A comparative analysis of two space designs and the lighting effects of the Des Moines Art Center

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A comparative analysis of two space designs and the lighting effects of the Des Moines Art Center

by

Todd Lowell Bellis

A Thesis Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of

MASTER OF ARCHITECTURE

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Ames, Iowa
1990

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INTRODUCTION

The purpose of this thesis is to show that light is a necessary ingredient in the creation of the form of any type of building. Building form is dependent on many variables, but regardless of these variables, the form of a building should be related to light. This thesis will present the basic premise that light and building form must work in unison to create a good design. This will be accomplished by examining basic ideas of light and building form. A short history of building form in architecture together with several authorities' opinions on light will be the evidence necessary to show this important connection. The examination of an art gallery as a building type will be employed in order to observe a realistic situation involving light and building form. The Des Moines Art Center will be used as the case study.

All architects must have a basic knowledge of light to competently practice architecture. These important lighting concepts are being disregarded in architecture today. This thesis will make designers aware of these concepts. They must know that light is present and needs to be accounted for in all design, regardless of the building type.

This thesis is an exploratory survey which examines light and its connection with design and architecture. The physical aspects of light are only dealt with in order to provide the information necessary to understand light and its use in design. The first step to understanding light and building form is to get a good understanding of light itself.
LITERATURE REVIEW

Light

What is light? This question will be answered by providing several definitions of light from varying sources. The characteristics, types, and sources of light will also be discussed.

Light defined

Webster's New Collegiate Dictionary, defines light as: "...something that makes vision possible; the sensation aroused by stimulation of the visual receptors; an electromagnetic radiation in the wavelength range including infrared, visible, ultraviolet, and X-rays and travels in a vacuum with a speed of about 186,281 miles per second..." (Woolf 1981, 658). Light obviously is something that allows us to see, but it also has other qualities, such as energy.

Light as energy

Light is a form of energy, radiant energy. Light radiates equally from its source, it spreads in all directions, and its brilliance lessens as its distance from its source increases (Ching 1987, 287). Now that we have a very basic definition of light, it will be easier to understand how light behaves.

Light characteristics

Light is one type of wave which travels in relatively straight lines, called rays, that stay perpendicular to the wave fronts (Halliday 1970, 688). Since light travels in a straight line, it is very easy to predict, a fact that is integral to the study of light and its effects on buildings and space, and a significant design tool.

Another important and basic characteristic of light is that it is reflected off of any opaque surface that it strikes. Francis Ching points out just how important reflected light is to our vision, "The sun, stars, and electric lamps are visible to us because of the light they generate. Most of what we see, however, is visible because of the light that is reflected from the surfaces of
objects" (Ching 1987, 287). This principle of reflected light must be understood by designers so they can correctly predict what light will do when it hits surfaces.

**Light sources**

The most important source of light that this planet has is the sun. Without it life would cease to exist. St. Denis was reputed (in medieval times) to have said of light, "...creation was an act of illumination, but even the created universe could not exist without light. If light ceased to shine, all being would vanish into nothingness" (Simpson 1964, 52). Without the sun there would be no light, no energy, no warmth, and no life.

One would think that light being an essential ingredient in our lives would be perceived as essential, but this is not the case. L. C. Kalff, a noted lighting designer, wrote of light, "Human life is unthinkable without light, which often dominates all our thoughts and activities, without our being aware of it" (Kalff 1971, v). If light is so important to life, why do we overlook it? Perhaps because it is so essential to our lives and so available to us, we tend to take it for granted. We forget that it is almost always around us.

"The source of all natural daylight is the sun. Its light is intense but will vary with the time of day, from season to season, and from place to place. It can be diffused by cloud cover, haze, precipitation, or any pollution that may be present in the air" (Ching 1987, 294). The unpredictable nature of the earth's atmosphere may seem insurmountable. It is indeed unpredictable, but the sun is not. The light from the sun is one of the most constant things on earth. It hasn't changed for millions of years, and probably won't change for millions of years to come. With the technology available today we can accurately predict the position of the sun at any given time, on any day. Designers must learn to use this to their advantage.

**Natural and artificial light**

Light may be characterized as natural or artificial. Natural light is defined as daylight, sunlight, or light produced without man's doing. Artificial light on the other hand is light produced
by man, most often electric light. Natural light has basically one source, the sun.

Daylight is a complex entity whose beauty and splendor comes from its constantly changing nature. This, however, leads to complexities in designing buildings. Fuller Moore, lighting designer observes: "...daylighting is at once the newest and the most ancient, the most obviously simple and the most subtly complex of these rediscovered lighting strategies" (Moore 1985, vii).

"Artificial light is natural light that is produced by manufactured elements. The quantity and quality of light produced differs according to the type of lamp used. The light is further modified by the housing which holds and energizes the lamp" (Ching 1987, 295). Artificial light has its place in architecture, but it cannot replace the sun. It offers some, but not all of the advantages that the sun offers man. The best scenario is probably the combination of natural and artificial light.

Natural and artificial light used together offer architecture unlimited possibilities. "When natural and artificial lighting are properly integrated, daylight minimizes the use and expense of artificial light, while artificial lighting compensates for inadequate lighting" (Daylighting 1982, 24). A problem that faces many designers today is the blending of daylight and artificial light in a space. This needs to be considered in order to have an efficient lighting system.

"Instant, safe, predictable, and absolute, artificial lighting has tended to overwhelm building design since the industrial revolution. Electricity has also made possible constant illumination levels that do not reflect the natural rhythms and the unpredictable variations of each day's new light" (Moore 1985, vii). With electric light so readily available and natural light appearing difficult to design with, electric light has superseded the sun. The way in which design has evolved has caused architecture to suffer tremendously. Along with architecture, man has suffered.
Light as a biological need

Light is a biological need, an idea that has been documented by several well-known lighting designers. William Lam, who has published numerous articles on light, writes of the biological need of light, "Visible evidence of the presence of sunlight satisfies a basic biological need, providing important clues about three-dimensional form and orientation in addition to indicating the state of the weather" (Lam 1977, 25).

"People have known a long time about the therapeutic properties of light, and have tried to reproduce these in artificial lighting systems. A combination of the energy crisis and an interest in conservation, along with technological breakthrough enable us to understand daylight and improve ways of introducing more daylight into buildings" (Vischer 1987, 109).

People enjoy daylight, it is something that most everyone needs. Benjamin Evans, F.A.I.A., writes about daylight, "People like daylight. They like their interior spaces to have plenty of daylight. If people like something, it stands to reason they will consider it valuable and that when they have it they will be more satisfied and productive than when they don't have it. This should be justification enough for architects to introduce daylighting into their building designs" (Evans 1987, 78).

A basic definition along with the characteristics and sources of light have been presented. It has been demonstrated that in order for man to survive light must be present. Light is a basic biological need of man. These ideas provide the emphasis to consider light when building form is being created.

Form

In order to completely understand how light and form work together, an explanation of form is necessary. This will be accomplished through a definition of form and then an explanation of light and form working together with architecture.
Form defined

Webster's New Collegiate Dictionary defines form as, "...the shape and structure of something as distinguished from its material" (Woolf 1981, 447). A very loose definition. Francis Ching defines form more exactly as follows: "The point is the generator of all form. As a point moves, it leaves a trace of a line - the first dimension. As the line shifts in a direction other than its own, it defines a plane - a two-dimensional element. The plane, extended in a direction oblique or perpendicular to its surface, forms a three-dimensional volume. Point, line, plane, and volume. These are the primary elements of form. All visible forms are, in reality, three-dimensional" (Ching 1987, 92). With our understanding of light and form, we can discuss how light and form work together.

Light and form

Light is an essential ingredient in the viewing of form. Light is what gives form. "...light and vision are inseparable; neither exists without the other. Natural light sources gave the world its visible form. Man's understanding of his surrounding was shaped by the sunlight, moonlight, the sky and the stars..." (Erhardt 1985, 49). Light is not the only interpreter of form - touch is another - it is however an important one.

Light as a formgiver

William Lam examines how light as a formgiver relates to designing, "Light has always been recognized as one of the most powerful formgivers available to the designer, and great architects have always understood its importance as the principle medium which puts man in touch with his environment" (Lam 1977, 10).

Frank Lloyd Wright realized the importance of light as a formgiver and understood that light in itself wasn't enough to give form. Light's product, the shadow, was needed. He wrote, "Shadows have been the brush-work of the architect when he modeled his architectural forms. Let
his work, now, with light diffused, light refracted, light reflected - use light for its own sake - shadows aside" (Wright 1928, 198).

**Form and lighting design**

In the past architecture has suffered from the dependence on electric light; this has happened because designers have not examined the technology. They have failed to realize that light must be looked at first, then the technology applied to reach an end result, not the other way around. William Lam expresses this viewpoint: "If perception-based lighting design is once again to assume its proper place as a formgiver for architecture, it will not be because of the availability of cheaper glass, the introduction of more efficient light sources, or the generation of more sophisticated computer programs for calculating light levels. Innovations in each of these fields, applied indiscriminately, have already made significant contributions to the pervasive role of lighting as a destroyer of form. Technology, per se, is powerless to produce a good luminous environment. Concepts, not hardware, are the missing ingredients in the conventional approach to the design of the luminous environment" (Lam 1977, 12).

**Form, light, and architecture**

Form, light, and architecture are the three essential concepts when studying light's effect on building form. An explanation of how form is to be utilized in this thesis is imperative. For the purposes of this thesis form will be analyzed in the following way: first of all, in terms of how a building looks in elevation; secondly, in terms of plan or roof view; and finally the form in terms of section or building parts. In order to determine the total form of a building all of these points must be examined.

**Form and building orientation**

In order to analyze building form it is advisable to have a basic knowledge of light's effects on structures. When examining building form and light it is important to look at the orientation of
the building. Any building orientation can use daylight to some extent; each however will give a different effect.

For admitting light, north openings may need to be larger than other openings because very little direct sunlight enters them. East and west openings are very hard to control because they let large amounts of early morning and late afternoon light into the spaces. And finally the south elevation receives a great amount of direct sunlight. Each of these orientations is different in terms of how daylight strikes it and enters the building. Therefore the form of each elevation should reflect these differences.

Evans writes: "Probably the most significant design determinant in the use of daylight is the geometry of the building - the walls, ceilings, floors, windows, and how they relate to each other. Some very significant buildings have been shaped by considerations for daylight - the early Greek and Egyptian temples, the Gothic cathedrals..., and some greatly admired recent buildings by Kahn, Wright, Aalto..." (Evans 1987, 82).

This section points out that form and light need to work together in building design and gives us an important method to analyze buildings in terms of form. This method will be applied in later sections. Now that we have an understanding of light and form it is important to discuss ways in which light can enter a building.

Daylighting Devices

To understand how to design with light and how it effects form, one must understand a number of daylighting devices and the effect (quality) they cause by admitting light to an interior space. First we will consider some basic definitions and then an explanation of the different types of openings used in these devices and their lighting effects.

A good definition of fenestration is offered by Fuller Moore: "any opening or arrangement of openings for the admission of daylight" (Moore 1985, 68). Ching states a basic principle in lighting design: "The size and orientation of windows and skylights control the quantity of natural
light that penetrates and illuminates an interior space" (Ching 1987, 208). This idea will greatly influence the form of a building.

In order for a designer to correctly place a window in a space it is necessary to determine the function of the fenestration and the function of the space. It is also important to understand the design result of placing certain fenestrations in specific places. Since form cannot be visualized without light, the placement of the fenestrations, which bring light into a space, is of great consequence in determining how the space is lit. Furthermore: "The quality of light - its intensity and color - is determined by a window's orientation and placement in a room" (Ching 1987, 208). This placement of the fenestration also effects the form of the building. The two types of fenestration will be explained in the following sections.

Openings for direct light

These allow sunlight directly into a space (See Figure 1). Direct sunlight does several things: it can provide a space with high levels of illumination, sunlight can create a contrast of bright and dark shadow patterns, and can define forms to a high degree (Ching 1979, 182). It also can cause some adverse effects if the fenestration cannot be shaded. One is unwanted glare which can be very distracting as well as disabling. Another is destruction of many materials due to the characteristics of sunlight. Still another is exorbitant heat build up due to excessive solar gain.

Openings for indirect light

This type of fenestration prevents sunlight from entering directly, but admits diffuse ambient light (See Figure 2). The design result of this type of fenestration is consistent balanced light levels in the space (Ching 1979, 182). Now that the two types of fenestration have been described, their placement in a space and their immediate effects can be analyzed.

Fenestration placement

This section will deal with several different possibilities of window placement within a wall plane and of skylight placement. These will be presented in a generic way so that they will
apply to any space. The design result or effect on the space will also be shown so that the designer may understand the effects of certain fenestration placement.

Opening within a wall plane

The first type of opening is a fenestration located entirely within a plane (See Figure 3). This fenestration placement will cause the opening to appear as a bright area on a surface. This type of opening can cause glare if the surface surrounding the fenestration is much darker in contrast to the opening. This condition can be, "...ameliorated by allowing daylight to enter the space from at least two directions" (Ching 1979, 183).
Figure 2. Opening for indirect light (Ching 1979, 183)

Figure 3. Opening within a wall plane (Ching 1979, 183)
**Figure 4.** Opening next to a wall plane (Ching 1979, 183)

**Opening next to a wall plane**

A second fenestration placement is an opening in a plane next to a second plane (See Figure 4). This type of opening will throw light onto this plane. Speaking of the second plane, Ching says: "This illuminated surface will itself become a source of light and enhance the light level within the space" (Ching 1979, 183).

**Corner opening**

A third type of fenestration placement is adjoining openings in planes meeting in a corner (See Figure 5). This placement can be viewed as two of the "openings next to a plane" working in conjunction with each other, because it will have a similar effect on the space as the opening next to a plane. This type of opening could be used to add light to a dark corner of the space.
Figure 5. Corner opening (Ching 1979, 188)

Figure 6. Window wall (Ching 1979, 185)
Window wall

Another type of fenestration is the window wall. This construction will allow great amounts of light to enter the space. "If they are oriented to capture direct sunlight, sun-shading devices may be necessary to reduce glare and excessive heat gain within a space" (Ching 1979, 191).

Skylight

This is the last type of opening that will be discussed. Located within the ceiling plane, a skylight will provide a great deal of light directly to horizontal and vertical planes. "Locating a linear skylight along the edge where a wall and ceiling plane meet will allow incoming light to wash the surface of the wall, illuminate it, and enhance the brightness level of the space. The form of the skylight can be manipulated to capture direct sunlight, indirect daylight, or a combination of both" (Ching 1979, 190).

![Skylight Diagram](Ching 1979, 185)

Figure 7. Skylight (Ching 1979, 185)

One possible problem associated with overhead lighting is that of veiling reflection. These reflections can seriously impair the vision of the user. James Nuckolls describes this problem as follows: "Veiling glare is a disabling glare that results when extreme contrast within a task
prevents the viewer from properly discerning the task (e.g., the reflections from shiny magazine paper that prevent the magazine page from being easily read)” (Nuckolls 1983, 141).

**Bidirectional lighting**

It is fairly easy to predict the design result of each of these types used alone, but several used together become more unpredictable. An important concept to remember about light and fenestration is, “Bidirectional daylighting raises the level of diffused light in a space and reduces the possibility of glare” (Ching 1987, 209). Put in simpler terms, using several light sources creates more diffuse reflected light, giving a better balanced overall light.

![Figure 8. Bidirectional lighting (Ching 1987, 209)](image)

With the information presented above we now have an understanding of how openings affect space in terms of light. This will be used as a tool to analyze building form in later sections.

**History of Building Form And Light**

Looking at the historical use of light and its effects on building form will provide several precedents dealing with the importance of light to building form. During most of history, daylight
has been the primary source of light. Daylight has been supplemented by artificial light; this is accomplished through the burning of fossil-fueled and more recently by the use of electricity. Light has been a monument determination of form, mostly because light was essential for life to proceed in a normal fashion. Therefore, it was important that buildings took a form that allowed light to penetrate the interior in specific ways. This basic need for natural light has become less important with the invention of the electric light. These ideas will be substantiated by an examination of the history of building form.

**Ancient Egypt**

In ancient Egypt the very bright, arid, and hot climate greatly influenced building form. Building walls were very thick, the massive walls were required structurally. The thick walls in turn acted as thermal mass. In the day the walls absorbed the heat keeping the interior cool, while at night the heat was radiated into the space. Finally, with the thick walls, window penetrations were very deep causing the very bright light to be reflected off the opening boundaries several times before it reached the interior. This softened and diffused the light creating a more evenly lit space. This building form was directly influenced by light.

Light was also used in very dramatic, theatrical ways. As Moore writes, the Great Temple of Ammon, a Hypostyle Hall, used light to accentuate the axial quality of the space. Light was intentionally varied from a very well-lit space at the entrance, to progressively darker spaces, until the final space which was the darkest (Moore 1985, 3). This procession of spaces was only possible through the gradation of natural light. The building form was intentionally varied to change the light levels in various spaces. This can be evidenced by examining the section below.

The general form of the building is influenced by this need to let light into the space. The large clerestory that is popped up on the roof, is a direct result of light requirements, which greatly influenced the form of the building (See Figure 11).
Figure 9. Plan of the Temple of Khons, Karnak (Fletcher 1987, 50)

Figure 10. Section of the Temple of Khons, Karnak (Fletcher 1987, 50)

Figure 11. Section through Hypostyle Hall, Temple of Ammon, Karnak (Moore 1985, 4)
The ancient Egyptians were very concerned with the way light entered their spaces. They had to be in order to survive. Several examples of how their building forms were developed have been given. Their architecture is an example of how important light, building form, and architecture are to each other.

Ancient Greece

In ancient Greece, the buildings were planned and laid out with regard to the sun. The form of the buildings was affected in terms of section but more importantly in terms of their orientation. The site was intentionally laid out so that early morning sun would strike the entrance thus lighting the interior (See Figure 12). In order to see how the form of the orientation was effected it is necessary to examine the building in terms of the site or plan views.

"The orthogonal ancient Greek town plan provided solar access to houses for lighting and heating. It is likely that this solar utilization was intentional; the Greek's use of the sundial evidences their knowledge of the sun's movement" (Moore 1985, 5). Socrates, in describing the Greek houses, points out that some of the houses were two stories and that the south side was often only one story to allow light to enter the courtyard and to get to the second story (Moore 1985, 5).

Figure 12: Site plan of the Acropolis, Athens, Greece (Fletcher 1987, 110)
Ancient Rome

The ancient Romans used light very effectively as will be discussed in the following text. The most significant development in Roman times was the creation of the round arch, the dome and the barrel and groin vaults. The round arch allowed large openings, which in turn allowed great quantities of light to enter into spaces. The dome and vault allowed the spaces to be very large. Another new aspect of Roman architecture was the use of glass. The material was not new; the use of colored-glass had existed for about 3,000 years, but it was a Roman who realized that transparent glass would let light in while keeping the elements out of the interior spaces (Butti 1954, 19). This innovative idea for letting light in is reinforced by the writing of Seneca, a Roman philosopher, in A.D. 65, "Certain inventions have come about within our own memory—the use of window panes which admit light through a transparent material, for example" (Butti 1954, 19).

Vitruvius, a Roman architect, examines the effects of the sun on a building's design due to both light and climate. "We must begin by taking note of the countries and climates in which homes are to be built if our designs for them are to be correct. One type of house seems appropriate for Egypt, another for Spain...one still for Rome, and so on with lands and countries of varying characteristics. This is because one part of the Earth is directly under the sun's course, another is far away from it, while another lies midway between these two...It is obvious that designs for homes ought to conform to diversities of climate" (Butti 1954, 15). Vitruvius understood the complex differences in the sun in different areas of the world. And as he points out it is essential that the form each of these buildings takes must be different.

There are several good examples of Roman architecture to study in terms of light and form. The first building to look at is the Pantheon, located in Rome it was built from 120-124 A.D. (See Figures 13 and 14).
This building is important in that it introduces a skylight that is unglazed. The single fenestration lights the interior in such a way that it also gives the observer a connection with nature. The light is direct and it continually moves around the space. The space has been described as follows: "To complete the illusion, there is the deliberate lack of orientation achieved by lighting the whole building from a single, central source. The eye is almost inevitably drawn up, through the richly traceried pattern of light and shade cast by the coffering, to the light that floods in through the great central opening" (Boethius and Ward-Perkins 1970, 260). In this case the form of the building in terms of light was deliberately designed in order to create a desired effect within the space. Light greatly influenced the form of the building.

Another specific Roman example is Nero’s Golden House, built in Rome from 64-68 A.D. The house had several daylighting devices: an oculus skylight and several concealed clerestories (See Figures 15 and 16).

Figure 13. Plan of Pantheon (Mansell 1979, 26)
Looking at the section it is obvious that the lighting of the space became a very important concept in terms of the design of the space. The need to create a specific light effect in the central space along with the need to spread light throughout other rooms in the house is accomplished through the use of the building form.

Byzantine Architecture

Byzantine architecture is the next area to be examined. Byzantine architecture contributed the dome and pendentives over the rectangular space. This was unique up to this time because the Roman's domes were always continuously supported by the circular or polygonal walls of the space below. The most influential building in terms of light is Hagia Sophia in Istanbul,
Figure 15. Plan of the Golden House of Nero (Moore 1985, 7)

Figure 16. Section of the Golden House of Nero (Moore 1985, 7)
built from 532-537 A.D. Light was used in spectacular ways to give a special quality to the space. Light enters the centralized space through the clerestory and dome windows. Light also enters through the galleries and aisles.

Procopius of Caesarea, Emperor Justinian's house historian, wrote of Hagia Sophia right after it was built, "singularly full of light...you would declare that the place is not lighted by the sun from without, but that the rays are produced within itself" (Otto 1979, 19). The dome became a very symbolic part of the architecture. Procopius also wrote, "From the lightness of the building it does not appear to rest upon a solid foundation, but to cover the place beneath as though it were suspended from heaven by the fabled golden chain" (Otto 1979, 19).

Figure 17. Plan of Hagia Sophia (Fletcher 1987, 289)
Figure 18. Section of Hagia Sophia (Fletcher 1987, 289)

The form of the building relates to light in order to create an effect. The dome had to be punctured and raised in order to give the space the magical quality it possesses. There are several other aspects of the form of the building which relate to light. The thick walls that the sloped fenestrations are placed in cause light to bounce into the interior. Another important part of the form is the curved ceilings, which help to reflect light throughout the interior. The form of this building is greatly influenced by daylight; without this light and form connection this magnificently lit space would not be possible.

Gothic Architecture

The next period of architecture that used light to influence its building form is the Gothic period, generally seen from 1140-1600. Light became a very symbolic idea of power, heaven and god. Its fire and beauty needed to be brought into the church. The massive walls of the buildings
were replaced by very open frameworks supporting a wall of glass. Flying buttressing became the framework to hold up the roof and keep the vaults from pushing the walls outward. Light entered the interior in vast amounts. But it entered not through clear glass, but through magnificent stained glass. This opening up of the structure is a direct result of desire to utilize light in a specific way. The building form can be seen by looking at section through the building.

Figure 19. Section through Amiens (Fletcher 1987, 187)
"Light entering the interior is not clear daylight, which would produce shadow, highlight, and plastic effects, but light washed with many hues and diffused throughout the interior. Drawing space into a continuity, this light emphasizes distances, intensifies the vertical, increases the apparent length of the church from entrance to altar. Consequently, the outer skin of the church is transformed into zones of space and light" (Otto 1979, 21). The structure of the Gothic period was based on space, light, and plastic effects. Abbot Suger had an interesting theory about light, helping to form the architecture of the time. Suger's theory was that one could understand the light of God more readily through the light of material objects on the earth, such as stained glass. Stained glass had three properties: it was the bearer of holy images; it resembled rich stones, because of its material; and the most important aspect was its mysterious qualities, "it glowed without fire" (Banner 1984, 21). Light in the Gothic church was, "...a spiritual power, capable of exercising an influence as inspiring as architectural form (Jantzen 1984, 67)."

As historian Hans Jantzen points out in his book, High Gothic, "The story of light in medieval places of worship makes it quite clear that its particular character was directly related to architectural form. In the classic Gothic cathedrals its quality, abundance and distribution contributed decisively to the design of the interior (Jantzen 1984, 69)." Light was a direct interpreter of the form of the Gothic cathedral, both in terms of its interior and exterior form. Renaissance and Baroque Architecture

The Renaissance period is known for its very balanced and even light. There is generally no play of light and dark in the interior spaces (See Figure 20). However, in the Baroque, light becomes part of the architecture. The light is very dramatic and is used in a theatrical way. It is designed with the spectator in mind, being used to evoke emotion (See Figure 21). "Churches tend to be unevenly lit. Windows are high and often small, and most of the daylight comes through a lantern in the dome. The result is an evocative, sometimes dramatic chiaroscuro effect similar to
Figure 20. Section through S. Giorgio Maggiore: Venice (Fletcher 1950, 662)

Figure 21. Section through the Church of the Assunta (Borsi 1980, 130)
that in paintings. The light may be quite strong in some parts but deep pools of shadow are left in
the recesses, in doorways, under arches, behind pillars, etc." (Kitson 1966, 41).

Another important aspect of Baroque lighting is that light became part of the architecture,
the building, the sculpture. Architecture became totally integrated with daylighting design. If
light was to be used in this integrated, dramatic way, it needed to be understood. The form of the
building needed to directly relate to light in order for this to occur. This can be seen by examining
the Baroque building section. The buildings become light gatherers; they don't just let light in,
they control it.

Baroque architecture is one of the best examples of how building form and light are related
in architecture. As has been shown, light, architecture, and form, work in harmony with each
other and the result is the creation of marvelously lit spaces.

Industrial Architecture

Industrial architecture changed other architecture substantially. Up to this time,
architects had to use daylight to light their buildings and deal with the climatic changes of the area.
They could not disregard the effects of light on their design. Light was very important to building
form.

With the industrial revolution came many changes. The problem of lighting the interior
was solved in the late nineteenth century with the application of the electric light. The invention
of steel framing replaced load-bearing masonry in many buildings. The thick walls that used to be
needed to hold a building up, became extinct. As a result, the thermal characteristics of the
building were drastically altered. Larger openings were possible, allowing a great amount of light
to enter, along with great amounts of heat from the sun. The problem of too much solar gain was
solved (after World War II) by the use of conditioned air. Concurrently, with the advent of
fluorescent lighting, daylight was no longer needed. Design no longer was dependent of light.
Building form was to change dramatically, up to this time the depth of the building was limited by
Figure 22. Section through Crystal Palace (Mansell 1979, 151)

the amount of light that could enter the space. With the electric light buildings could become very deep. The form of the building could exist independently from nature (See Figure 22).

Modern movement

In the early twentieth century the modern movement became the new style. These architects reacted negatively to the ornamentation of earlier styles. Their simplified designs incorporated and expressed the new technologies that the industrial revolution brought about. Fuller Moore explains in his book, Concepts and Practice of Architectural Daylighting, that architects, "ignoring the climate, used new building technology as an end, directly generating the building form. Because the (building) components were mass produced in a variety of distant locations, and because these architects allowed (even encouraged) the ignoring of the influence of
climate and customs, this international style reflected none of the climate and customs, this international style reflected none of the localized elements characteristic of traditional architecture" (Moore 1985, 14). The forms of the buildings were not related to light, and the effects on the spaces in terms of light were catastrophic. Great amounts of light were allowed to penetrate many spaces regardless of the function (See Figure 23).

Figure 23. View of the Lever House (Crouch 1985, 327)

Architecture today

The field of architecture has become very sophisticated. It is nearly impossible for an architect to understand all of the building systems that are necessary to design a building today. Fuller Moore points out: "Specialists emerged in each technical area, and the architect became
dependent on them during the critical conceptual design phase regarding environmental control. He lost the capacity to evaluate independently the various technical choices in terms of their effect on the overall design" (Moore 1985, 14). One of these areas that the architect lost control of was lighting. Daylighting is viewed as being very mysterious and hard to design with. This is one of the problems in architecture today, architects are disregarding light and its use in the design process. As has been shown, throughout history building form had been directly related to daylight. Why then, do the architects of today refuse to respond to it in their designs? If our ancestors designed with daylight thousands of years ago to help create the form of their buildings, then why can't we do the same thing? Architecture today needs to incorporate the vast technology available with the established historical precedents that have been successful throughout the ages.

This examination of the history of buildings has shown how important light is to building form. Light has successfully been incorporated into the design of buildings throughout history; the architects of today need to realize how important it is to architecture. Light must be considered in the design of all buildings. Building form needs to relate to light and to the architecture. Architects must realize that for thousands of years man has used light in his design, and thousands of years of design cannot be wrong.

Famous Architects' Use of Light

"Much is known about daylighting, yet few claim to have mastered the art" (Lindsey 1983, 27). The few architects who have mastered light, have done so in extraordinary ways. Louis I. Kahn

Louis I. Kahn is very well known in this regard. He had a great knowledge of light and of what light is to man. "We were born of light. We only know the world as it is evoked by light, and from this comes the thought that material is spent light. To me natural light is the only light, because it has mood - it provides a ground of common agreement for man - it puts us in touch
with the eternal. Natural light is the only light that makes architecture architecture" (Myers 1979, 184).

**Le Corbusier**

Another great architect, Le Corbusier, has spoken about the importance of light. "Architecture is the correct and magnificent play of masses brought together in light. Our eyes are made to see forms in light; light and shade reveal these forms..." (Ching 1979, 180). Light is also a crucial aspect of life, as Le Corbusier has said, "Light is the key to well-being" (Sobin 1979, 181).

**Frank Lloyd Wright**

Wright was a master in the use of glass and daylight, always an integral part of his designs. "...the fenestration during Wright's early years was so developed as an integral part of the architectural form both in terms of its interior and exterior that the changing patterns of light naturally became a part of each ensemble" (De Nevi 1979, 188). Wright had very deep feelings about light and its effects on civilization. He said, "The more we desire sun, the more we will desire the freedom of the good ground and the sooner we will learn to understand it. The more we value light, the more securely we will find and keep a worthwhile civilization to set against prevalent abuse and ruin. Because of light, the cave for human dwelling and work, for play and toil, is at last disappearing" (De Nevi 1979, 189).

This has shown the importance of light to the field of architecture. The great masters have a respect for light. They understand it in terms of its physical attributes and its relationship to man. It is definitely a part of architecture that must be thoroughly understood by all designers.

**Light and Art Galleries**

The purpose of this thesis is to show that light is a necessary ingredient in the creation of the form of any type of building. Probably the most important building type with regard to light is the art gallery. This is one reason it was chosen as the building type for the analysis. Art and
light must work together in some sense in order for the viewing of art to occur. These points confirm the art gallery is an excellent example for a building study in terms of light.

**Art galleries as a building type**

Art galleries display some sort of art (painting, sculpture, mosaics, etc.), and in order to view art, light is required. Either artificial or natural light can be used, however, in some extraordinary cases the absence of light is required. But in each of these cases light and building form must always interact.

**Light in gallery spaces**

It is necessary to have a general understanding of light in gallery spaces. "Lighting artwork thus demands compromise: balancing the light needed to protect art and that needed to display it" ("Shedding some light on art" 1984, 105). This statement is the basis for lighting artwork. Art needs light to be seen, but light, as will be shown later, is very destructive to a lot of art. It becomes a game of give and take, balancing the light so that it lights the artwork but does not destroy it becomes a very complex proposition, one that must be handled by an experienced professional.

**Light for an art museum**

Lighting a museum has become complex. It no longer just means specifying the correct fixture. The only suitable solution lies deep in the design state of architecture. The form of the building will determine how light enters the spaces and in turn the way the art work is lighted. "Museum lighting no longer involves just equipment; it has become inseparable from the museum's architectural form. The two must be resolved in concert with conservation. Not an easy task, but then, as lighting consultant Jules Horton says, 'Museum lighting can be as complicated as art itself.'" ("Shedding some light on art." 1984, 107). Perhaps the solution is art; art, light, and architecture together.
This complex problem is often such an overwhelming factor to the architect that instead of
risking large amounts of light entering the space, he or she sometimes goes too far in the opposite
extreme. The architect uses no daylight, a circumstance just as harmful functionally and
aesthetically to museums. As Dr. Wilcomb Washburn, points out in an article, "Natural Light and
the Museum of the Future", "In an age in which it is technically possible to provide more daylight
within a building than ever before, it seems to me a dangerous trend that museums are
progressively walling themselves up in artificially lighted caves..." (Washburn 1965, p. 64).

The solution is not the elimination of natural light nor is it the total use of artificial light.
The answer is probably natural light with artificial light working in close harmony with the
architecture itself, something that is very difficult to achieve. The answer to lighting an art
gallery can only come from an understanding of art and the light needed for displaying it.

Art and exposure to light

It is very important that artwork be well lighted, but it must also be protected from the
harmful qualities that light possesses. To accomplish this an article in Progressive Architecture,
points out, "Most artwork, especially that made of organic materials, will deteriorate under all
but the smallest amounts of light - amounts sometimes too small to adequately see the art"
("Shedding some light on art."). If the architect can just understand the problem, a good
design can be found in the form of the building.

There are three important points to consider when evaluating light's detrimental effects
on artwork: the duration of its exposure, its intensity, and its spectral make-up. The first of the
factors, duration, is extremely important. Many curators regularly rotate their artwork to avoid
very long exposures to light. The second factor, the intensity of the light, is also important. If
artwork is in very bright light all the time, damage can occur. And the third factor is the spectral
make-up of light. "Ultraviolet light causes even greater damage. The short, ultraviolet
wavelengths alter the molecular structure of organic materials" ("Shedding some light on art.").
What is too much light? The Illuminating Engineering Society has provided us with a way of evaluating the light levels in art galleries.

Illuminating Engineering Society lighting recommendations

The Illuminating Engineering Society (I.E.S.) has recommended a light level of 20 footcandles in gallery spaces concerned with detrimental light levels. Light is measured in terms of its intensity, the units used to measure light are either footcandles or lux. One footcandle is equal to 10.7639 lux (Moore 1985, 272). The I.E.S. has given recommended maximum values of illumination for several materials. They recommend 300 lux (27.8 footcandles) for: metal, stone, glass, ceramics, stained glass, jewelry, and enamel. A maximum of 150 lux (13.9 footcandles) for: oil and tempera paint, undyed leather, horn, bone, ivory, wood, and lacquer. Fifty lux (4.6 footcandles) is recommended for: textiles, water-colors, tapestries, prints and drawings, manuscripts, miniatures, painting in distemper, wallpapers, gouache, and dyed leather. These recommendations are given as averages.
OBJECTIVE OF THE STUDY
The Des Moines Art Center As a Case Study

The Des Moines Art Center (DMAC) will be the complex used for this case study. The purpose of this case study is to examine a built project that will provide evidence substantiating the concept that building form should relate to light. The DMAC was used in this analysis for several reasons. First of all, it is an art gallery, which as was presented in the previous chapter is an important building type with regard to light. Secondly, its proximity and the author's personal experience with the DMAC will be essential in analyzing the complex. And finally, the complex consists of three separate portions designed by three different architects, each approaching his design in a completely different manner. This fact will provide an invaluable comparison, since the portions are connected. See Figure 24 for the DMAC site plan.

The first portion of the building was completed in 1948 and was designed by Eelde Saarinen. The exterior wall facing is of Iowa Lannon stone. The floor plan is U-shaped, mostly a single story space. The second addition, designed by I. M. Pei, was finished in 1968. It is basically a two-story rectilinear floor plan and closes in Saarinen's U-shaped courtyard. Pei responded to Saarinen's design by incorporating a stone similar to Lannon stone as the aggregate in the concrete which was used to construct the building. The final design is provided by Richard Meier; the building is clad in white porcelain panels and glass, with granite as a new major element. This most recent addition was completed in 1984, and consists of three separate buildings.

A missing element in the analysis of the three portions of the DMAC is the design objective of each architect. This could be very helpful in analyzing and comparing the three spaces. Unfortunately, this information has not been published or is not available at this time.

DMAC Complex as a Whole

The site plan, in Figure 24, shows the interrelationship of the three designs. Saarinen's portion is very long and horizontal and creates two U-shaped spaces as it winds across the site. The
Pei portion, the southern most, closes in the larger of the two U-shaped area of the Saarinen building to create an outdoor sculpture garden. A reflecting pool is a major portion of the garden. Pei uses this

Figure 24. Site plan Des Moines Art Center ("Richard Meier" 1986, 38)
to reflect light in the northern windows to help supplement the lower levels of light associated with north elevations. And finally the Meier design consists of three parts: the main gallery space located on the northern part of the site and two secondary buildings (a restaurant and a sculpture display area) attached to the western wing of the Saarinen building. This thesis will deal mainly with the main building.

The deliberate siting of the buildings can be seen in the site plan. Each building respects the other's existence; each is carefully placed so that it does not interfere with the essential light that the other buildings need. This corroborates the idea that the form of the site plan owes itself, at least partially, to the lighting requirements of the buildings that created it.

Saarinen's Building

The first part of the complex to be discussed in detail is the original building, designed by Saarinen. Looking at the plan one sees a very simple U-shaped floor plan which seems to create a courtyard very suitable for natural lighting. But Saarinen did not use it for this purpose. Instead of utilizing natural light for the gallery spaces, he chose to light them almost entirely with artificial light. The gallery spaces are created almost entirely by solid walls, for there is a noticeable absence of fenestration in the gallery spaces. See the floor plan in Figure 25. This is a partial floor plan, only the gallery spaces are shown.

The long, horizontal form of the Saarinen building can be seen in the elevations in Figures 26 and 27. The only spaces where fenestration appears in the building are the entries, offices, and support areas. The display areas of the building have very little glass, thereby greatly limiting the amount of daylight that enters the gallery spaces. This lack of daylight can be seen by examining the cross sections in Figures 27 and 28. The cross section of the Saarinen building proves that very little of the design was derived from how daylight enters the gallery spaces. The program for this building simply seems to take the stand that daylight and art should not interact. And the building form responds in this way. As we have seen, Saarinen worked with daylight very little in his design;
therefore it is unnecessary to discuss further how the building form is effected by daylight. The Pel addition, on the other hand, is effected by light.

Figure 25. Saarinen plan (Des Moines Art Center)
Figure 26. Saarinen East elevation (Des Moines Art Center)
Figure 27. Saarinen South elevation/section (Des Moines Art Center)
Figure 28. Saarinen cross section (Des Moines Art Center)
The Pei addition, a very simple design, is a two-story, rectangular building which, differing from the Saarinen design, utilizes daylight almost entirely. Daylight is an essential ingredient in the existence of the Pei addition; the building is a working masterpiece at controlling the light. This is partially accomplished through the form of the building. The Pei addition can be seen in Figure 29.

![Diagram of the Pei addition, south and east sides](image)

**Figure 29.** View of the Pei addition, south and east sides

From the floor plan the first thing that becomes very evident is the application of solid East and West walls, see figure 30. The design result of this is the elimination of the hard-to-control east and west light. The only place Pei has used East and West glass is in the large butterfly-shaped skylight that hangs over the central space and is designed so very little direct sunlight enters the space. This action can be seen in the cross sections in Figures 35 and 36, and in the elevations in
Figures 32 and 34. The southern wall of the skylight along with the butterfly-shaped roof piece are designed to allow very little southern light to enter the space. While the east and west light being low in the sky strikes on the vertical walls of the skylight, reflecting light downward. Therefore, direct sunlight seldom enters the gallery space. There are also two small windows, one on each elevation above the corridors that connect the Pei addition with the rest of the complex. Direct sunlight is stopped in this case by the very deep recesses in which the windows are placed.

The north and south light is controlled through the use of deep recesses in the North and South walls, these act as fins and overhangs that regulate the light. The South wall of the Pei addition consists of very deep recesses and overhangs to stop the high summer and the low winter sunlight. These overhangs or shelves also serve as light reflectors that bounce light very deep into the space. This action can be seen in the cross sections in Figures 35 and 36. The elevation of the South wall can be seen in Figure 31. The design result is a balanced light level throughout the gallery space along with the absence of most of the direct sunlight. This is an excellent condition for an art gallery, and it is carried out through the form of the building.

The North wall is very similar to the South wall in terms of its deep recesses and overhangs. This can be seen in the cross sections in Figures 35 and 36 and in Figures 29 and 33. The deep recesses act as fins which stop the early and late-day, east and west light, from entering the building. The north light which is very good ambient light is reflected into the space by the deep shelves and the reflecting pool, thus creating a very balanced light in the upper level spaces.

Pei has very carefully selected and applied several types of daylighting devices in his design. A skylight is used over the upper gallery space to light the middle areas of his addition. Pei has used openings within a wall plane. These small windows can be seen in the east and west elevations in Figures 32 and 34, are located over the entrances to the addition. Pei incorporates openings next to a wall plane in both the south and north elevations, see Figures 31 and 33. These openings are the long, vertical windows located on the outer edges of the addition. They create lighter interior walls
Figure 30. Pei floor plan (Des Moines Art Center)
Figure 32. Pei West elevation (Des Moines Art Center)
Figure 33. Pei North elevation (Des Moines Art Center)
Figure 34. Pei East elevation (Des Moines Art Center)
which in turn help to light the rest of the space. And finally Pei applies window walls throughout the south and north elevations, the direct sunlight is carefully controlled by the fins and overhangs in the display areas of the addition; while the corridor areas (the non-critical display areas) are left relatively unprotected. Pei has very carefully designed with the different types of daylighting devices and the result is very well lit spaces.

Figure 35. Section of the Pei addition showing summer sunlight (Des Moines Art Center)

Thus, in summary, using controlled north and south fenestration and eliminating the difficult-to-control east/west light, and providing a skylight, Pei has completely controlled the quality and the amount of light that enters the space. It is evident that the form of the building was greatly influenced by the way light was to enter the building and in turn light the interior.
Figure 36. Section of the Pei addition showing winter sunlight (Des Moines Art Center)

Meier's Addition

Meier's design consists of three different portions all connected to the same complex. The main, largest portion will be the only one discussed in detail for the following reasons: first of all, because it is the primary display area of the three portions; secondly, because the three interiors are very similar; and finally because the forms of the three portions are all comparable in terms of light. The main portion of the Meier addition can be seen in Figure 37.

The roof plan in Figure 41, reveals two courtyards that are present for several reasons, one of which is to allow light into the lower levels. From the floor plans in Figures 38–41, it is evident that fenestration has been applied to most of the exterior walls without regard for their orientation. To further complicate matters the openings are not protected from direct sunlight as in the Pei addition.
Figure 37. View of main portion of the Meier addition, north and west sides (Des Moines Art Center)

The second level floor plan shows the application of a ring of glass block over the lower gallery space, allowing diffused light into the lower level. The second level plan (Figure 40) and the roof plan (Figure 41) show a large skylight over the main space and a perimeter glass ring around the roof of the top gallery space. The glass over the main atrium space is left unprotected, allowing a great deal of direct sunlight to enter the spaces at all times of the day. The second level
Figure 38. Meier addition: lower level floor plan (Meier 1984, 360)
Figure 39. Meier addition: first level floor plan (Meier 1984, 360)
Figure 40. Meier addition: second level floor plan (Meier 1984, 360)
Figure 41. Roof plan Meier addition (Meier 1984, 360)
gallery space is given a small amount of protection by the application of fabric light diffusers over the perimeter glass ring. Unfortunately, all of the remaining horizontal glass is left unprotected. The floor plans of the Meier addition reveal lighting strategies that are inconsistent with the information provided earlier in this thesis on proper lighting techniques for gallery spaces.

The elevations of the Meier building are very complex. They appear to be extremely well-thought-out but with further analysis it will be shown that they are poorly designed in terms of light. The design incorporates several techniques for admitting natural light. We have already examined one daylighting device, the skylight, which was discussed in the previous paragraph. All of the elevations employ an opening next to a wall plane several times: specifically, the windows on the far right of the east elevation (Figure 45), the large windows on the upper far right of the south elevation (Figure 42), and the curved window area on the second floor of the west elevation (Figure 43). Corner openings are used on the first and second levels, these can be seen on the far left side of the north elevation (Figure 44), and behind the stairs on the east elevation (Figure 45). The final daylighting device used is the window wall, Meier uses this type in the connection between the Saarinen and Meier building, this can be seen in the far left of the east elevation (Figure 45). It is also used in the curved wall on third floor see the north and west elevations (Figures 44 and 43), and again on the west elevation (Figure 43) in the center.

The elevations show that the types of openings on the four elevations are very similar in design, each type is used repeatedly, many times on different elevations. This creates some lighting problems because each daylighting device produces a specific design result, as was presented in the section on "Daylighting Devices", and when applied to a situation it is not designed for, problems arise. The result in many cases is unwanted direct sunlight and light levels that are much too high for the safe display of art.
Figure 42. South elevation of the Heier addition (Des Moines Art Center)
Figure 43. West elevation of the Meier addition (Des Moines Art Center)
Figure 44. North elevation of the Meier addition (Des Moines Art Center)
Figure 45. East elevation of the Meier addition (Des Moines Art Center)
The cross sections through the Meier addition verify the fact that there is an absence of control; direct sunlight enters spaces from all orientations. This action can be seen in Figures 46 and 47. The Meier addition has unsuccessfully applied many of the daylighting devices that have been discussed in this thesis; when fenestration is used, it is usually left unprotected. The result is environmentally dangerous for the display of art, just the opposite of the Pei addition.

Figure 46. Section through the Meier addition showing summer sunlight (Des Moines Art Center)
Figure 47. Section through the Meier addition showing winter sunlight (Des Moines Art Center)

Pei and Meier Comparison

The comparison of the Pei and Meier portions of the DMAC complex will be based on a previous analysis of each building and the author's personal experience. The form of the Pei addition is greatly influenced by the way the light enters the space. Pei has done an excellent job of controlling the light so that sunlight strikes very few of the interior surfaces. The design helps to eliminate many of the lighting problems associated with direct openings. This researcher questions whether Meier fully considered the effects of light on building form in his design.

In Pei's design the natural environment around the building is visible from almost all points in the building. The space is designed so that the viewer can take advantage of the very important
connection with nature. Meier has provided the gallery spaces with light and a connection with the natural environment too, but he has disregarded the importance of controlling the light which usually comes when allowing the natural surroundings to be seen from the interior. The many problems which result will be elaborated on in the following sections.

Another very important item in the design is Pei's choice of materials. The buff colored concrete has a medium reflectance value that reduces the amount of light that is reflected into the spaces. Conversely, Meier uses highly reflective white walls which increases the amount of light that is reflected into the spaces.

Another important fact concerning the Pei building is that no internal shading devices, such as blinds or curtains, are needed. The control of daylight in the Meier addition is accomplished through fabric light diffusers and anti-ultraviolet absorbing glass which were designed into the building. There is no attempt to control the light by an architectural solution. It must be questioned whether Meier has disregarded the idea of architectural form responding to the lighting needs by responsive design of fenestration or cross sections, or by orientation. The design result is direct sunlight entering many of the gallery spaces. Meier has tried to reduce the amount of light that enters the space by the use of the fabric light diffusers, however, it must be questioned whether the diffusers eliminate enough light. There does not appear to be any logic regarding the placement of the light diffusers; they are applied to many, but not all of the windows throughout the gallery space. The question must be raised whether there is a more efficient method of controlling the light in these spaces.

A comparison of the Meier and Pei elevations reveals the differences in the lighting scenarios of the two buildings. The East and West elevations will be examined first; see Figure 48. Almost every surface in the Meier addition regardless of orientation has fenestrations. In Pei's design the elevations are deliberately designed so the hard-to-control light is stopped as was discussed earlier. The North and South elevations of the two buildings also reveal similar information. These are
compared in Figure 49. The Pei elevations have become glass walls. While the Meier North and South elevations are similar to the Meier East and West elevations. The Meier elevations are left relatively unprotected in terms of allowing sunlight to enter the building, while the Pei elevations are protected through the form of the building, this can be seen in the sections in Figures 35, 36, 45, and 46. By comparing these elevations it is apparent that the designs of these two buildings take very different stands on the approach to light and building form. The Pei building exemplifies the view that the building form should be used to control light, while the Meier design concept does just the opposite.

In summary, Meier has looked towards modern technology for some answers regarding the control of daylight. It is not enough to provide the technology without first understanding the problem. Technology needs to be incorporated with architecture; used alone as an end it is not capable of producing a good environment. The Meier and Pei additions can teach us a great deal about light and building form. Here are two very different buildings, one very complex and one very simple. But yet they both have chosen to use daylight as the major light source for their gallery spaces. It isn’t enough just to let light in; the form must relate to the sun and the architecture; they must work in unison. Fenestration cannot be arbitrarily placed regardless of orientation. The design result of each fenestration must be understood and examined before implemented.

It is not a good practice to consider form, light, and architecture separately. Designed separately these will not work as one. But when considered together a marvelous marriage can occur. Extraordinary things can happen when the form of the building is influenced by light. It must be stressed that for an effective design the form of any building must be considered from other aspects, such as function. But it is a very dangerous thing not to consider light when designing, as can be witnessed from the previous examples. The next section will investigate how serious the lighting problem is in the Meier addition.
Figure 48. East and West elevation comparison between the Meier and Pei additions.
Figure 49. North and South elevation comparison between the Meier and Pei addition.
Personal Experiences

One of the reasons that the DMAC was chosen as the structure to be analyzed in this thesis is because of the author’s personal experiences with the complex. In all of my visits to the DMAC previous to the construction of the Meier addition, I have not once seen any of the fenestrations in the Pet building concealed in order to stop light from entering the space. Unfortunately the same can’t be said for the Meier addition. On numerous occasions I have witnessed several windows completely covered in order to stop the light from entering the space. This can be seen in the photograph in Figure 50. With the many possible items that can be displayed, it is imperative that the design of the art gallery be very flexible. This was stated in the initial program of the Meier addition and Meier’s design should have responded to this. (Lighting Survey 1988, 1). The very presence of a covering over the windows in the Meier addition raises the question whether the form of the Meier design relates to daylight. If it did, would the covered windows be necessary? Proper control of light is the responsibility of both the architect and the client. From the onset, the architect and the client should know that an art gallery is intended to display works of art and that some response to or study of lighting needs must be made.

Design involves a high degree of risks related to the control of light. And the Meier addition has taken many risks, along with these risks some lighting problems have surfaced. This problem has forced the DMAC to examine the lighting conditions of the Meier addition, and implement a solution. The problem as stated by the DMAC: “Natural daylight is the primary light source in the galleries designed by Richard Meier. Daylight cannot be cut off during non-viewing hours and light levels are unacceptably high. Natural daylight is more damaging to objects because it is much richer in violet and blue light than incandescent lighting at the same footcandle measurement. The windows admit light levels of 100-250 footcandles. These high light levels are damaging to works on display, especially contemporary media” (Lighting Survey 1988, 1).
The DMAC is currently examining the problem, and their plan is as follows. "An extensive lighting survey will be undertaken over the course of three seasons to determine the extent of natural daylight levels. It will take into account different times of day. Each (space in the Meier addition) will be evaluated on the basis of a grid system of light readings. A physical model of the Meier..."
building will also be constructed to scale, and will be used for an analysis of natural light under daylight conditions. Various proposed solutions to light reduction will first be tested on this model as a three dimensional laboratory. This offers an advantage of measuring the effects of various light reduction solutions before committing funds to the actual work." (Lighting Survey 1988, 1).
DATA ACQUISITION

There are several ways with which to analyze a space in terms of light quality and quantity. One of the most reliable methods of analyzing spaces is the use of physical lighting models. This idea is substantiated by Harvey Bryan, he writes, "Physical scale models... rely on the physics of light, which suggest that a daylighting model that exactly duplicates a full-scale space, if tested under the same sky, will yield identical results. Although it is not always possible to exactly duplicate a full-scale space, the advantages of using physical scale models significantly outweigh the disadvantages" (Brentrup 1985, 262). For the acquisition of the data required for the study of the DMAC, two physical lighting models of the Pei and Meier additions were constructed.

Modeling provides the architect with several important tools that are required to completely analyze a space. The first of these items is ease of measuring light readings throughout the spaces. To obtain a full picture of the light conditions of a space it is necessary to examine the space at any given time of any particular day. Easy measurement becomes possible only through modeling of the space. Secondly the model allows ease of photographing of the space so that specific lighting scenarios can be examined and compared.

Construction of the Physical Lighting Models

There are several important aspects that need to be examined before the actual construction of the models can begin. First of all, the scale of the model must be determined so that the actual size of the model can be resolved. If it is too large it cannot be easily manipulated to duplicate the lighting of the spaces, and if it is too small photographing the model could prove difficult. The space must also be constructible; if a great amount of detail is required the scale must be large enough to allow for detailed work. And finally the actual measurement of the lighting conditions requires enough space to allow for the placement of certain light measuring equipment along with adequate space for the hand and arm of the person analyzing the space. The next step is to plan the building of the model.
The model must be carefully planned and laid out so that all contingencies are built into the model from the onset. There are several items to be aware of when building models. The space must be built very accurately; this is essential if the conditions in the model are to correctly replicate those in the actual building. This means that the model must be dimensionally the same as the actual space, at a smaller scale. The reflectance of the materials used in the built space must be closely represented in the model; this is important to correctly duplicate the actual light levels in the space. Any important exterior items that could cause the light levels in the space to change must also be constructed, such as landscaping, grass, or a paved space directly outside a window. It is important to plan for camera portals so that all the spaces to be analyzed in the study can be photographed. The materials that the model is constructed of must be opaque so that light is not transmitted through the material into the space. Illustration board is a good opaque material, however care must be taken to sufficiently brace the material so that warping does not occur over time. And finally all exterior joints must be sealed to eliminate undesired light. This can be accomplished through the use of electrical tape and/or aluminum foil.

The scale of the models of the Pei and Meier buildings is $1/2" = 1'-0"$. This was large enough to allow for ease of construction, ease of movement to duplicate the lighting conditions, ease of photographing, and ease of light level measurements. The first step in building the models was to determine the actual size of the models, including any exterior items that must be constructed. The Pei model is roughly five feet wide, six feet long, and two feet high; while the Meier model measures four feet wide, five feet long, and three feet high. For each model the first item to be built was the base. The foundation must be designed so that the models may be manipulated easily but also are very strong. This was accomplished by using simple wood construction. The bases were built of 2x4's and plywood. Two tripods were built so that the models could be manipulated to any desired angle. The next step was to accurately mimic the actual reflectances of the materials used in the actual spaces.
The reflectances of the materials used on the models were determined by the following process. First of all colored samples were created and matched with the actual materials used in the buildings. Then the illuminance of a standard photographic gray card, with a known reflectance value of eighteen percent, was measured with the actual materials and the simulated model materials. With this information and the formula below, the actual reflectances of the materials were found. The formula is: \[ R_b = R_a \times \left( \frac{E_b}{E_a} \right) \]. The symbols mean: \( R_b \) = reflectance of sample b, \( R_a \) reflectance of sample a (gray card), \( E_a \) = illuminance reflected from sample a, and \( E_b \) = illuminance reflected from sample b (Moore 1985, 170). When a close match was found, it was then fine-tuned with the air-brush until the materials appeared the same. Since this is an integral part of the modeling process it was necessary to air-brush all of the pieces in the Pei addition. The bush-hammered concrete walls were simulated by drawing parallel vertical lines on the illustration board with grey colored pencil. The terrazzo floor was duplicated by air-brushing a lighter color on a beige, base-colored piece of illustration board and then the mortar joints were drawn on with brown colored pencil.

Illustration board was also the main material used to build the Meier model. Illustration board was found which was very close in reflectance to the actual space, in this case air-brushing of the materials was not required. The granite areas of the building were simulated with grey "Canson Paper" which was tuck glued to the illustration board. The wooden floors were built of actual birch plywood with an oak stain. This was the best way to represent the actual oak flooring in the Meier space.

The actual construction of the models took place in two sections. The Pei model was the first to be constructed, it was begun in March of 1989, and the construction was completed on September 9, 1989. The construction of the Meier model was begun in August of 1989 and was completed on October 7, 1989. The building of the physical lighting models was carried out in a manner very similar to the way in which the actual construction was accomplished. The base or foundation was the first thing to be constructed. In the Pei model the floor areas were built onto the base, and the solid
east and west walls went up next. The north and south facades were placed onto the model, at the same time the stairs and bridge were built in. And finally the roof beams were built into the model and then they were covered with the actual roof pieces. The Meier model was built in two sections, necessary so that the model can be split in half to work on the interior space. This was not necessary in the Pel model because of the large open space. The large center portion (granite block) was built first, going floor by floor and placing walls as the construction moved up. The large curved main space was then built next to the granite area. The skylight areas were then built into the model. And finally the lower subterranean area was attached to the model. And finally the exterior context was constructed where necessary.

Physical Lighting Model Testing

In order to correctly model the sun at different times of the year a sun angle protractor is required. This is used so that the model can be manipulated to accurately predict where the sun will be at any given time any given month of the year (See Figure 51). Using the chart in Figure 51, the model is manipulated until the shadow from the peg is cast and lines up with a specific time of the day on a specific month. Care must be taken not to tilt the model too far from horizontal; when this occurs the light readings may be altered due to reflectances from the sky and the landscape around the model. The light readings can then be taken, and the spaces can be photographed. The hours of the day and the times of the year to be analyzed are very important. The first time of the year is December 21, the winter solstice, when the sun is in its lowest position. The second time is September and March 21, the solar equinox. And the final time of the year to be represented is June 21, the summer solstice, the time when the sun is at its highest position. On each of these days certain times have been chosen that will give a good representation of what the light quality would be like throughout the day. The exact hours to be tested are as follows: 10:00 A.M., 12:00 P.M., 2:00 P.M., and 4:00 P.M., whenever possible. The testing of the Pel model occurred on September 10, 1989. The Meier model
was tested on October 8, 1989. The testing of each model takes several hours to complete. The set-up and dismantling of the model laboratory takes about an hour to an hour-and-a-half. The rest of the analysis, the measuring and recording of the light readings, and the photographing of the spaces, takes about four hours for each model.

A photographic record is necessary for a comparative analysis of the two buildings. The analysis will be studied first in general sense to obtain an overview of each space; then specific times and months will be compared. This comparison will be valuable in terms of studying and presenting the quality of light that enters the spaces. The photographs were taken with a manual 35 mm camera, using a 28 mm wide angle lens to simulate interior viewing conditions as the eye sees them. The film was Kodak 400, providing a realistic color rendering. This process provides accurate information regarding actual light penetration, but does not correctly represent actual light quality in all cases.

The final item that will be analyzed is the actual light readings in the spaces at the different times of the year. This is necessary for the comparison of the general light conditions of the two spaces. The results will be presented in terms of light sections and comparative charts which will illustrate the overall light levels throughout the two buildings. Through the comparison of the photographs of the Pei and Meier spaces and the light sections, a direct relationship between light and building form will be developed.
Figure 51. Sun angle protractor (Moore 1985, 223)
PRESENTATION OF RESULTS

The results from the testing are very informative. Several important things can be seen from both the slides and light charts and sections of the two models. The first step is to examine the slides of the Pei and Meier spaces. The Pei and Meier additions are shown several times throughout the year. Upon examination of the slides of the Pei space it is evident that during most of the times tested the space has very little direct sunlight striking the interior surfaces. The areas where direct sunlight strikes surfaces are briefly identified in the chart in Figure 52. The small amount of sunlight that does penetrate into the space usually forms large, single, continuous shapes. The continuous shapes help to reduce the amount of contrast by reducing the number of times the eye is forced to jump back and forth from light to dark. This in turn reduces the amount of discomfort that a viewer might encounter.

The photographic record of the Meier addition shows that the majority of the times tested there are great amounts of direct sunlight entering many of the spaces. The areas where direct sunlight strikes surfaces are identified in the chart in Figure 53. The pattern of the sunlight in the Meier addition differs from that of the sunlight in the Pei addition in that it does not form single continuous shapes, but is broken into several pieces or patterns. This is due to the larger quantity of openings and the large number of glazing bars on several of the windows and skylights. This may have been designed due to the design objectives for the Meier addition.

The basic light characteristics of the Meier and Pei additions have been described in the previous paragraphs. It is apparent from the slides and the light charts that the two additions have very different lighting strategies. The lighting conditions present in the two additions will be more specifically examined by means of actual light levels, by comparing the two additions at the same time of the day and year, in the next section.
<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>UPPER LEVEL</th>
<th>LOWER LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>September/March 21</td>
<td>10 A.M.</td>
<td>No direct sunlight</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>12 P.M.</td>
<td>Floor</td>
<td>No direct sunlight</td>
</tr>
<tr>
<td></td>
<td>2 P.M.</td>
<td>No direct sunlight</td>
<td>No direct sunlight</td>
</tr>
<tr>
<td></td>
<td>4 P.M.</td>
<td>No direct sunlight</td>
<td>Floor</td>
</tr>
<tr>
<td>June 21</td>
<td>10 A.M.</td>
<td>No direct sunlight</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>12 P.M.</td>
<td>No direct sunlight</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>2 P.M.</td>
<td>No direct sunlight</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>4 P.M.</td>
<td>No direct sunlight</td>
<td>Floor</td>
</tr>
<tr>
<td>December 21</td>
<td>10 A.M.</td>
<td>Floor, back wall, west wall</td>
<td>No direct sunlight</td>
</tr>
<tr>
<td>(4:00 P.M. not available)</td>
<td>12 P.M.</td>
<td>Floor, back wall</td>
<td>No direct sunlight</td>
</tr>
<tr>
<td></td>
<td>2 P.M.</td>
<td>Floor, back wall, east wall</td>
<td>No direct sunlight</td>
</tr>
</tbody>
</table>

Figure 52. Chart describes areas where direct sunlight strikes surfaces
**MEIER LIGHT ANALYSIS**

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>MAIN SPACE</th>
<th>LOWER LEVEL</th>
<th>GROUND LEVEL</th>
<th>MONITOR WALL</th>
<th>UPPER LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>September/March 21</td>
<td>10 A.M.</td>
<td>All walls Curved stairs Floor</td>
<td>Walls Floor</td>
<td>Floor</td>
<td>Curved wall Floor</td>
<td>Floor West wall</td>
</tr>
<tr>
<td></td>
<td>12 P.M.</td>
<td>All walls Curved stairs Floor</td>
<td>Floor</td>
<td>Floor</td>
<td>No direct sunlight</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>2 P.M.</td>
<td>All walls Curved stairs</td>
<td>Floor</td>
<td>No direct sunlight</td>
<td>Curved wall Floor</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>4 P.M.</td>
<td>Curved wall Curved stairs</td>
<td>Walls Floor</td>
<td>No direct sunlight</td>
<td>Floor</td>
<td>Floor</td>
</tr>
<tr>
<td>JUne 21</td>
<td>10 A.M.</td>
<td>All walls Curved stairs Floor</td>
<td>Walls Floor</td>
<td>Floor</td>
<td>Curved wall Floor</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>12 P.M.</td>
<td>All walls Curved stairs Floor</td>
<td>Floor</td>
<td>No direct sunlight</td>
<td>No direct sunlight</td>
<td>Floor East wall</td>
</tr>
<tr>
<td></td>
<td>2 P.M.</td>
<td>All walls Curved stairs Floor</td>
<td>Floor</td>
<td>No direct sunlight</td>
<td>No direct sunlight</td>
<td>Floor East wall</td>
</tr>
<tr>
<td></td>
<td>4 P.M.</td>
<td>Curved wall Curved stairs</td>
<td>Floor</td>
<td>No direct sunlight</td>
<td>Floor</td>
<td>Floor East wall</td>
</tr>
<tr>
<td>December 21 (4:00 P.M. not available)</td>
<td>10 A.M.</td>
<td>All walls Curved stairs Floor</td>
<td>Walls Floor</td>
<td>Floor</td>
<td>Curved wall Floor</td>
<td>Floor West wall</td>
</tr>
<tr>
<td></td>
<td>12 P.M.</td>
<td>All walls Curved stairs</td>
<td>Floor</td>
<td>Floor</td>
<td>Curved wall</td>
<td>Floor</td>
</tr>
<tr>
<td></td>
<td>2 P.M.</td>
<td>Curved wall North wall</td>
<td>Walls Floor</td>
<td>No direct sunlight</td>
<td>No direct sunlight</td>
<td>Floor East wall</td>
</tr>
</tbody>
</table>

*Figure 53. Chart describes areas where direct sunlight strikes surfaces*
The second matter to be discussed is the actual light levels in the Pei and Meier additions. These will be analyzed in terms of actual footcandles, the results will be presented via light sections and comparative charts. A photometer was used to measure the actual light levels in the models at the different times measured. The photometer used was cosine-corrected and color-corrected, important in order to obtain correct light level readings. A grid system was applied to the floors in order to determine a constant point in each model for the measurement to take place. The actual light levels in the two portions are shown in Figures 54 and 55. It must be stressed that these light measurements were taken in order to obtain a comparison of the conditions present in the two spaces. The light levels have not been altered to represent changes in the light intensity due to seasonal changes in the sky. Therefore, the light levels may not represent actual light levels in the model throughout the year.

The measurements were taken by placing the photometer into the model and taking a measurement at a level of four feet above the floor. This was done to acquire average light readings throughout the space.
## PEI LIGHT READINGS

Note: All light readings are in footcandles

<table>
<thead>
<tr>
<th>DATE</th>
<th>AREA</th>
<th>10 A.M.</th>
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<th>2 P.M.</th>
<th>4 P.M.</th>
<th>AVG.</th>
</tr>
</thead>
<tbody>
<tr>
<td>September/March 21</td>
<td>L.L. West</td>
<td>14</td>
<td>19</td>
<td>10</td>
<td>7</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>L.L. Middle</td>
<td>15</td>
<td>20</td>
<td>10</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>L.L. East</td>
<td>11</td>
<td>55</td>
<td>10</td>
<td>7</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td>U.L. West</td>
<td>10</td>
<td>14</td>
<td>10</td>
<td>6</td>
<td>10</td>
</tr>
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<td>12</td>
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</tr>
<tr>
<td></td>
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<td>17.8</td>
<td>10.6</td>
<td>16.3</td>
</tr>
<tr>
<td>June 21</td>
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<td>10</td>
<td>10</td>
<td>6</td>
<td>7.5</td>
</tr>
<tr>
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<td>8</td>
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<td>11</td>
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</tr>
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<td></td>
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<td>12.3</td>
<td>13</td>
<td>10.8</td>
<td>11.8</td>
</tr>
<tr>
<td>December 21</td>
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<td>57</td>
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<td>N.A.</td>
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</tr>
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<td>38</td>
<td>21</td>
<td>N.A.</td>
<td>26.3</td>
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<tr>
<td></td>
<td>L.L. East</td>
<td>30</td>
<td>70</td>
<td>19</td>
<td>N.A.</td>
<td>39.7</td>
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<tr>
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<td>16</td>
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<td>27</td>
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<td></td>
<td>Average</td>
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<td>40.3</td>
<td>15.5</td>
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<tr>
<td>Total Avg</td>
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<td>25.1</td>
<td>14.3</td>
<td>10.8</td>
<td>16.7</td>
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</table>

Figure 54. Chart showing light levels in the Pei addition
### MEIER LIGHT READINGS

**Note:** All light readings are in footcandles

<table>
<thead>
<tr>
<th>DATE</th>
<th>AREA</th>
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<th>12 P.M</th>
<th>2 P.M.</th>
<th>4 P.M.</th>
<th>AVG.</th>
</tr>
</thead>
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<td>23</td>
<td>27</td>
<td>21</td>
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<tr>
<td></td>
<td>Ground</td>
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<td>11</td>
<td>10</td>
<td>6</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>Ground back</td>
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<td>6</td>
<td>9</td>
<td>7</td>
<td>7</td>
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<tr>
<td></td>
<td>Main space</td>
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<td>75</td>
<td>38</td>
<td>19</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>Monitor wall</td>
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<td>25</td>
<td>20</td>
<td>30</td>
<td>26.3</td>
</tr>
<tr>
<td></td>
<td>Second level</td>
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<td>16</td>
<td>25</td>
<td>18</td>
<td>26.5</td>
</tr>
<tr>
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<td>Third level</td>
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<td>70</td>
<td>60</td>
<td>45</td>
<td>59.3</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>30.8</td>
<td>32.3</td>
<td>27.0</td>
<td>20.9</td>
<td>28.7</td>
</tr>
<tr>
<td>June 21</td>
<td>Sub-level</td>
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<td>26</td>
<td>30.3</td>
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<tr>
<td></td>
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<td>16</td>
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<td>10</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Ground back</td>
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<td>32.4</td>
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**Figure 55.** Chart showing light levels in the Meier addition
Comparing the levels of light in the two additions it is evident that those in the Pei addition are much lower then those in the Meier addition, see Figures 56, 57, and 58. The highest level found in the Meier addition is 250 footcandles, a level over three times higher than the highest level in the Pei addition, a level that is very dangerous for the display of certain types of artwork. The average level in the Pei addition is seventeen footcandles, an acceptable average level for displaying artwork based on the recommendations from the I. E. S. The I. E. S. has recommended a level of twenty footcandles in gallery spaces designed to avoid detrimental light levels. The average level in the Meier addition is 32.4 footcandles, a level much too high, based on I. E. S. standards.

The comparison of the light levels in the spaces in Figures 56, 57, and 58 confirms that the light levels in the Meier addition are much higher then the levels in the Pei addition, and more importantly are higher then the levels set by the I. E. S. in all but one of the times tested. On the

**LIGHT LEVEL COMPARISON OF THE PEI AND MEIER ADDITIONS**

![Bar chart showing light level comparison](image)

Figure 56. Light level comparison for September/March 21
Light sections are basic building cross sections with the light levels superimposed over the actual sections, creating a method of viewing the quality of light in the building. The light sections of the Pei and Meier buildings allow a comparison of the two spaces in terms of balanced light. See Figures 59-62.

On the other hand, the light levels in the Pei addition are lower than the average I.E.S. levels in all but three of the times tested. The higher levels are partially due to the form of the buildings. The form of the Pei addition does respond to light and the light readings corroborate this idea. However, in the Meier case, the question again must be raised whether the form of the building responds to light.

The light sections in Figures 59-62 illustrate the light levels present in the two additions at the different times of the year and show the light quality in each space. The light levels in each area of the Meier addition are very diversified. While the section of the Pei addition illustrates a very even

![Light Level Comparison Graph]

Figure 57. Light level comparison for June 21
light level throughout the space. These two different approaches may be due to the design objectives of the individual architects.

The results of the photographic record and the light levels have been compared and analyzed, the question has been raised whether the form of the Meier addition does not respond to light while the Pei addition does. It has been shown through the light sections that the majority of the glass in the Pei addition is protected from direct sunlight through the form of the building. The same cannot be said of the Meier addition. And the light levels substantiated these findings. However one would expect a much larger amount of glass area in the Meier addition and a smaller glass area in the Pei addition. A comparison of the glass areas of the two additions can be seen in Figure 63.

**LIGHT LEVEL COMPARISON OF THE PEI AND MEIER ADDITIONS**

![Graph showing light level comparison for December 21](image)

Figure 58. Light level comparison for December 21
Figure 60. Meier addition light section at lower level.

([Diagram of Meier addition light section at lower level])
Figure 61. Meier addition light section at first level
As was expected the glass area of the Meier addition is greater than the glass area in the Pei addition. The total glass area in the Meier addition is approximately 3244 sq. ft., while the glass area in the Pei addition is 2539 sq. ft. The Meier addition has only twenty-two percent more glass area. A greater amount of glass area in the Meier addition is not enough to account for the much higher light levels in the Meier addition. Therefore it is most probable that the higher levels are indeed due to the forms of the buildings and their reflectances. It must also be presented that the total glass areas of the elevations of the two buildings is inverse to the total amount of building glass area. The amount of glass on the Pei elevations is approximately 2307 sq. ft., while the glass area of the Meier elevations is 1893 sq. ft. The Pei elevations have approximately seventeen percent more glass area than the Meier addition elevations. One would expect from these findings that the light levels in the Pei

**Comparison of Glass Area of the Pei and Meier Additions**

![Chart showing comparison of glass area for the Pei and Meier additions](image)

Figure 63. Chart showing comparison of glass area for the Pei and Meier additions
addition would be higher then the levels in the Meier addition. However, as was presented previously, this is not the case; the light levels are lower in the Pei addition because of the form of the building and the lower reflectances in the structure. The higher levels in the Meier addition are probably due to the form of the building not responding to light and the higher reflectance.
SUMMARY AND CONCLUSION

The information presented in the first seven chapters of this thesis presents the information needed to substantiate a definite connection between light and building design, form being an important part of the design. The history of light and building form has been shown to be a very important part of architecture. This fact, along with the many quotations and evidence presented from authorities in this area show that a design connection between light and building form is necessary. The need for this connection is particularly true of the art gallery, and the Des Moines Art Center is no exception.

The evidence that has been presented for the analysis of the DMAC is as follows: elevations, plans, light sections, comparative charts, photographic records, and the light levels of the two additions. This information gives us the facts necessary to demonstrate the necessity for a connection between light and building form. The results of the analysis show that the form of the Pei addition responds to light effectively to meet recognized standards of quantity for the display of art work while the form of the Meier addition does not.

Architecture and light have been working together for thousands of years, and this thesis will not change the architecture that has been built. It does however accomplish some important goals; these goals will aid the field of architecture and all designers. First of all, in the professional world of architectural design there is not enough time nor money to work out extensive lighting solutions for all buildings; there are too many other complex issues in today’s practice. However, this lack of time and money does not mean that light can be totally disregarded. Light should be constantly thought about during the design process. The design need not be totally dependent upon light as long as the basic ideas of light and building form are applied. Light does not need to be the total determiner of a space, just one important one.

Secondly, I believe this thesis will help all of us, when designing, to remember the great importance of light to space. It has been shown through several examples and many quotations of
famous architects, that light is indeed a major part of architecture. Light has been important throughout history; it should not change now. Light and architecture must remain working partners in order to create a workable living architecture.

And finally, I have learned and grown a great deal from this experience. Light is a very difficult entity to master and its connection with architecture is extremely important. Once the basic lighting strategies are applied to a project, even in the smallest of ways, the architecture will greatly benefit. Natural light is one of the few completely free things left for man to use. Light will always be prevalent in our lives; we must use it to our advantage and allow our architecture to forever blossom from its benefits.
BIBLIOGRAPHY


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