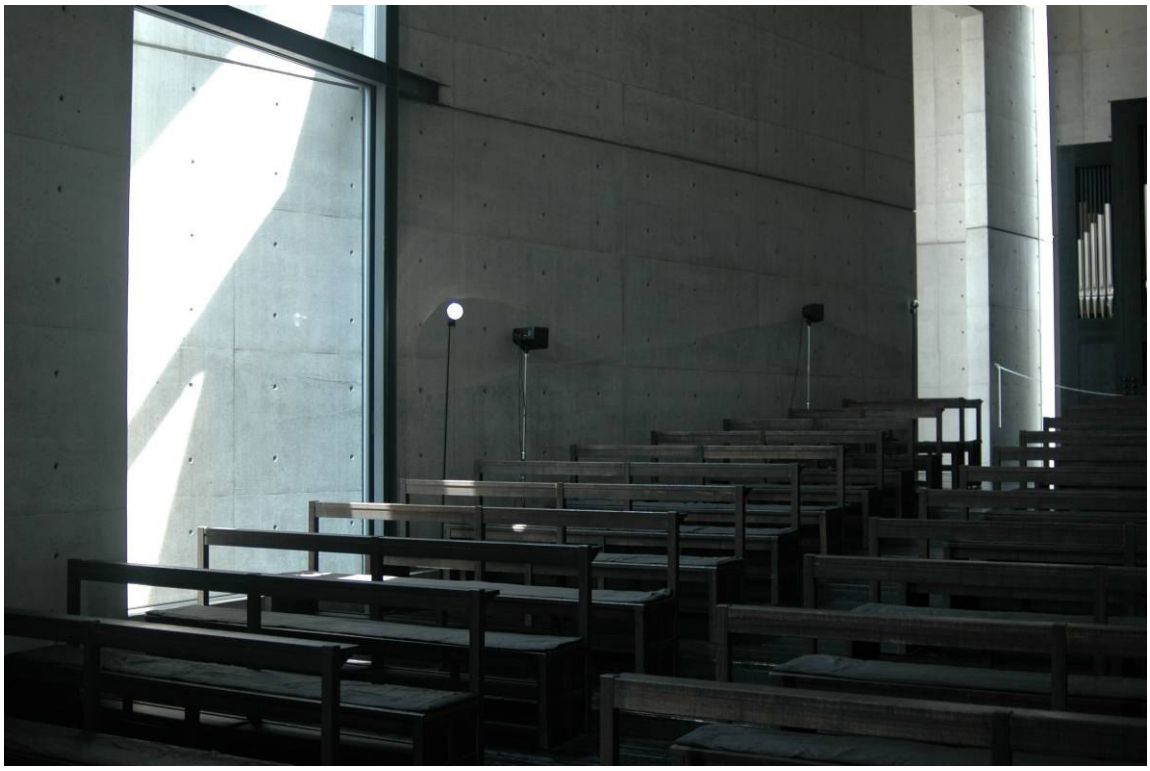

Figure 45: West wall on the left side of the image. (Photo by S. Gill, 2005)

Figure 46: The entry into the chapel from the rectangular opening in the west wall. (Photo by S. Gill, 2005)

e) Ceiling – The flat exposed concrete roof is devoid of any opening to the exterior.

f) Floor – The dark wooden floor with oil stain finish provides a change in material as compared to the dominant use of concrete on all other surfaces. The planks have been

used in the temporary scaffolding during the construction of the chapel. Also from the worshipers' seats, the floor has a gradual slope down towards the altar on the south side. The level change is in terms of small steps in the central aisle (see Figure 47).

Figure 47: The dark brown wooden floor. (Photo by S. Gill, 2005)

4.3.1.2 Visual Perception of the Envelope

The spatial envelope covers a small area of 113 m². But, the way different surfaces and boundary edges meet provides a strong perspective that enhances the overall depth of the space. The downward slope of the floor provides a forced linear perspective that creates an illusion of the space opening in size towards the south end (see Figure 48).

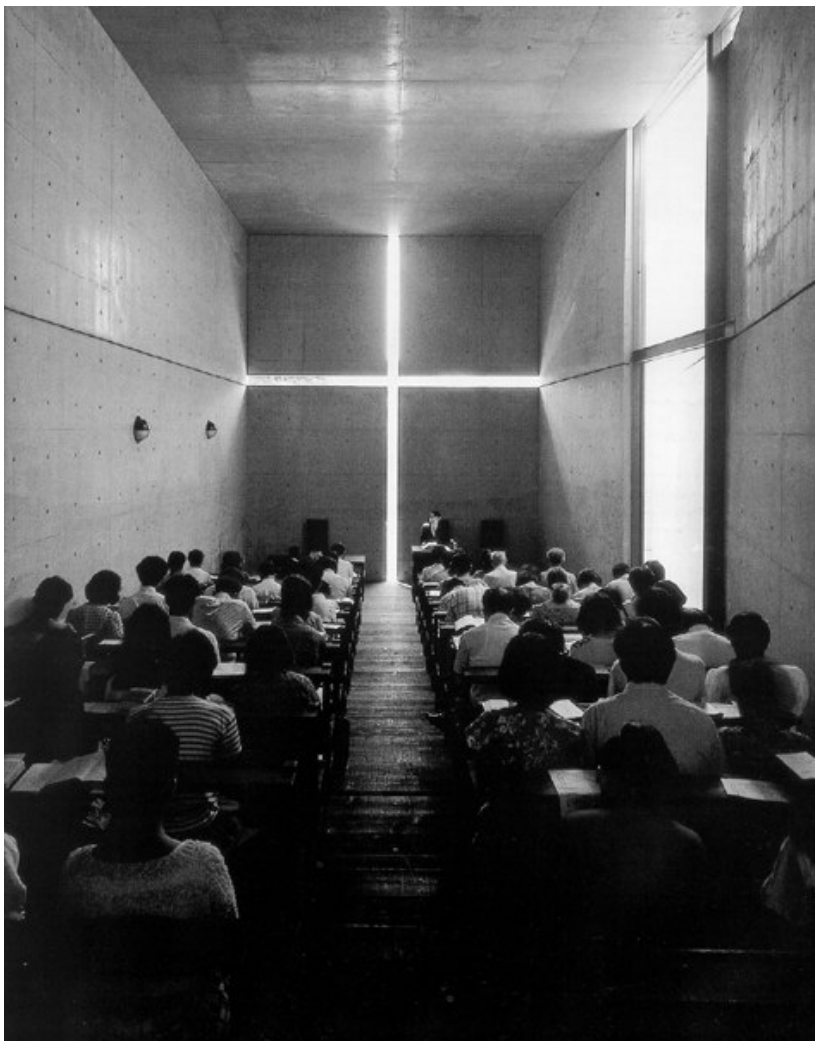

Figure 48: The linear perspective towards the south. (Barandon, J., 2001, http:// architecture.mit.edu/~barandon/ 4.203/images/ jpegs/cross%20people.jpg)

Also, the intensity with which the south light enters from the front wall adds to the perceived increase in the overall volume of the space. The entrance sequence is through a narrow L shaped space, and thus the transition into the main space is dramatic as the space appears to explode rather than contract with the splay-wall on the west side helping to achieve this effect (see Figure 48).

The space is dark so that the effect of light entering through the narrow openings appears more powerful. The material is predominantly grey colored exposed concrete except for the dark brown colored wooden flooring. Due to the dark colored material on the floor, the space seems to increase in size along the vertical axis as the light is reflected by the exposed concrete walls with a mirror like finish. Also, the ceiling is at a 5.9 m height thus adding to the vertical stimuli as perceived by the observer. The light openings have been kept minimal, and the main emphasis is on the cross shaped opening on the south wall from where the space seems to be lit in a powerful manner.

4.3.1.3 The Character of Space

The overall character of the space is dominated by the visual appearance of the dominant surfaces and boundary edges. The uniformity in the material used for the expression provides a strong visual connectivity between different surfaces. The dark interiors with grey colored concrete dominate the visual perception of the envelope and contribute to a quiet and calm interior space. The character of the space could be termed as satisfying and peaceful. The monochromatic color scheme provides for soft and shadowed interiors (see Figure 49). The only variation is in the light entering the space through different

openings. The underlying silence of the space seems to be broken by the powerful rays of sun entering from the south wall.

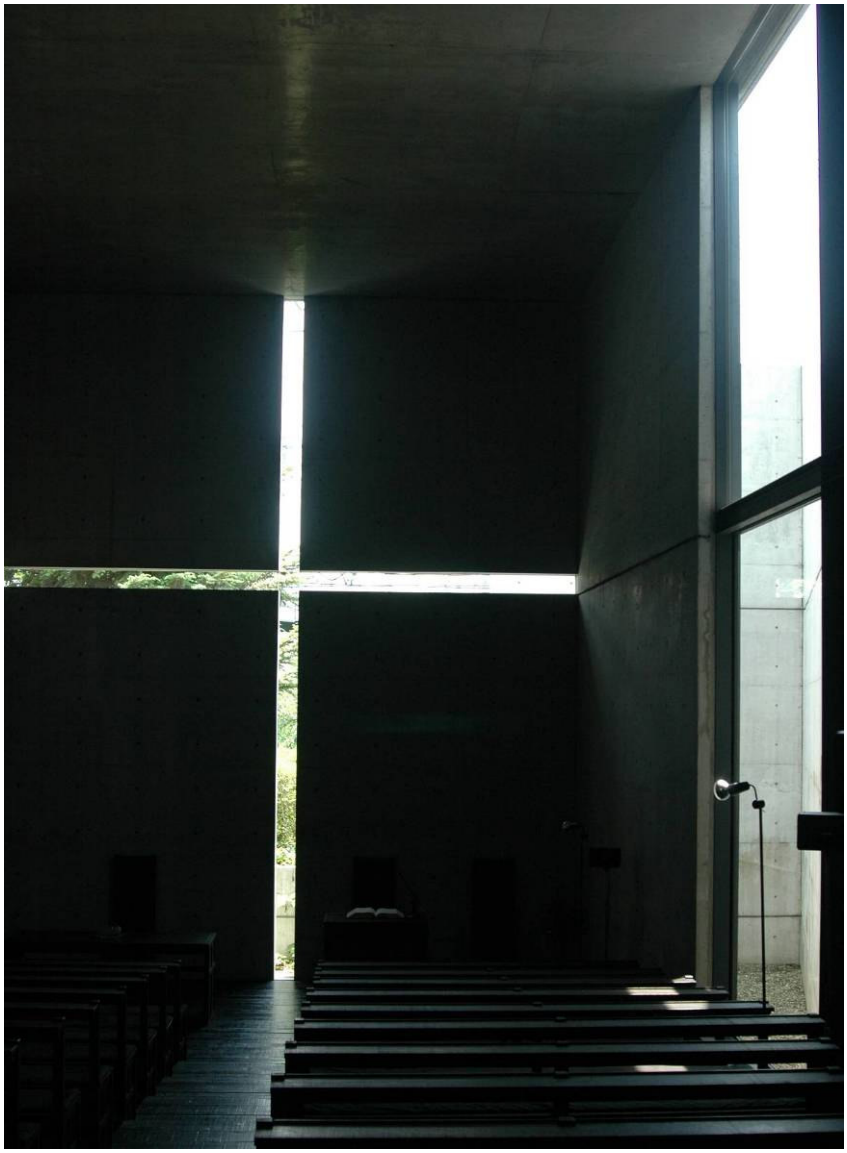

Figure 49: Interior view towards the altar in the south. (Photo by S. Gill, 2005)

The unity of the space is further reinforced by the strong pattern of formwork on the concrete wall, and in a way it wraps the enclosed spatial envelope. The restrained expression of the spatial envelope is achieved through pure and well proportioned cubic volumes that convey a muted and a serene character. Size, shape, and proportions of the spatial envelope become further dominant due to the monochromatic surfaces that provide visual clarity and overall richness of space.

4.3.1.4 Distortion of the Spatial Envelope

The only visible distortion in the spatial envelope is in the view from the north end of the chapel as one looks towards the altar (see Figure 48). The perspective view from behind worshipers' seats seems to be enlarged at the far end instead of shrinking in size. This happens due to two major reasons. First, is due to the downward slope of the floor that counters the upward thrust that the floor lines exert in a normal perspective. So the section at different depths of the perspective seems to maintain an overall constant size with the distortion taking place in the shape as the far end square is stretched in a downward direction. Second, is due to the splay-wall on the west side that moves in an outward direction when seen from the entrance on the north side of the chapel. This makes the overall volume expand in a manner that contradicts with the normal perspective of the rectangular volume.

The thrust exerted by these two things is counterbalanced by the light flowing from the south end of the chapel that expands from the narrow slits into a wider and well uniform spread towards the north wall. These two effects create a delicate balance in the space that is born from the internal collision and tension exerted by the two axial thrusts.

The distortion of the space is aimed at increasing the overall volume of the chapel in the way it is perceived by the observer. The effect of natural light is aimed at relieving the tension built in the space due to this forced perspective.

Figure 50: Interior view of the chapel. (Photo by S. Gill, 2005)

4.3.1.5 Clarity of the Spatial Envelope

There is a strong visual clarity in the spatial envelope due to the underlying continuity in the expression of different surfaces. The overall form of the space is related to a simple well proportioned box pierced by a wall on the west side that acts as a design accent. The number of dominant boundaries is minimal with the pattern of formwork on the concrete walls and the horizontal groove acting as connectors between different surfaces.

The cross shaped opening on the south wall acts as the principal light source for the space. Light from this opening washes along four surfaces – east and west walls, floor and ceiling. The light and shadow patterns are similar on all the four surfaces thus reinforcing the order and symmetry in the space. The way light spreads into the chapel is in harmony with the main north-south axis and thus maintaining the integrity of the spatial envelope (see Figure 50).

4.3.1.6 Proportioning of the Spatial Envelope

The space inside the chapel has been arranged by means of a simple geometric relationship. The Church of Light measures 5.9m wide x 17.7m long x 5.9 m high. The proportion of the space can be reduced to a simple ratio i.e. 1:3:1. Thus the spatial envelope can be said to be made of three identical cubes with each side measuring 5.9m. The height to width ration is 1:1, meaning that the section is a square one thus emphasizing on the single long axis that runs from north to south. This further brings a perceived sense of depth in the space making the overall volume grow rather than shrink. The basic proportions bring in a controlled order inside the space as each surface or dominant edge relates to another through simple geometric proportions.

4.3.1.7 The Color of Architectural Space

The predominant color of the spatial envelope is grey out of the exposed concrete that can be seen on all the major surfaces except for the floor. The variation due to the light levels creates a shift in the value and saturation of grey color. The dark brown floor is not affected by the change in light levels and maintains a constant hue throughout the

surface. Although the dark interiors might seem to reduce the perceived size of the envelope, this is not the case inside the chapel. The effect of direct sun rays from the south wall tends to dominate over the basic color of the architectural space. The light as it enters from the cross shaped opening breaks free the static quality of space inside the chapel, making a strong connection with the outside. The space seems to flow and merge freely with the exterior, and the tension inside the space is relieved.

The controlled use of color helps in maintaining the overall stability and clarity of the space. There is no overloading on terms of the visual stimuli resulting from the presence of different colors. Thus, the space retains a simple character where light, as it enters the space, acts as a strong visual and focal accent.

4.3.2 ARTICULATION OF THE SPATIAL ENVELOPE

The articulation in the Church of Light has been achieved by the use of dominant pattern on the surface boundaries of the spatial envelope. The monochromatic surfaces are made more interesting with the pattern that continues on all the different wall surfaces. The openings are small but bring in the kind of light that is powerful in the way it illuminates the space. The pattern provides the controlling condition to maintain perceptual simplicity in the chapel while the varied effects of light have been used to enliven and create interest in the space.

4.3.2.1 Patterning the Dominant Boundaries

The pattern of formwork on the concrete surfaces is one of the most visible attempts in articulating the spatial envelope. The concrete walls have a strong pattern of dots that are

the left over marks of steel bars used in the scaffolding. The small circular dots have been recessed into the wall surfaces, thus providing a play of light and shadow that adds to the overall depth of the space. The ceiling has lines that run in perpendicular directions depicting the rectangular steel frames used for the formwork. The pattern on different surfaces breaks them down into small squares with each small square establishing the overall scale of the space. The repetition in the pattern provides order and symmetry to the spatial envelope.

4.3.2.2 Penetration of the Spatial Envelope

There is a strong sense of penetration inside the chapel. This is due to the strong contrast created when the observer is oriented towards the altar. The bright cross shaped opening seen against the dark grey concrete surfaces is aimed at heightening the depth perception.

4.3.2.3 Articulation with Subspaces

The chapel avoids any attempt to merge with a subspace. The sense of enclosure is all the more dominating, and this creates a powerful play of light inside the spatial envelope. There is a well marked sequence into the chapel that is connected with an L shaped court. Once inside the chapel, there is not much of visual relief with views to the adjoining spaces or the exterior. The visual interest of the space is aimed at connecting with the exterior through the quality of light and not the view available through an opening. The only view towards the exterior is through the full glazed opening on the

west wall. This view is of a closed nature where all one can see through the opening is the splay-wall running out of the spatial envelope (see Figure 51).

Figure 51: View out of the chapel from the full height glazed opening in the west. (Photo by S. Gill, 2005)

4.3.2.4 Spatial Banding

The spatial banding inside the chapel has been achieved by two predominant design elements. First, is the horizontal grove that runs along the arm of the cross on the south wall. This breaks down the east and the west wall into two halves that seem to meet

along the south wall with the spread of light blurring this distinction. A band of light from the south opening is the second design element. The effect of light, in this case, makes for a dynamic spatial banding of the envelope as this illuminated strip moves along different surfaces in the darkness of shadow.

4.3.2.5 Curvature and Level Change

The layout of the spatial envelope is based on linear geometry that is devoid of any curves. The entrance sequence to the chapel can be said to follow an S pattern where one is made to walk around the entire periphery before making a final U turn that reveals the inside of this church. The curvatures of the path exist as a metaphysical entity in the overall composition and circulation pattern of the church. The basic shape is rectangular with one of the west walls running at a different angle. This provides the necessary transition from the exterior with an L shaped entrance court that is aimed at dramatizing the size, shape, and proportions of the chapel.

Once inside the spatial envelope, there is a level change as one walks down towards the altar. This is aimed at providing another transition that draws the observer towards the bright rays of the sun entering from the cross shaped opening on the south wall just behind the altar.

The alternate play of light and shadow is extremely interesting in the way these transitions have been achieved. From the bright open exterior there is the dark, narrow L shaped entry court. Then, there is a gradual increase in the intensity with which the light is made to enter through different openings. The consummation is with the light rays entering through the south wall appearing to break free the darkness of the space inside.

4.3.3 ROLE OF THE STRUCTURAL SYSTEM

The use of concrete as a building material for the chapel removes the need for a separate structural system. The load bearing walls act as the structure that defines the overall form. The uniformity in the material provides an overall even gradient to the way natural light renders the space. The emphasis on the openings is an intended design element, thus the flat surfaces are perceived in their original shape without any distortion due to the uneven illumination of the physical planes. Also as a structural material concrete provides the flexibility of placing the openings at any of the desired locations that might interfere if there was a separate structural system in place.

4.3.3.1 Prominence of Building Form

The building form has been kept simple to remove any ambiguity of the space and provide a strong sense of orientation inside the chapel. The exterior is exposed concrete with the only visible relief to the structure coming from the openings. This is aimed at providing an inward looking space that is devoid of any visible connections to the exterior due to a highly sense of neighborhood around the site. The external membrane seems to be minimalist from the exterior as well as the interior. The transition from the outside to the inside takes place in terms of the light levels and a controlled effect of light inside the chapel that provides order to the overall form.

4.3.3.2 Structure Patterning the Spatial Envelope

The structural patterning of the spatial envelope in the Church of the Light has been achieved by the use of formwork in the construction. The small dots that are recessed

from the surface boundaries add visual interest to the space. The light sources are well spaced and provide a strong sense of orientation to the space. The bright light source towards the rear of the altar provides the necessary emphasis while the indirect and diffused lighting help in creating a strong focal accent. The pattern of light and shadow is removed of any ambiguity due to the presence of a single direct source of natural light.

Figure 52: Cross shaped slit opening in the south wall. (Photo by S. Gill, 2005)

4.3.3.3 The Sources of Light

There are four different sources of natural light inside the chapel.

a) Cross shaped slit opening in the south wall – This is the most powerful source with the direct rays of sun passing through the narrow slit and illuminating four different planes. The pattern of light and shadow is similar on all four planes, however the effect is less visible on the dark wooden floor as compared to the other three concrete surfaces. There is a visible use of contrast when oriented towards the altar. The source of light makes for a strong visual element when seen against the dark grey concrete wall on the south side (see Figure 52).

b) Full Height glazed opening in the west wall – This provides more of a diffused quality of light inside the space; one that washes along the splay-wall to make a quiet transition from the exterior into the interior. This provides a soft illumination as it is protected from the direct rays of the setting sun by the natural shade from the extension of the splay-wall in the exterior (see Figure 53).

c) Slit opening at the top of the splay-wall on the west side – The light washes along the ceiling and illuminates the space from the top. This provides an even modeling and a gradual transition from the concrete ceiling to the dark wooden floor (see Figure 46).

d) Full Height slit opening where the splay-wall meets the north wall – The light that enters from this opening acts as a source that guides the visitor from the dark L shaped entry court into the chapel. This is the first source of natural light that makes its presence felt inside the darkness of the chapel (see Figure 44).

Figure 53: Full height glazed opening in the west wall. (Photo by S. Gill, 2005)

4.3.3.4 Structural Synthesis for Architectural Beauty

The light sources have been placed in a manner that the structure is revealed in the shadows and not through a bright even illumination of the space. The form does not dominate the space, instead it provides an ideal setting to appreciate different effects of

light. The light openings have been carved out of different surfaces to achieve the desired effect of relating the interior with the exterior through a quiet relation based on the penetration achieved by the bright rays of the sun. The structure is articulated through a pattern that does not overload the visual stimuli thereby providing a peaceful and quiet space; one which is aimed at providing a way to relate with the eternal. The visual harmony in the space is achieved through the blending between the structure, function, and program requirement of the space. The visual emphasis on the cross shaped opening, with the light breaking past the darkness, helps in achieving the function of meditation inside the chapel. The ambiguity in the way structure reveals in relation to the overall form creates an element of mystery that dramatizes the effect of natural light inside the space. The perceptual distortion from the sharp brightness gradients has been diminished by the use of a horizontal groove that runs at the height of the lower arm of the cross.

4.3.4 MOVEMENT THROUGH SPACE

The movement of the visitors to the chapel is exploratory in nature. The path is well defined and in a strong relation to the sequential arrangement of spaces. This creates visual interest and minimizes confusion as people find their way around a building.

4.3.4.1 Stimulus for Movement

There are a number of focal accents that have been used along the path defining the movement pattern across the chapel. Most of these focal accents are the light sources that slowly increase in their overall intensity with which they make their presence felt.

Upon entering the L shaped entry court, the visitor is cut out from any visible source of light. The darkness is cut through by light filtering from a full height slit opening in the north wall of the chapel. At this point, the interiors are still dark and the light source only helps to guide the visitor into the boundary of the spatial envelope. Once inside the chapel, the visitor has to turn 180 degrees to face in the direction of the altar. This shift is all the more dramatic with the light now entering from a small slit in the south wall at full intensity silhouetting the wall against the powerful rays of sun emerging from a cross shaped opening. This cross bathed in extreme brightness pulls the visitor towards the altar making a connection between the sacred and the profane (see Figure 54).

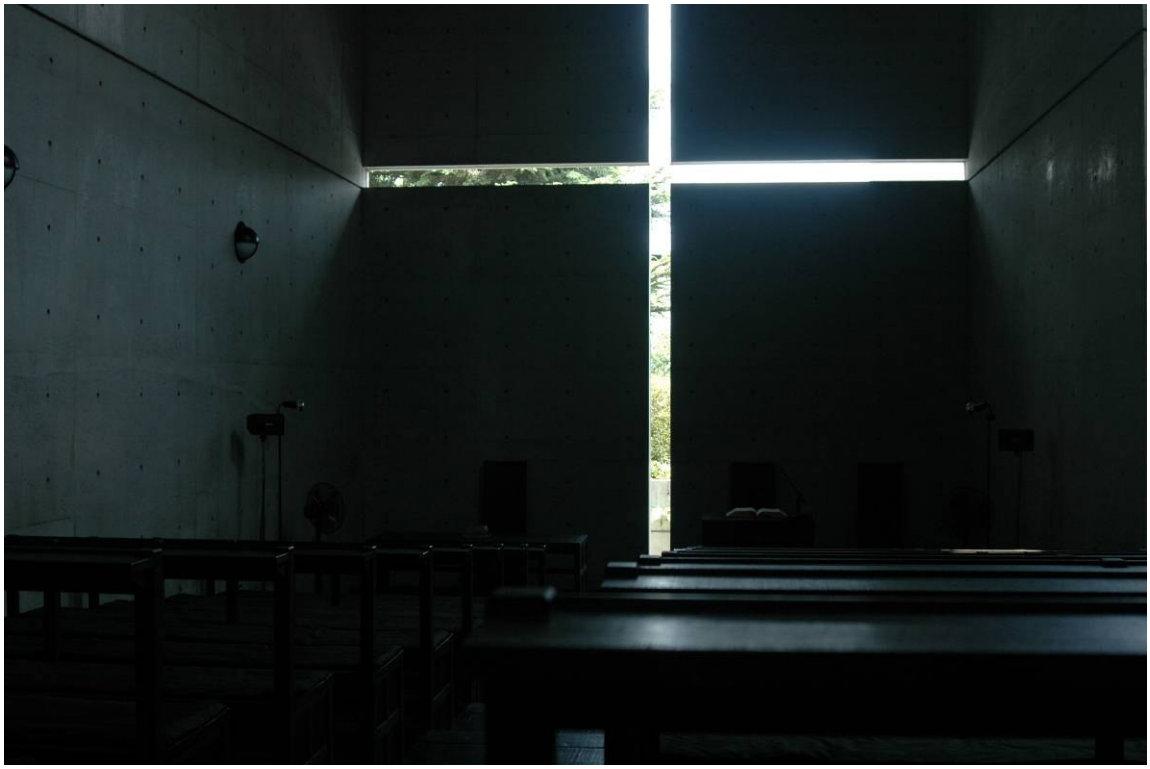

Figure 54: Interior view of the chapel from the worshipers' bench. (Photo by S. Gill, 2005)

4.3.4.2 People Move toward Light

The use of light to guide the way people move around the chapel has been done in a manner that closely relates to the circulation path. The spatial layout does not provide for any number of permutation and combinations while walking inside the church. The effect of light is aimed at accentuating the transition between different spaces. The light from the opening on the south wall attracts visual attention and provides a strong impetus overpowering any source of distraction from this linear perspective focused towards the altar (see Figure 48).

4.3.4.3 The Zones of Transition

There are three main zones of transition in the spatial layout of the chapel. First, is the L shaped court with its dark shadows creating a strong contrast with the outside. Second, is the appearance of the first major opening that is a full height slit on the north wall bringing in bright diffused light to create a strong contrast with the previous transition. Once the eye adjusts to this light source, the interiors still appear dark. On a U turn around the entrance, one is made to go through the third transition in which all that is seen is a cross illuminated by a natural source of light. The direct rays of light from the opening on the south wall create a temporary blindness in which everything else fades away. Slowly the eye adjusts to this extreme bright source and becomes aware of the matter born through the direct rays of the sun.

4.3.4.4 Brightness Changes as a Function of Movement

The movement, from the outside to the inside of the chapel, brings in a mixture of gradual and abrupt changes in brightness. The L shaped entry court makes for a dark narrow entrance making the far end seem invisible. Slowly the eye adapts to this darkness and is hit by the north light entering from the slit opening. The contrast created in this transition makes the eye adjust and search for all that is revealed through this light illuminating the space. At this point, the visitor makes a U turn to face in the direction of the altar. This is where the change in brightness strikes with utmost intensity. The direct rays of sun piercing the cross shaped opening behind the altar create a strong symbol that creates visual interest. The emptiness of the space is broken, and all that one is forced to see is the cross with light spreading from it and illuminating the space. The power of this image is all the more striking in the relatively dark interiors.

CHAPTER V

RESULTS

This chapter describes the results from the analysis of the spatial envelope in three of the selected buildings- (1) Chapel of Notre Dame du Haut Ronchamp by Le Corbusier, (2) Kimbell Art Museum by Louis I. Kahn and (3) Church of the Light by Tadao Ando. The underlying characteristics of natural light - (a) Orientation, (b) Intensity, (c) Mystery, (d) Shadow, (e) Contrast, (f) Color and (g) Variation have been discussed in this chapter as visible inside the spatial envelope.

5.1 CHAPEL OF NOTRE DAME DU HAUT RONCHAMP BY LE CORBUSIER

The characteristics of natural light, as they relate to the overall perception of the spatial envelope inside the Chapel of Notre Dame du Haut Ronchamp, have been listed and explained below.

5.1.1 ORIENTATION

The chapel sits on a site that is at the summit of a hill and looks over towards the four horizons. The chapel in plan is composed of four different curvilinear walls; two on the east and south side bend inward whereas the other two on the north and west side bend outward. The south and east walls act as receptors for the majority of sunlight that enters the chapel through the gap between the roof and the vertical surfaces in an attempt to break the static nature of the enclosed interior space, whereas the north and west walls

act as containers that define the sacred from the profane in a manner that removes any immediate connection with the outside environment. The concave and convex profiles of the walls are composed of two opposites that have been joined together with the curvilinear roof to form a unanimous whole. The functions these two kinds of walls (convex and concave) serve are in direct contrast and builds a visible tension in the form of the chapel that can be seen both from the outside as well as the inside.

Inside, the chapel is oriented along an east-west axis that has an asymmetrical layout of the different openings for the entry of natural light. The main axis connects the confessional in the west wall to the altar placed in front of the east wall, creating a strong visual connection between the two important functions housed inside the chapel. This provides a strong sense of orientation to the visitors as they move inside the spatial envelope. The worshipers' desk is placed towards the south wall next to the small openings bringing in direct light. Most of the space towards the north wall is empty, thereby highlighting the asymmetry present inside the chapel. There are both direct and indirect sources of light. Openings for natural light have been oriented towards the four cardinal directions to receive a characteristic quality of light at different times of the day.

The way different openings have been oriented further highlights the emphasis on creating a contrast that is visible in the form of the building and is an attempt to draw visual attention of the observer. The south wall has a number of small openings that brings in direct sunlight from the splayed windows that are deeply recessed, thereby creating a transition zone for the bright light to make a quiet but powerful entry into the interior of the chapel. This is the most visible effect that can be seen all along the path of

movement followed by a visitor inside the spatial envelope. On the other hand, the placement of the vertical tower, in the west corner of the south wall, brings in light from the clerestory opening that is oriented towards the north. The constant diffused light from the north is made to flow through the entire height of the tower before it falls on the altar placed beneath the domical roof. The bright altar does not reveal the source of light that is far removed from the view of the observer standing at a distance. The visual interest is generated by the partial hiding of this information that directs the movement of the observer towards this small chapel before he can fully appreciate the play of light and shadow from its hidden source of natural light.

A similar effect has been used in the two small chapels placed in the vertical towers along the north side of the spatial envelope. The vertical towers stand with their backs turned against each other suggestive of the contrast generated in the inside in terms of the different kinds of light they receive. The one towards the west end has its clerestory opening directed towards the setting sun, whereas the tower towards the east end of the north wall receives its share of light from the morning sun. Thus, the space inside is rendered in an altogether different kind of light; one that has an added element of color when compared with the vertical tower on the south side that opens out to the blue skies of the north.

The openings oriented along the east and south wall are aimed at highlighting the free standing elements of the choir. Whereas the observer oriented towards the east can see the visible source of light on the east and south walls, the small openings on the east end of the north wall are hidden from the direct view. This helps in controlling the

amount of focal accents while still achieving a homogenous blend of natural light from three different directions (north, east and south) in the space next to the altar. The only variation from this diffused and uniform effect of light is from an opening placed behind the altar that has the statue of the Virgin Mary made visible through a silhouette against the bright light of the morning sun. This is aimed at providing a symbolic meaning to the sacred nature of the space through a controlled effect of natural light.

5.1.2 INTENSITY

The small openings of light inside the chapel help to contain the interior space from any major views of the exterior. The amount of penetration is to an extent that lights the periphery of the spatial envelope while maintaining a dark interior space. The intensity of light source is all the more visible in this setting as the light rays can be seen cutting through the darkness that envelops the inside of the chapel. The small openings oriented towards the east and south side help to bring daylight in a manner that does not reveal the exterior space but highlights the shape of the opening bathed in sunlight.

The different openings for light articulate the surface boundaries that define the spatial envelope. The light is made to flow along a dominant surface boundary that creates a strong transition zone between the outside and the inside. The orientation of major openings towards the south side of the chapel puts further emphasis on highlighting the source of natural light through the intensity with which it breaks through the darkness of the chapel.

5.1.3 MYSTERY

The mystery of the interior space where everything is not revealed at once helps maintain the sacred nature of the spatial envelope, by which the inside is far removed from its immediate environment. The continuous adjustment of the eye, to the bright and dark surfaces, heightens the awareness for different sources of light as the visitor attempts to comprehend the spatial geometry through the varied play of light and shadow inside the chapel. The extreme brightness of the openings towards the south side blinds the view of the observer, which further controls the amount of information that can be read through a single window. The removal of anything extraneous that might create a focal accent brings about a strong focus on the source of light as it makes the transition from the exterior to the interior of the spatial envelope. The intensity with which the light is made to enter inside the chapel creates a strong contrast between the highlights and the lowlights that restrict the complete understanding of the space at any given point in time. The exploratory nature of the space further helps in achieving the mystery that characterizes the inside of the chapel.

The extreme brightness of the openings on the south side creates a silhouette in which the entire wall is seen washed with light. The power of this image creates a strong impression on the mind of the observer as the space seems to be removed of any material connection with the outside. The mass of the building is lost in this darkness, and the emptiness of the space is highlighted by the strong rays of light breaking into the shadowed interior space. There is an underlying silence associated with the character that the play of light and shadow creates inside the chapel.

5.1.4 SHADOW

There are no sharp shadows inside the chapel. This is due to the rough grainy texture on the wall surfaces that diffuses and scatters the light with each subsequent reflection. The only play of light and shadow can be seen at a microscopic scale where the whiteness of the wall surfaces dilutes into shades of grey due to the shadows cast by the small projections of the uneven texture. Apart from this, most of the recessed surfaces have soft shadows that help understand the spatial depth in the overall perception of the spatial envelope. The softness of the shadows can be appreciated to a greater extent due to the white finish of the vertical boundaries inside the chapel. The soft and diffused nature of shadows helps in counterbalancing the effect of rough texture on different surfaces that could otherwise be discomforting in its appearance.

5.1.5 CONTRAST

There is a good amount of contrast due to the significant difference between the brightness ratio of the foreground to the background while moving inside the chapel. This is due to the limited size of the openings that result in a shallow surface penetration leaving the interiors dark and devoid of a good amount of natural light. The brightness seen on the white vertical surfaces contrasts to the dark colored flooring and the grey concrete on the ceiling. There is a significant increase in the perceived brightness on different surfaces seen from the dark interior space of the chapel. The strong contrast creates a heightened awareness of the penetration by natural light thereby creating a hierarchy of spaces from the darkest in the center to the extreme bright on the periphery.

5.1.6 COLOR

The interiors of the chapel are painted in white lime that provides a clean, pure, and neutral background to observe the effects of light as it passes through clear, colored, and painted glass in the different window openings on the south wall. The predominant color inside the spatial envelope is white, which is mostly present on the vertical surfaces and stands out in contrast to the dark colored flooring and grey concrete ceiling. Whiteness on the wall surfaces acts to purify the mind of the visitor of all the different colors seen in the exterior of the chapel thereby creating a strong transition from the outside to the inside, one that signifies the boundaries of the sacred, marked, and distinct from the profane. The effect of light filtering through the colored glass is all the more strong and powerful when seen against the predominant white colored background. The use of primary colors painted on the glass creates interesting patterns of shadows especially on the splayed openings in the south wall. The sporadic appearance of color in different openings creates a magical effect where the eye is not able to read as regular pattern in the way light renders different openings.

The red colored chapel on the east side of the northern wall stands out in terms of the use of bright color that differentiates it from the other two chapels placed in the vertical towers. The light renders the entire space in a dramatic fashion that seems to modify the interior in a way that would be symbolic of a heavenly light. When compared to the other two towers, the quiet and silent interiors of these chapels colored in white light seem to be completely transformed into something that dominates over the plain white. The prevailing character inside this chapel signifies a much more dynamic space

with high energy levels. The use of deep carmine red, painted on the wall surfaces, creates a strong visual emphasis inside the spatial envelope.

Color has been used with a similar eye catching effect by painting the enameled doors in bright primary colors. This provides for a sculptural point of entry into the chapel that relies on the power of color to define the character of a space and to bring out the white color inside the chapel in a stark manner. The effect of highlighting the entrance doorways stands in direct contrast to the violet wall adjacent to the sacristy. The dark violet colored walls seem to disappear in the shadows that engulf the space. The effect, in this case, is to dissolve the mass of a surface through the use of a dark color seen overlaid with shadows.

5.1.7 VARIATION

The variation in the quality of light inside the chapel can be seen with the movement of the sun spread across the entire length of the day. The morning light creates a silhouette of the statue of the Virgin Mary placed in the square opening in the east wall behind the altar. Also, the altar on the east end of the north wall shines in a bright colored light that relates its nature to the rays coming from the rising sun. Slowly the sun moves towards the south, and the openings in the south wall appear predominant in the way they are lit by the intense bright light. The funnel shaped shafts of light are seen creating subtle effects like the colored shadows they project onto the splayed openings that change in brightness as the sun moves across the sky. Finally, the setting sun brings in its own characteristic light into the chapel placed in the vertical tower that stands towards the west end of the north wall.

5.2 KIMBELL ART MUSEUM BY LOUIS I. KAHN

The characteristics of natural light as they relate to the overall perception of the spatial envelope inside the Kimbell Art Museum have been listed and explained below.

5.2.1 ORIENTATION

The Museum building is composed of 16 cycloid shells oriented along a north south axis. The main source of natural light inside the museum is a 2½' slit at the apex of the vault that runs along the entire length of the spatial envelope. The movement of the sun is along the east-west axis which is perpendicular to the main axis of the spatial envelope. This means that the quality of natural light entering from the opening on the top of the vault remains constant except for the intensity of light that changes with time as it enters the interior of the museum. Each section across the entire length receives a similar quality of light, an effect that is a result of the way the building has been oriented. The directional aspect of sunlight is controlled by perforated aluminum reflectors and is partially opaque to bring in a diffused and uniform quality of light that does not affect the artwork on display.

The glazed wall on the west side of the spatial envelope helps maintain a strong visual connection with the environment. The entrance porch on the west side helps to shade the interiors from the direct rays of the setting sun. Also, it acts as a transition space for the eyes to adjust to the relatively low levels of illumination inside the museum.

5.2.2 INTENSITY

The quality of daylight inside the spatial envelope is soft, diffused, and uniform resulting from the controlled penetration allowed by the daylight fixture at the top of the vaulted ceiling. Most of the direct rays of the sun are obstructed by the partially opaque aluminum reflector, thereby cutting down on the intensity with which natural light enters the spatial envelope. The reflected light is made to flow along the curve of the ceiling, thereby providing an even spread to the space below.

The intensity of the daylight can be seen at the ends of the long vaulted ceiling where it creates a small gap with the gable end of the circle. The direct light from the south as well as the reflected light from the north opening creates a strong visual emphasis. The shape and size of these openings further relate to the form of the spatial envelope emphasizing the basic geometry of the major boundary edges. The closed nature of the opening, that hardly reveals any view to the outside, retains the intrinsic character of the space, which helps the visitor to appreciate the beauty of the artwork on display. It further marks the transition from one spatial envelope to another creating a strong sense of orientation when moving inside a single spatial envelope.

5.2.3 MYSTERY

The element of mystery is induced in the way aluminum reflectors hide the actual light source and in turn become a secondary source of light along with the silvery light reflected of the vaulted ceiling in exposed concrete. The light seems to flow from the top off the cycloid shell rendering all the objects on display in a soft and uniform light. The controlled quality of natural light creates an illusion of a light source other than the sun.

The spatial envelope seems to be bathed in a silvery light that provides a monochromatic background in combination with concrete and travertine. This helps to appreciate the artwork on display that is seen in the foreground without realizing that the actual generator for the underlying character of the space is the sun.

5.2.4 SHADOW

The absence of the directional quality of natural light produces soft diffused shadows. This results in the absence of strong patterns of light and shadow being projected on different surfaces and boundary edges. The lack of focal accents helps the visitors to concentrate on the works of art that further control and guide the movement pattern inside the spatial envelope. The amount of visual stimuli conveyed by the soft shadows helps to provide relevant information about the spatial depth but at no point competes for greater visual attention.

5.2.5 CONTRAST

There is a significant amount of contrast between the objects being displayed as seen against a restrained monotone background. The use of artificial sources of light directed towards these objects creates additional emphasis in terms of the higher brightness ratio when combined with the natural light that renders the entire spatial envelope in a uniform manner. The contrast between the brown colored oak flooring and the use of travertine and concrete on the vertical walls' surfaces helps to distinguish between the freestanding objects on the floor as well as the paintings displayed on the low height partitions.

5.2.6 COLOR

The dominant visual boundary inside the spatial envelope is the vaulted ceiling which renders the entire space in a silvery light as it is reflected off the grey exposed concrete to all the different directions. This creates soft and monotone imagery inside the museum providing for a peaceful and satisfying setting to appreciate the works of art that have been put on display. The only variation from the silvery grey seen on the vaulted ceiling is the beige color tone of travertine seen on the vertical wall surfaces and on the periphery of the floor, then finally moving towards the golden brown color of the oak wood flooring. The use of materials with similar texture helps to provide good visual continuity throughout the space. The controlled and muted expression of the space provides a neutral background to appreciate the works of art as they stand out in the foreground.

5.2.7 VARIATION

The variation in the light quality inside the museum is due to the difference in the intensity of the light at different intervals of time. The change in the light levels due to the movement of the sun across the sky, especially in the presence of a thick cloud cover, can be seen inside the museum. But with the skylight being the main source of light that is further controlled by the perforated aluminum reflector, there is not a great variation in the overall quality of light. It is only during the transition when artificial sources of light become predominant that the change in the intensity of natural light becomes significantly visible.

5.3 CHURCH OF THE LIGHT BY TADAO ANDO

The characteristics of natural light as they relate to the overall perception of the spatial envelope inside the Church of the Light have been listed and explained below.

5.3.1 ORIENTATION

The church is a rectangular shaped box that is oriented along a north south axis with the altar placed in front of the south wall. The amount of penetration inside the spatial envelope is controlled by the small size of openings thus maintaining a relatively dark interior space. The openings for light are oriented towards the south, west, and north direction with the east wall devoid of any opening to the exterior.

The full height slit opening in the north wall that is divided by the splay wall as the two intersect is the first source on natural light seen by the visitor making an entry into the chapel through the L shaped entry court. The diffused light entering from this opening breaks the darkness of the space to guide the movement of the visitor by acting as one of the focal accents present inside the spatial envelope. On a complete 180 degree turnaround, the visitor faces towards the altar placed in front of the south wall containing a cruciform opening. The direct light entering through this opening attempts to break the dark interior space of the chapel as it spreads light along four dominant surface boundaries: floor, ceiling and the walls on the east and west side.

Once the eyes get adjusted to the high contrast between the brightness of the opening and the dark interior space, other sources of light start to take effect. The full height glazed opening in the west wall brings in diffused light as it is shaded by the splayed wall that projects outwards and controls the view towards the exterior from this

opening. Another source of bright diffused light is along the gap between the splay wall and the ceiling. The light from this small narrow opening highlights the way the splay wall breaks the rectangular geometry of the space creating a small L shaped space serving as the entry court leading into the main chapel.

5.3.2 INTENSITY

The intensity of the different light sources is born out of the dark interiors of the chapel. The controlled amount of penetration creates a strong emphasis in developing a connection between the sacred and profane through the power with which light enters into the chapel. The cross shaped opening is lit up in extreme bright light that connects it with the symbolic meanings of the projected geometry created by this void in the thick concrete wall. This is further reinforced by the light and shadow pattern that is seen moving across the ceiling and the wooden floor.

The darkness that engulfs the interior of the chapel can be seen through the effect of the north light that enters through a narrow slit. Even this source of light seems so bright that it serves to act as a focal accent. The light that enters from the gap between the ceiling and the splayed wall has an altogether different effect on the character of the space. The intensity of light along this opening attempts to break the static nature of the enclosed space by making the ceiling float on the top without any visible support towards the west end of the chapel. The tension inside the space is relieved, and another connection with the outside is drawn through the intensity of natural light breaking into the dark interior space of the chapel.

5.3.3 MYSTERY

The mystery inside the Church of Light arises from the way the sequential arrangement of different spaces unfolds one after another. Starting from the bright space in the exterior the visitor is made to move all along the periphery of the chapel providing a transition in which the form and geometry of the spatial envelope is demystified. It is only once the visitor comes across the splayed wall cutting across an L shaped entry court that the simple geometry of the chapel is made complex. The entrance sequence is all the more dramatic where a narrow dark passage provides another transition in which the meanings of form and geometry disappear. The light from the slit opening in the north wall provides a low level of illumination making the eye adjust to the orientation of the chapel that demands a complete 180 degrees turnaround at this point. When the light overpowers the darkness and removes the ambiguity to reveal the spatial envelope, the sacred from the profane is defined. The cross shaped opening provides a metaphysical meaning to the space in which there are no other focal accents that try to compete for greater visual attention. The simplicity of the form revealed at once highlights the emptiness of the space that builds a visual tension inside the chapel forcing the visitor to see beyond the narrow opening. The extreme brightness helps hide the view to the exterior and the actual source of light, thus retaining the element of mystery that further highlights the sacred nature of the spatial envelope.

5.3.4 SHADOW

The different patterns of shadows resulting from the light entering through the cross shaped opening in the south wall can be seen on the floor, ceiling, and the east and west

walls of the chapel. This provides a much stronger emphasis on the linear axis connecting the north and south end of the spatial envelope with a sharp sense of the spatial depth as defined by the dominant boundaries. The long shadows help retain a relatively dark interior space despite the strong sense of penetration through the different openings. The overlapping of dark shadows on the grey colored concrete surface creates an effect in which the building mass appears to dissolve, thereby highlighting the emptiness of the space.

5.3.5 CONTRAST

The difference in the brightness ratio of the openings and the exposed concrete surfaces creates a strong visual contrast inside the chapel. The geometry of the openings is highlighted in the extreme bright light that provides a greater visual emphasis seen against the grey colored surfaces in the exposed concrete. The emptiness of the space is seen to be pierced by the strong rays of light entering through these openings creating a two fold dialectic between the bright and the dark, and light and shadow.

5.3.6 COLOR

The dominant surface boundaries are expressed through the use of exposed concrete. The grey color of the surfaces appears to be dark when projected with the long shadows. The low light levels inside the chapel make it hard for the grey color to act in a dominant manner. Instead, the monochromatic surfaces appear to fade in the dark interior space dissolving in a fashion that brings out the white bright light to dominate inside the spatial envelope. The restrained expression of the surfaces helps the different sources of light to

act as focal accents depicting the importance of natural light in defining the sacred nature of the space.

5.3.7 VARIATION

The variation inside the chapel can be seen in terms of the movement of shadows that help in relating to the source of light inside the spatial envelope. The intensity of the light varies throughout the entire length of the day and is at its peak once the sun is overhead. The contrast between the different surfaces and the openings for natural light is continuously changing as the sun moves across the sky and cutting through the cloud cover. The hue of the grey color of the exposed concrete appears to fluctuate with the changing light levels inside the spatial envelope.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This thesis discusses the characteristics of natural light that are visible inside the buildings made of concrete in late twentieth century. Throughout the history of architecture, natural light has been dealt in different ways to achieve the desired effect inside a built form. New materials have been used in innovative ways while experimenting with color, texture, and reflective properties of the surface to create an interesting play of light and shadow. Reinforced concrete is one such medium that brought in a new kind of flexibility in dealing with the overall form, design, and placement of the different openings while exploring the effect of natural light inside a building. In pursuing this investigation, the study addressed three major objectives. First, is to identify the characteristics of natural light visible inside these spaces. Second, is to understand the use of natural light to illuminate different spaces. Third, is to explore the relation between the characteristics of natural light to the overall perception of the space. Following these objectives, the study developed two hypotheses on the basis of a literature review. The first hypothesis examined the link between the design of a built form in relation to the quality of natural light inside a space by showing that the *overall perception of a space is affected by certain basic characteristics of natural light.* The second hypothesis highlighted the way natural light, both direct and diffused, has been used inside a spatial envelope to create visual interest by using it as a design element.

Thus the second hypothesis suggests that *the overall character of a space can be enhanced by emphasizing the source of natural light as a visual element.*

To test these hypotheses, the effect of natural light was studied in three buildings made out of reinforced concrete in the late twentieth century. These three buildings are Chapel of Notre Dame du Haut Ronchamp by Le Corbusier, Kimbell Art Museum by Louis I. Kahn and Church of the Light by Tadao Ando. The criteria for the final analysis was based on the selection of a spatial envelope in each of the buildings which helped to provide an ideal framework for studying the effects of light. The method was based on the principles of visual perception and the use of images depicting the varied effects of light inside the spatial envelope.

The analysis of the selected spatial envelopes in the three buildings was aimed at listing the underlying characteristics of natural light that become visible inside these spaces. The emphasis was on analyzing the effects of natural light in relation to the overall perception of the space using the process of visual perception that formed the basis of the criteria used in this study.

The results of the analysis show that the three projects employ similar design principles to achieve some of the common effects of light, and that the listed characteristics of light in relation to the overall perception of the space do not vary to a great extent when moving from one project to another. The characteristics of natural light were listed as: (a) Orientation, (b) Intensity, (c) Mystery, (d) Shadow, (e) Contrast, (f) Color and (g) Variation (see Tables 1 through 7).

Table 1: Orientation

Chapel of Notre Dame du Haut Ronchamp by Le Corbusier	**Kimbell Art Museum by Louis I. Kahn**	**Church of the Light by Tadao Ando**
The chapel is oriented along an east-west axis that connects the confessional in the west wall to the altar placed in front of the east wall. The south and east walls act as receptors for the majority of sunlight that enters the chapel through the gap between the roof and the vertical surfaces in an attempt to break the static nature of the enclosed interior space, whereas the north and west walls act as containers that define the sacred from the profane in a manner that removes any immediate connection with the outside environment.	The Museum building is composed of 16 cycloid shells oriented along a north-south axis. The movement of the sun is along the east-west axis which is perpendicular to the main axis of the spatial envelope. Thus, the quality of natural light entering from the opening on the top of the vault remains constant except for the intensity of light that changes with time. This creates a diffused interior space where the visitor can easily focus on the artwork.	The church is oriented along a north south axis with the altar placed in front of the south wall. The openings for light are oriented towards the south, west, and north direction with the east wall devoid of any opening to the exterior. The different light openings act as visual accents that help in connecting different spaces that define a strong circulation pattern. This creates a unified experience of the space.

Table 2: Intensity

Chapel of Notre Dame du Haut Ronchamp by Le Corbusier	**Kimbell Art Museum by Louis I. Kahn**	**Church of the Light by Tadao Ando**
The small openings of light inside the chapel help to contain the interior space from any major views of the exterior. The amount of penetration is to an extent that lights the periphery of the spatial envelope while maintaining a dark interior space.	The quality of daylight inside the spatial envelope is soft, diffused, and uniform resulting from the controlled penetration allowed by the daylight fixture at the top of the vaulted ceiling.	The intensity of the different light sources is born out of the dark interiors of the chapel.
The intensity of light source is all the more visible in this setting as the light rays can be seen cutting through the darkness that envelops the inside of the chapel.	Most of the direct rays of the sun are obstructed by the partially opaque aluminum reflector thereby cutting down on the intensity with which natural light enters the spatial envelope. The reflected light is made to flow along the curve of the ceiling thereby providing an evenly lit space.	The power with which light enters into the chapel creates a strong emphasis that helps in defining the sacred nature of the space. The cross shaped opening is lit up in extreme bright light that connects it with the symbolic meanings of the projected geometry created by this void in the thick concrete wall.

Table 3: Mystery

Chapel of Notre Dame du Haut Ronchamp by Le Corbusier	**Kimbell Art Museum by Louis I. Kahn**	**Church of the Light by Tadao Ando**
The mystery of the interior space where everything is not revealed at once helps in maintaining the sacred nature of the spatial envelope, by which the inside is far removed from its immediate environment.	The element of mystery is induced in the way aluminum reflectors hide the actual light source and in turn become a secondary source of light along with the silvery light reflected of the vaulted ceiling in exposed concrete.	The mystery inside the Church of Light arises from the way the sequential arrangement of different spaces unfolds one after another.
The continuous adjustment of the eye to the bright and dark surfaces heightens the awareness for different sources of light as the visitor attempts to comprehend the spatial geometry through the varied play of light and shadow inside the chapel.	The artwork on display acts as the focal accent seen against a subdued background rendered with a mystifying quality of space that hardly reveals the source at any given point in time during the entire length of the day.	Starting from the bright space in the exterior, the visitor is made to move all along the dominant boundaries of the spatial envelope thereby providing a transition in which the form and geometry of the spatial envelope is demystified.

Table 4: Shadow

Chapel of Notre Dame du Haut Ronchamp by Le Corbusier	**Kimbell Art Museum by Louis I. Kahn**	**Church of the Light by Tadao Ando**
There are no sharp shadows inside the chapel. This is due to the rough grainy texture on the wall surfaces that diffuses and scatters the light with each subsequent reflection.	The absence of the directional quality of natural light produces soft diffused shadows. This results in the absence of strong patterns of light and shadow being projected on different surfaces and boundary edges.	The different pattern of shadows resulting from the light entering through the cross shaped opening in the south wall can be seen on the floor, ceiling, and the east and west walls of the chapel.
The softness of the shadows can be appreciated to a greater extent due to the white finish of the vertical boundaries inside the chapel. The soft and diffused nature of shadows helps in counterbalancing the effect of rough texture on different surfaces that could otherwise be discomforting in its appearance.	The amount of visual stimuli conveyed by the soft shadows helps in providing relevant information about the spatial depth but at no point competes for greater visual attention.	The long shadows result in retaining a relatively dark interior space despite the strong sense of penetration through the different openings. The overlapping of dark shadows on the grey colored concrete surface creates an effect in which the building mass appears to dissolve, thereby highlighting the emptiness of the space.

Table 5: Contrast

Chapel of Notre Dame du Haut Ronchamp by Le Corbusier	**Kimbell Art Museum by Louis I. Kahn**	**Church of the Light by Tadao Ando**
There is a good amount of contrast due to the significant difference between the brightness ratio of the foreground to the background. This is due to the limited size of the openings that result in a shallow surface penetration leaving the interiors dark and devoid of a good amount of natural light.	There is a significant amount of contrast between the objects being displayed as seen against a restrained monotone background.	The difference in the brightness ratio of the openings and the exposed concrete surfaces creates a strong visual contrast inside the chapel. The geometry of the openings is highlighted in the extreme bright light that provides for a greater visual emphasis seen against the grey colored surfaces in exposed concrete.
The strong contrast creates a heightened awareness of the penetration by natural light, thereby creating a hierarchy of spaces from the darkest in the center to the extreme bright on the periphery.	The use of artificial sources of light directed towards these objects creates additional emphasis in terms of the higher brightness ratio when combined with the natural light that renders the entire spatial envelope in a uniform manner.	The emptiness of the space is seen to be pierced by the strong rays of light entering through these openings creating a two fold dialectic between the bright and the dark, and light and shadow.

Table 6: Color

Chapel of Notre Dame du Haut Ronchamp by Le Corbusier	**Kimbell Art Museum by Louis I. Kahn**	**Church of the Light by Tadao Ando**
The interiors of the chapel are painted in white lime that provides a clean, pure, and neutral background to observe the effects of light at is passes through clear, colored, and painted glass in the different openings on the south wall. The use of primary colors painted on the glass creates interesting pattern of shadows especially on the splayed openings in the south wall. The sporadic appearance of color in different openings creates a magical effect where the eye is not able to read as regular pattern in the way light renders different openings.	The dominant visual boundary inside the spatial envelope is the vaulted ceiling which renders the entire space in a silvery light as it is reflected off the grey exposed concrete to all the different directions. This creates soft and monotone imagery inside the museum providing for a peaceful and satisfying setting to appreciate the works of art that have been put on display.	The dominant surface boundaries are expressed through the use of exposed concrete. The grey color of the surfaces appears to be dark when projected with the long shadows. The low light levels inside the chapel make it hard for the grey color to act in a dominant manner. Instead, the monochromatic surfaces appear to fade in the dark interior space dissolving in a fashion that brings out the white bright light to dominate inside the spatial envelope.

Table 7: Variation

Chapel of Notre Dame du Haut Ronchamp by Le Corbusier	**Kimbell Art Museum by Louis I. Kahn**	**Church of the Light by Tadao Ando**
The morning light can be seen to create a silhouette, south light creates subtle effects like the colored shadows projected onto the splayed openings that change in brightness as the sun moves across the sky. Finally, the setting sun brings in its own characteristic light into the chapel placed in the vertical tower that stands towards the west end of the north wall.	The variation in the light quality inside the museum is due to the difference in the intensity of the light at different intervals of time. The change in the light levels due to the movement of the sun across the sky especially in the presence of a thick cloud cover can be seen inside the museum.	The variation inside the chapel can be seen in terms of the movement of shadows that help in relating to the source of light inside the spatial envelope. The intensity of the light varies throughout the entire length of the day and is at its peak once the sun is overhead.
The emphasis on the subspaces is continuously changing thereby breaking the static nature of the chapel.	This creates a subtle dynamism inside the spatial envelope.	The hue of the grey color of the exposed concrete appears to fluctuate with the changing light levels inside the spatial envelope, thereby creating a strong pattern of movement in terms of the shadows.

The results summarize each of the characteristic that are seen to affect the overall perception of the spatial envelope in each of the three projects. This validates the first hypothesis. There was a considerable amount of contrast that helped in distinguishing between the light and the dark as well as the background and the foreground. The relatively low light levels in each of the three spatial envelopes created a strong visual focus on the source of natural light. The source of natural light was used as a visual accent to maintain strong connectivity in the overall pattern of movement inside the spatial envelope. This helped in creating a much more unified space thereby validating the second hypothesis, that the overall character of a space can be enhanced by emphasizing the source of natural light as a visual element. The results of the analysis show that the three projects employ similar design principles to achieve some of the common effects of light, and that the listed characteristics of light affect the overall perception of the space.

The emphasis on the source of natural light was a common and recurring theme in all of the three buildings. The results support both hypotheses and also demonstrate that the character of an interior space is dependent upon the way a designer brings natural light into the space.

Finally, it should be noted that due to the limited scope of the thesis a relatively small number of examples were selected that are not representative of all those architects that have worked in the context of the present study. However, it is suggested that a further investigation should be undertaken to include more buildings that represent some of the leading examples by architects who have experimented with the effect of natural

light in relation to the quality of a space. The scope of the study can be expanded to other building types that employ different materials of construction as well as looking at different time periods that can further test this study's hypothesis and in validating the underlying criteria used in the final analysis. A further extension could be made to include the realm of artificial lighting that could be analyzed based on the principles of visual perception.

REFERENCES

Ando, T. 1995. *Tadao Ando: Complete Works*, Phaidon Press, London.

Archive Colour Slides Ltd., Dublin, Ireland, 1984, Notre Dame du Haut Church.

Baker, G. H. 1984. *Le Corbusier: An Analysis of Form,* Van Nostrand Reinhold, New York.

Baker, N. and Steemers, K. 2002. *Daylighting Design of Buildings*, James & James Ltd, London.

Barandon, J. 2001. The Church of Light, Tadao Ando. Available: http:// architecture.mit.edu/~barandon/4.203/images/jpegs/, accessed April 8, 2006.

Bechtel, R. B. 1967. Human movement and architecture, *Transaction*, Washington University, May 1967: 53-56.

Brownlee, D. B., and Long, D. G. 1991. *Louis I. Kahn : In the Realm of Architecture*, Rizzoli International Publications, Inc., New York.

Curtis, W. J. R. 1996. *Modern Architecture since 1900*, Prentice Hall, Upper Saddle River, New Jersey.

Dubos, R. 1968. *So Human an Animal*, Charles Scribner's Sons, New York.

Frampton, K. 2003. *Light and Water*, The Monacelli Press Inc., New York.

Gärling, T. 1970. Studies in visual perception of architectural spaces and rooms IV: the relation of judged size of space under different viewing conditions, *Scandinavian Journal of Psychology*, 11: 133-145.

Gibson, J. J. 1986. *The Ecological Approach to Visual Perception*, Lawrence Erlbaum Associates, Mahwah, New Jersey.

Hopkinson, R. G. 1963. *Architectural Physics: Lighting*, H.M. Stationery Office, London.

Jay, PA. 2002. Subjective criteria of lighting design, *Lighting Research & Technology*, 34 (2): 87-99.

Kahn, L. I. 1971. The room, the street and human agreement, (AIA Gold Medal acceptance speech, Detroit, June 24, 1971), *AIA Journal*, 56, September 1971: 33.

Kahn, L. I. 1975. *Light Is the Theme: Louis I. Kahn and the Kimbell Art Museum: Comments on Architecture*, Kimbell Art Foundation, Forth Worth, Texas.

Lai, J. Y. C. The Chapel of Notre Dame du Haut Ronchamp, Le Corbusier. Available: http://www.0super.net/upload/edited/, accessed April 20, 2006.

Lam, W. M. C. 1977. *Perception and Lighting as Formgivers for Architecture*, McGraw-Hill Book Company, New York.

Le Corbusier. 1975. *Ronchamp*, Oeuvre de Notre-Dame du Haut, Strasbourg, Germany.

Lobell, J. 1979. *Between Silence and Light: Spirit in the Architecture of Louis I. Kahn*, Shambhala Publications Inc., Boulder, Colorado.

Michel, L. 1996. *Light: The Shape of Space: Designing with Space and Light*, Van Nostrand Reinhold, New York.

Millet, M. S. 1996. *Light Revealing Architecture*, Van Nostrand Reinhold, New York.

Miyake, R. 1994. *Light and Space: Modern Architecture*, A.D.A. Edita Tokyo Co., Ltd., Tokyo.

Moore, F. 1985. *Concepts and Practice of Architectural Daylighting*, Van Nostrand Reinhold, New York.

Oliva, A., and Torralba, A. 2001. Modeling the shape of the scene: a holistic representation of the spatial envelope, *International Journal of Computer Vision*, 42 (3): 145-175.

Pare, R. 1996. *The Colours of Light*, Phaidon Press Limited, London.

Pauly, D. 1997. *Le Corbusier: The Chapel at Ronchamp*, Birlhauser (Princeton Architectural Press), Berlin.

Phillips, D. 2004. *Daylighting: Natural Light in Architecture*, Architectural Press, Burlington, Massachusetts.

Plummer, H. 1987. *Poetics of Light,* Architecture and Urbanism, Tokyo.

Plummer, H. 1995. *Light in Japanese Architecture*, Architecture and Urbanism, Tokyo.

Plummer, H. 2003. *Masters of Light*, Architecture and Urbanism, Tokyo.

Portoghesi, P. 1994. Light and modern architecture. In *Light & Space: Modern Architecture*, Futagawa, Y. ed., Ga International Co Ltd, Tokyo.

Schmier, H. 2005. The Chapel of Notre Dame du Haut Ronchamp, Le Corbusier. Available: http://www.myfourthirds.com/folder.php?id=906, accessed April 15, 2006.

Simon, G. 2003. View of the east wall facing towards the altar. Available: http://www.galinsky.com/buildings/ronchamp/, accessed April 20, 2006.

Solon, V. L. 2006. Principles of Architectural Polychromy, http://archrecord. construction.com/inTheCause/onTheState/0402solon-1.asp, accessed April 16, 2006.

Tanizaki, J. 1977. *In Praise of Shadows*, Leete's Island Books, Stony Creek, NY.

Taylor, L. H., and Sucov, E. W. 1974. The movement of people towards lights, *Journal of Illuminating Engineering Society*, 3: 237-241.

Thibaud, J. 2001. Frames of Visibility in Public Spaces, *Places*, 14 (1): 42-47.

Tzonis, A. 2001. *Le Corbusier: The Poetics of Machine and Metaphor*, Universe Publishing, New York.

Weinel, E. F. Detail of the openings on the south wall. Available: http://arch.ou.edu/ arch/2423/Chapter%2028/Ronchamp%20Int.jpg, accessed April 20, 2006.

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