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Use of the case study method to provide initial design strategies for daylighting as a primary design determinant in earth-integrated structures

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USE OF THE CASE STUDY METHOD TO PROVIDE INITIAL DESIGN STRATEGIES FOR DAYLIGHTING AS A PRIMARY DESIGN DETERMINANT IN EARTH INTEGRATED STRUCTURES

by

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Dean of the Graduate College

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Graduate College Faculty Representative

ABSTRACT

Use of the Case Study Method to Provide Initial Design Strategies For Daylighting as a Primary Design Determinant in Earth Integrated Struictures

by

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Daylight, a natural energy source in the form of electromagnetic radiation, has been one medium by which one defined and perceived architectural space and form. That was why the creative use of daylight was and continues to be so important in the development of any built environment, especially those which have been integrated into their sites.

This study has explored the possibilities of using natural daylight as a primary design determinate to enhance the interior environment of selected earth integrated architectural works. Four commercial institutional projects of various sizes were investigated as case studies to provide insight on the effectiveness of daylighting techniques in these facilities, and further , to provide an analytical method that could be adopted by a designer in the initial stages of a project to conceptualize an appropriate daylighting design.

This study had three distinctive objectives.

(1) To examine techniques presently used to allow natural light to penetrate into a building's interior environment and how these techniques were applied to buildings that had been placed below grade. Four large commercial and institutional environments that were placed below grade and used daylight as a means of lighting their interior spaces were investigated for their characteristics.

(2) To examine the techniques found in the literature search as a means to develop an set of delighting strategies for initial design concepts of earth integrated facilities.

(3) To suggest how these findings provided an approach that designers could utilize conceptualizing the potential advantages of natural daylight during the preliminary stages of designing earth integrated buildings.

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ACKNOWLEDGMENTS

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At times it did not seem to be worth the effort but with your support I reached my goal and I sincerely thank you for being there helping me along the way.

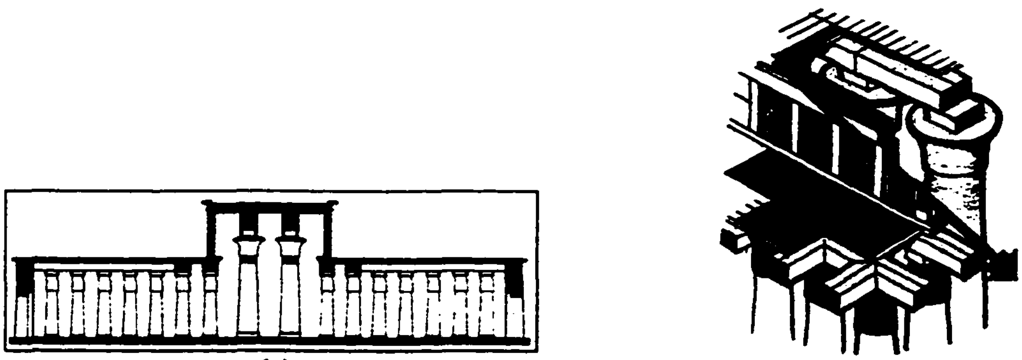
CHAPTER 1

INTRODUCTION

Historical use of daylight

The concept of using natural light to illuminate the interior spaces in a structure (daylighting) is not new. The concept of daylighting can be seen throughout history. From the creation of time, the sun has provided the primary source of light that could be used and manipulated in many ways to provide both light and heat. Any opening that allowed daylight to penetrate into an otherwise dark area has been identified as natural daylighting. A good example of the early use of natural light as a source of illumination for interior spaces in a structures was in the great Hypostyle Hall at Karnak in Egypt 1312 B.C.. Incorporated within this hall was the simple idea of controlling natural daylight by means of a clerestory. It was accomplished by designing the central axial path with larger columns creating a difference in height between the central axial path and the two adjacent colonnaded side halls. The openings left by the difference in roof heights created by the different sized colonnades were then covered by stone grills that provided protected openings that allowed beams of light to be projected into the dark interior of the temple (Figure 1 Kurtich & Eakin 1993, 180).

In Ancient Greece examples of early daylighting techniques were found in the form of light shafts and large screening colonnades on the east and south facades of their temples. They also used the building's orientation to gather the sun's energy throughout the day. Atrium spaces and skylights brought natural light and ventilation into buildings in early Roman settlements. Examples of these techniques can still be seen at Bulla Regia in present-day northern Tunisia, the restored houses in Pompeii and Herculaneum in 200 B.C. and the Pantheon in Rome in 120 A.D. (Figure 2 Kurtich & Eakin 1993, 183).



(a) (b)

Figure 1 Great Temple of Ammon, Karnak, 1312 B.C.: (a) Section through Hypostyle Hall (b) Clerestory lighting detail. (Moore 1991). Source: Concepts and Practice of Architectural Daylighting, 1991, pg. 4

Figure 2 Underground atrium dwelling built by the Romans at Bulla Regia, present day Northern Tunisia. Source: Earth Sheltered Housing Design, 1985, pg.12

Prior to the industrial revolution the building envelope was the principal mediator between exterior and interior environmental conditions. This remained the case and for this investigation, but with modern technology the interior environment had become less dependent on the building's envelope. Prior to the great technological advances which occurred during the industrial revolution, the primary source of illumination was daylight as determined by climate, window size, and placement. Supplemental lighting was provided by candles and oil lamps. The industrial revolution ushered in a new era of technological advancements in electrical lighting with the invention of incandescent lamps and mechanical heating and cooling systems that were easier to control and manipulate. As a result, architects could choose to design buildings that relied on mechanical means rather than natural means to control the building's interior lighting environments.

The energy crisis in the early 70's caused architects to realize how dependent they had become on mechanical means to control the building's interior lighting environment. The rise in cost of supplementary energy caused architects to seek more energy efficient designs. This movement lead many professionals to rediscover the benefits of daylighting and solar energy as a means of lighting and heating a building's interior spaces in order to reduce the amount of supplementary energy used.

One new and innovative energy efficient design that was explored and developed during this period incorporated the use of the earth itself as one of the primary building elements in areas where temperature swings were large. This type of design, where the building was integrated into the site rather than merely being placed on the surface of the

site, resulted in a significant energy savings, prevented environmental damage from above ground structures, and preserved valuable open space (Dean, 1978, 34)

Earth integrated architecture, developed during this period, with its many benefits, had one inherent problem with respect to humans. By integrating a building into its site one limited the availability of natural light that reached the interior spaces of a building through apertures in walls. By restricting the amount of natural light that reached the interior of a building, one reduced the psychological and physiological benefit of a visual connection to the outside environment. This problem was examined by comparing various design techniques used to gain the benefits of natural daylight. Further, an analysis of how these daylighting techniques enhanced the interior spaces of buildings that were integrated into their site and how they had relieved the apprehension associated with underground spaces.

Statement of Purpose

It was the purpose of this study to investigate and evaluate the daylighting principles in the use of natural daylight as a primary design element in earth integrated structures to illuminate and enhance interior environments of these types of buildings.

Research into investigations of earth integrated design and related studies of daylighting was conducted to gain knowledge of new innovative earth integrated design techniques that have been used in conjunction with daylighting techniques to develop design strategies that took advantage of the qualities of earth integrated architecture. These include low visual impact, ecological preservation, and energy efficiency combined with the enhancing optical and perceptual qualities of natural daylight.

This investigation evaluated and determined the benefits and disadvantages of combining these techniques in the development of typical commercial and office buildings found in the Midwestern and Western regions of the United States.

Problems Associated with Earth Integrated Space

Author Andre O. Dean (1978) suggested that subconscious fears of being underground together with the frequent connotation of earth integrated space as inferior, utilitarian, and secondary in quality were major deterrents to accepting this type of construction and utilizing the considerable potential benefits of earth integrated architecture. The most often mentioned negative characteristic of underground space was the lack of natural light. The feelings associated with adequate natural light, its variability, and the subsequent psychological benefits it provided made it a very desirable element in any building structure (Carmondy 1983, 46).

The inherent problem with integrating any structure into its site was that it limited the usable area in which glazing was placed and the amount of glazing allocated for natural light and exterior views. This provided the parameters for the problem to investigate and determine if any principles or guidelines could be established solely from case study analysis to conceptualize appropriate daylighting for earth integrated structures. Therefore the hypothesis developed for this study was:

Could an analysis of four case studies generate sufficient data to provide realistic parameters for a designer, in the initial stages of the design process, to conceptualize appropriate daylight design for earth integrated institutional buildings?

Limitations

This study was limited to an investigation of the principles and techniques used to provide natural illumination for four institutional facilities that were integrated into their respective sites. It concentrated on the techniques that were utilized in the design of these facilities to provide natural illumination in their interiors and how these techniques were implemented to enhance the interior lighting environment. The technical aspects of lighting levels and mathematical calculations of those lighting levels have been estimated and documented when possible. However, it was not the investigator's intention to adopt these lighting levels as a formula to determine adequate interior lighting for other proposed buildings because the lighting levels were estimated at the time of day when the amount of annual available daylight was at its peak. Lighting levels achieved at different times throughout the year would be best analyzed for specific on site conditions and were beyond the scope of this study. The conclusions reached relating to daylighting standards were based on this investigation and the collective opinions of other professionals in the field of daylighting.

CHAPTER 2

REVIEW OF LITERATURE

Light and Human Visual Perception

Authors Kurtich & Eakin (1993) stated that light as we perceive it was one if not the most important components in the definition of space or the manifestation of form. Without natural light there would be no perceived visual space . Visible light is natural energy in the form of electromagnetic waves which travel through space at a frequency between 380 and 760 nanometers. Visible light's physical characteristics was defined in terms as follows:

- Illuminance
- Luminance

Illuminance and luminance were terms that corresponded to the quantities of light according to human visual response. Illuminance was a result of the amount of light striking a surface of an object. It was measured in footcandles or lux. The term footcandles was defined as the amount of light on a surface one foot or meter away from a standard candle. However, the human eye does not perceive light with regard to footcandles. The human eye perceives only the resulting luminance of a surface.

Luminance was a term used to describe the objective, physical attributes of brightness of the sky or a surface of an object and was a product of illuminance. The luminance of an object was defined as light being transmitted or reflected from any surface measured from a specific direction (i.e. English unit: footlambert. Metric unit: Candela per square meter) (Lam 1992, 8). Brightness, which was closely related to luminance, referred to the subjective visual sensation perceived by the human eye. Brightness was a function of the amount of light received at the eye and should not to be confused with luminance, the actual amount of light reflected from a surface in a given direction (Robbins 1986, 21). Glare was characterized on the basis of the effects it had on the observer as well as on the path the light.

Discomfort glare was defined as a annoying and sometimes painful sensation caused by extremely high levels of luminance or a non-uniform distribution of light in the field of view. This type of glare resulted from bright sources within the field of view that were not inherently distressing, but were seen in much darker surroundings. Disability glare, by contrast was caused from areas within the field of vision of such brilliance that it produced a scattering of light within the human eye. This reduced visual contrast to such a degree that seeing was reduced.(Moore 1991, 28).

Sources of glare were categorized on the basis of how they reached the eye. Glare produced by sources that were directly in the field of view were known as direct glare. The reflected image of the light source off a glossy surface also produced glare known as reflected glare. These sources of glare produced discomforting or disabling effects to an individual within that environment. Glare was an extremely important

consideration in the design of any daylighting system because of the impact it had on visual comfort.

Daylight as we perceived it came from one source, the sun. The sun was identified as an extended light source characterized by emitting parallel rays of light as opposed to rays diverging away from it. In the field of daylighting the source of natural light was broken into two main categories of illumination. The first category consisted of direct sunlight or diffused sky light illumination. Direct sunlight, considered to be a point source, had the capability of illuminating a horizontal surface with 6,000-12,000 footcandles and therefore was too intense for use as a source of task lighting. Illuminating engineers in the past excluded the use of direct sunlight even though the characteristics of natural light, including the vitality and sparkle associated with the use of sunlight added considerably to the visual variety and excitement of a space (Moore 1991, 30).

Direct sunlight was often considered undesirable for illumination purposes due in part to the solar gain and glare associated with it even though it has been proven that the use of direct sunlight introduced less heat into a building than most electrical alternatives while it provided the same amount of light (Moore 1991, 30). The other component in this category consisted of diffuse skylight, which resulted from the refraction and reflection of sunlight as it passes through the atmosphere. Diffuse skylight was considered to have been a distributed light source and was characterized as a soft, non directional, relatively shadow-free source of illumination (Moore 1991, 32).

The second category was referenced as an indirect light source. This was used to describe reflective surfaces that had been directly illuminated by direct sunlight or

diffused skylight and thus become a source of illumination. Because such a surface was illuminated by direct sunlight or from a diffused skylight, the surface took on the same characteristics of direct sunlight and therefore the quality and distribution of its light was virtually identical to direct sunlight emitted through a similar sized aperture. The resulting illumination produced by the reflective surface was determined by the reflectivity of the surface being illuminated by direct sunlight or from a diffused skylight.

Many of the approaches used in the field of daylighting today relied upon reflected light as a source of natural illumination. It was very important to consider how light reacted to certain building materials and how the texture and color of the material produced different effects when illuminated by a light source. Reflected surface illuminance (footlambert) was a function of the illuminance of a surface as well as the surface reflectance (Moore 1991, 21). Therefore, the reflection of light was divided into four categories:

- Specular
- Spread
- Diffused
- Combination

Specular reflections were produced from material with a highly polished surface such as a mirror or polished marble. This type of reflection was characterized by light reflected in one direction only. Spread reflections were similar to specular reflections, but due to small surface imperfections, a softer, more diffused reflection occurs. Diffuse reflections were also produced by materials with a flat or matte finish and were characterized by light reflected in every direction equally (Lam 1986, 52).

Since real surfaces reflected light unequally in different directions, the reflectance of a surface was dependent on the angle of incidence and the surface's diffusion characteristics (Moore 1991, 21). In this study interior building reflective finishes were categorized by the following terms:

- Rough
- Smooth
- Glossy
- Matte

The terms rough and smooth were used to categorize the type of finish material while the terms glossy and matte were used to categorize the leading surface of the material. A list of the most common reflectance of building material has been provided in appendix B.

Fundamentals of Daylighting

Daylight was justified as a light source for most buildings for several reasons. and some of the more important reasons follows:

- The Quality of natural light (i.e. color, intensity, contrast) Daylighting could provide visual communication channel to the exterior environment
- Energy conservation can result from the use of daylight as a primary or secondary source of illumination
- Certain psychological and physiological benefits could be provided that were not obtained with electric lighting or windowless buildings, such as: Visual stimulation,

health benefits enhanced by natural light, and color rendition associated with clarity of vision.

Natural daylight was considered a full spectrum light source and was a vital component in the evolution of the human visual response (Robbins 1986, 4). Since the evolution of the human eye was so closely linked to natural light, it became the basis from which all other light sources were compared. For this reason, natural daylight was expected to be incorporated into every building type where people work for extended periods of time.

Author Marguerrite Villecco (1979) believed that good daylighting design did not simply mean large windows but had to be approached both quantitatively and qualitatively on broader and more sensitive design terms. The concept of daylighting a building was directly related to the form, structure, and materials used in its construction and therefore, it should not have to be added to the building's design at a later time. The daylighting concept should was best considered as an integral part of the programming for the building's interior spaces and the aesthetics of its exterior. Many factors affected the decisions to whether or not to incorporate the use of natural light to help illuminate a building's interior. Villecco suggested some of the environmental factors that affected such a decision and were summarized as:

- Variations in the amount and source of daylight caused by the position and intensity of sunlight
- The luminance and luminance distribution of clear, partly cloudy, and overcast skies
- The affects of the local terrain, landscaping, and nearby buildings
- Climate and weather

According to author Claude Robbins (1986) other factors that affected the conceptual use of daylighting deal with the actual daylighting system design. These factors were:

- Daylight apertures (i.e. type, size, and placement)
- Glazing media
- Shading and sun controls other than glazing materials
- Electrical lighting

A careful analysis of these factors could lead to the development of daylighting concepts. These were comprised of specifying daylighting apertures necessary to provide the desired distribution of daylight in a room or a building. These concepts were grouped into seven categories (Robbins 1986, 63):

- Sidelighting
- Roof or toplighting
- Angled lighting
- Beam lighting
- Indirect lighting
- Atria lighting
- Combinations of the above

The use of these concepts required the building's envelope to be manipulated to allow daylight to reach the interior of the building (Robbins 1986, 63). Sidelighting was the most familiar approach to daylight design. Sidelighting concepts took advantage of both direct sunlight and sunlight being reflected from the ground or adjacent structures. Three distinct strategies of side lighting were developed by the 1940s - 50s. These strategies, which consisted of unilateral, bilateral, and trilateral lighting, have remained

relatively unchanged (Figure 3 Villecco 1979, 68). The positive characteristics of these type of systems included the strong directionality of the light and their capacity to provide primary lighting on two dimensional horizontal and vertical surfaces. These systems also had negative characteristics which included the capacity to cause blinding glare and high contrast in spaces which can affect visual comfort for many users. Sidelighting concepts involved view and non-view apertures more commonly known as windows and clerestories.

In earth integrated architecture, the application of sidelighting concepts was limited by the depth of earth integration. Sidelighting concepts were most appropriate in buildings that were located in cut-and cover earth integrated space. These techniques were most often used in conjunction with other methods used to expose portions of the structure to daylight. These techniques frequently incorporated atrium spaces, light wells, light courts, and courtyards, which are all viable methods of exposing a structure that has been integrated into its site. Sidelighting concepts were implemented into the interiors of earth integrated structures to bring natural illumination into spaces that would otherwise not receive daylight.

By placing windows in spaces adjacent to areas that were naturally illuminated by daylight allowed these spaces to borrow daylight from the adjoining daylit space. If special care was taken to protect against glare, sidelighting concepts become a strong device to bring daylight into earth integrated space.

Toplighting allowed daylight to penetrate a space from apertures that were located above the ceiling line and usually were incorporated into the roof structure. Toplighting involved different architectural treatments that affected the building's

exterior form and interior design. Toplighting concepts were used to increase the depth of penetration of sidelighting apertures. However, these concepts were also used most often in cases where sidelighting concepts were inappropriate.

It was important to note that these toplighting concepts incorporated the use of clear or overcast skies as a means of illumination, usually excluding direct sunlight. In recent years, new concepts have been developed that incorporate the use of sunlight, directly and indirectly, to enhance the interior spaces within a building (Robbins 1986, 87).

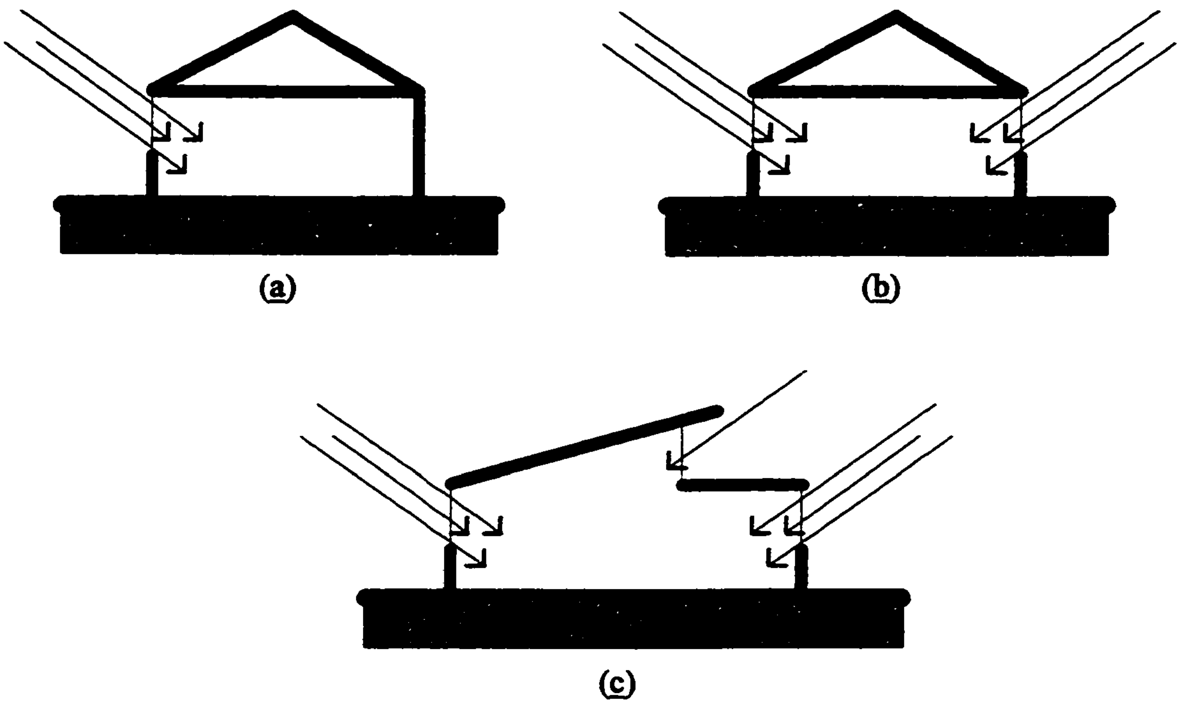


Figure 3 Sidelighting concepts (a) Unilateral lighting concept (b) Bilateral lighting concept (c) Trilateral lighting concept: Source: A.I.A. Journal, 1979, pg. 68.

The unique character produced by a daylighting system that incorporated toplighting apertures was significantly different from the character produced by a daylighting system

that incorporated sidelighting apertures. However, toplighting concepts had disadvantages that dictated how and where these concepts were used. Author William M. C. Lam (1986) states that many toplighting concepts performed poorly in temperate and frigid climates. Research has also shown that toplighting concepts were more susceptible to leaks in wet climates. The concept of toplighting was broken down into five categories as follows: (see figure 4)

- Horizontal lights and lightwells
- Angled roof apertures
- Sawtooth apertures
- Monitor apertures
- Direct and indirect beam lighting

Horizontal lights and angled roof apertures, more commonly known as skylights, provided a uniform level of illumination throughout a given space. Skylights incorporated the use of both sunlight and reflected skylight and were very efficient in providing general illumination on horizontal work planes. Lightwells had many of the same characteristics as skylights. Lightwells were defined as open shafts within the building extending from the roof one or more floors into the structure allowing more then one floor to take advantage of the light coming through the single aperture

Sawtooth apertures were another means in which daylight was directed by means of reflected skylight into the interior spaces of a building. Sawtooth apertures provided an even distribution of light throughout a building's interior with an accompanying small variety in the brightness pattern. A daylighting system that incorporated the use of

sawtooth apertures was a good way to provide uniform illuminance levels in large spaces within a building's interior.

When using a daylighting system that incorporated the use of sawtooth apertures, it was understood that this type of system had four distinct characteristics which were:

- A single aperture having a different illumination pattern than a series of apertures
- The light condition at the end of a series of apertures was different than that of the light condition under the first aperture in series. This is due to the last aperture borrowing light from the preceding apertures in the series
- The illumination pattern was determined by the sky condition present i.e. clear, partly cloudy, overcast
- The pattern of light characteristic of this type of aperture was determined from a series of three or more apertures

It was important to note that necessary provisions were made to provide protection against glare, sharp shadows, or veiling reflections associated with this type of daylighting system.

Monitor apertures were, in many respects, similar to a sawtooth aperture. However, a monitor, which had two or four glazing surfaces, allowed light to enter simultaneously from two or more directions. A system that used monitor apertures generally introduced more light into a building's interior spaces. A daylighting system that incorporated the use of monitor apertures was another good way to provide general illumination in large spaces (Robbins 1986, 105).

Robbins (1986) stated direct and indirect beam lighting was not a new daylighting concept, however, in recent years there has been a resurgence of research and

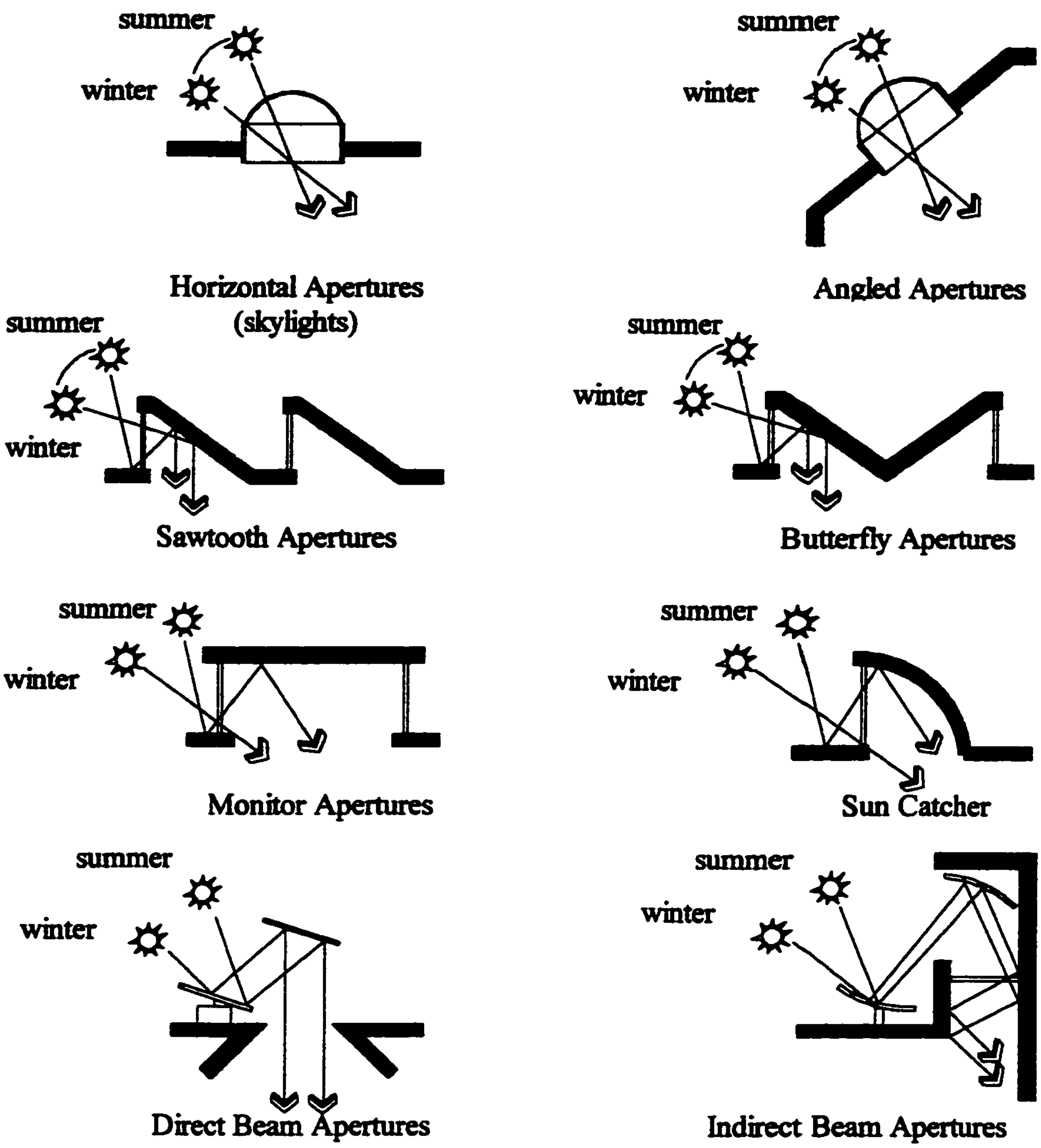


Figure 4 Toplighting concepts: Source: Source: Daylighting Design & Analysis, 1986, pg. 63.

development to use direct sunlight as a effective means to illuminate a building's interior. It was possible to produce attractive and effective illumination within a building's interior while protecting it against unwanted glare and overheating due to solar gain associated with the use of direct sunlight. Beam lighting was separated into two components: indirect and direct. Any aperture that allowed direct sunlight to penetrate into a building was considered to be a form of direct beam lighting.

Indirect beam lighting referred to light that has been redirected and redistributed throughout the space before the light was used for interior illumination (Robbins 1986, 8). Indirect beam lighting systems were comprised of three groups with respect to the means they used to manipulate light on the surfaces within the structure. The three groups were:

- Ceiling washer
- Wall washer
- Floor washer

Ceiling, wall and floor washers all involved the use of indirect sunlight to wash surfaces inside the building to create an interesting effect within the building where specific levels of illumination was not needed. Beam lighting systems were either very simple by design or relatively complicated involving many different components. Examples of this type of lighting were seen in the Civil and Mineral Engineering Building on the campus of the University of Minnesota and the Lockheed missiles and space building (see figure 4). With today's technology, beam lighting systems have become a more viable system to provide natural light in a building's interior.

The previously described toplighting concepts were used to provide natural illumination in earth integrated space to some degree. However, most of these concepts, with exception of direct and indirect beam lighting can only be implemented on structures that were located near the surface. Therefore, direct and indirect beam lighting has had limited success in projecting natural illumination into deep mined space. In the future with better technology, some experts have concluded this type of lighting system may become a strong tool which architects can use to project light into deep underground space (Bennett 1980, 75). Toplighting concepts had one major drawback with regard to earth integrated space. By using the roof as the medium in which to project light into a building, they elevated the risk of major leaks into the building shell. This risk may have discouraged their use as a viable means of projecting natural light into earth integrated building space

Atria, light courts and reentrants were other ways to manipulate the building's form to allow more of the building's interior to take advantage of daylight illumination. Atria were enclosed spaces that allowed light to penetrate the interior spaces of a building. Atria took advantage of top lighting and side lighting concepts to filter light into the building's interior.

Most often an atrium space was used as general circulation space for the building, which made them an integral part of the building's design. Most experts have agreed that, in general terms, atrium spaces were categorized into five different types with respect to how they were linked to the rest of the building. The five categories were envelop, attached, linear integrated, and core atria follow (see figure 5).

Core atria were considered to be the classical type of atria space which provided a glazed courtyard in the center of the building. The adjacent space that surrounds this glazed courtyard took advantage of the natural light provided by the atrium space.

An integrated atrium space was characterized by having only one side facing the exterior of the building. This type of atrium space may or may not have a glazed roof.

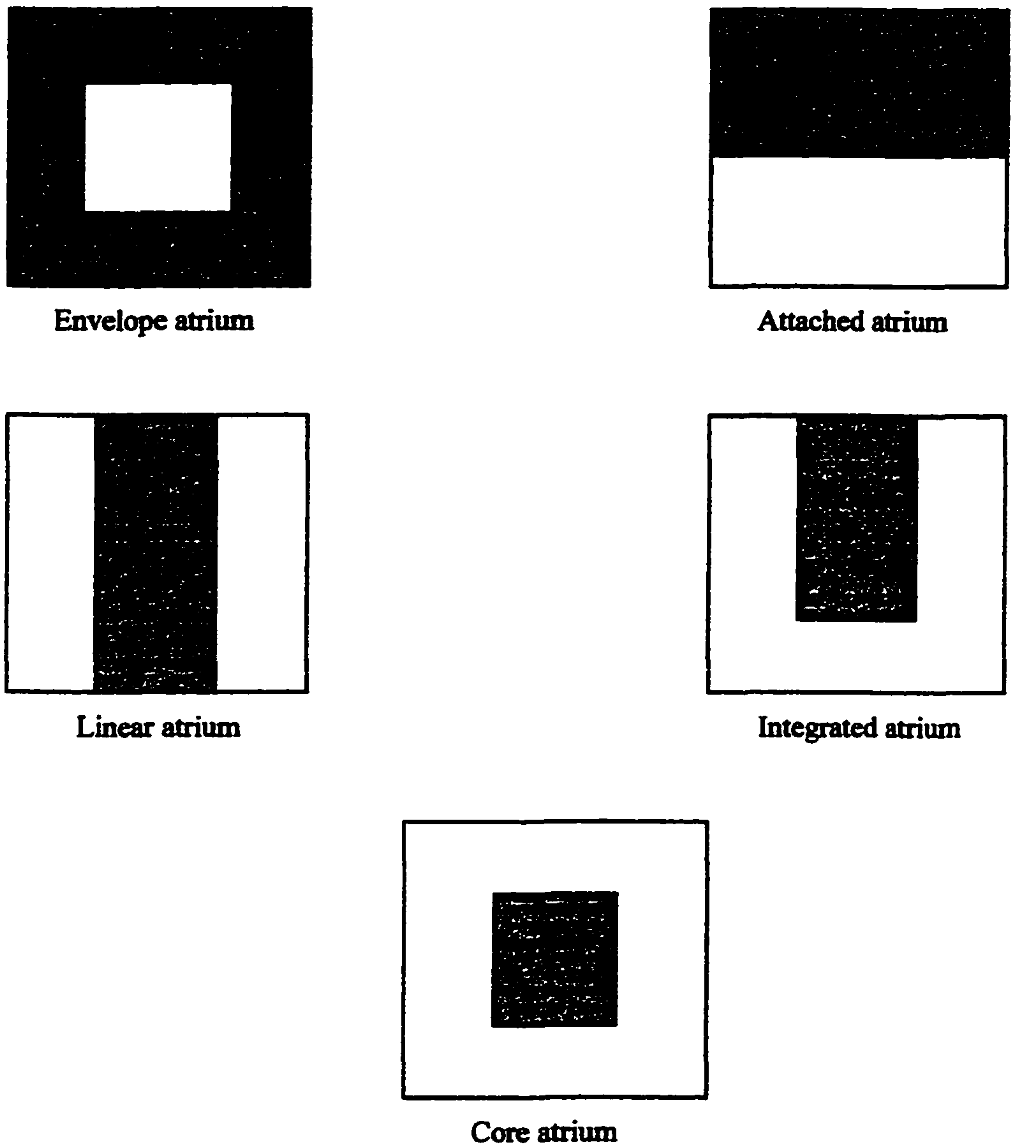


Figure 5 Atria concepts. Source: Sunlighting, 1986, pg. 157.

The linear atrium were characterized as large open spaces between two parallel building blocks and had glazed gables at both ends.

The attached atrium were considered to be glazed spaces added to the external wall of a building envelope.

The envelope atrium space was characterized by enclosing the entire building in an envelope of glazing.

Atria represented one powerful technique architects had use to provide natural illumination in earth integrated architecture. Multi-story atria were often associated with feelings of spaciousness and also provided visual interest within buildings.

Light courts were similar to atria, but light courts were not part of the building's interior space. Light courts replaced part of the building's core with an open court. This allowed more of the building's interior to gain access to natural light.

Light courts represented another powerful technique that was used to provide earth integrated structures with natural illumination. These courts provided the interior environment with a visual focus from an otherwise monotonous layout of inner connecting offices, walls, and corridors of a building (Robbins 1986, 113).

The use of various forms of reentrants was another technique which involved the shape and form of the building's interior and exterior. The term reentrant was used to describe the process of manipulating a building's envelope to produce an exterior design that optimized daylight penetration (see figure 6 Robbins 1986, 118).

The majority of reentrant designs were only practical in above grade structures. The reentrant forms that were most applicable to earth integrated structures were those forms that manipulated the building's form vertically.

Sun control and shading devices also played an important role in the effectiveness of daylighting concepts. These devices were divided into two categories, interior and exterior types, that were either moveable or fixed. These devices were often used in

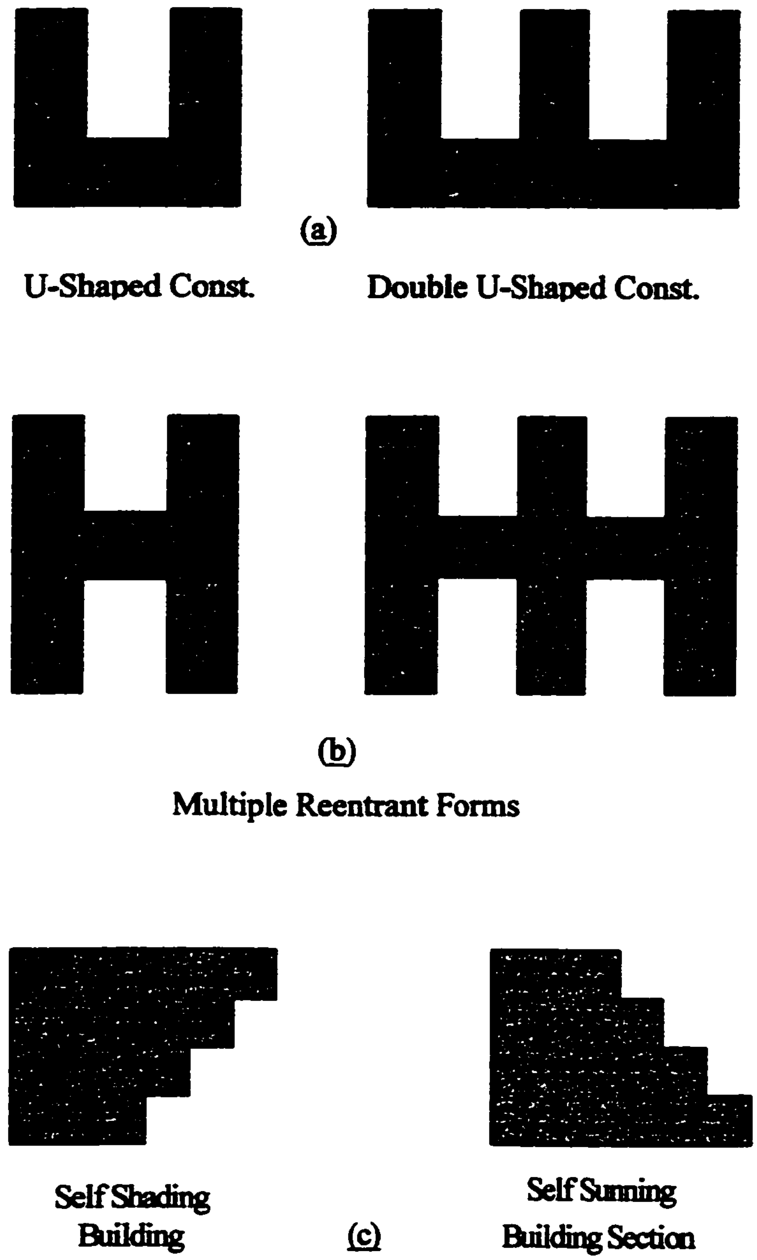


Figure 6 Reentrant concepts: (a) classical reentrant forms C or U and E forms. (b) Multiple reentrant forms. (c) Vertical reentrant forms. Source: Daylighting Design & Analysis, 1986, pg. 118

conjunction with daylighting concepts to enhance their performance and help protect against unwanted glare and overheating problems from occurring within a building's interior.

Sun control and shading devices were often used with daylighting systems that were designed for structures above grade. They were not applicable to many structures that were integrated into their site. However, it was important to note that many earth integrated structures incorporated daylighting systems based on systems used on above grade structures. Therefore, it was important to know the different types of sun control and shading devices that were currently used. The most common devices were (see figures 7A-B Robbins 1986, 119):

- Overhangs and extended overhangs
- Light shelves
- Horizontal louvers and blinds
- Vertical louvers, fins and blinds

It was beyond the scope of the study to make a detailed analysis to calculate the effectiveness of the techniques used in the practice of daylighting in the case studies chosen for this study. However, for informational purposes a comparative evaluation of the effectiveness of several daylighting methods has been tabulated and described in chapter 3.

Procedures for calculating levels of interior illumination from natural sources have been proposed in more then fifty different countries over the past ninety years (Commission Internationale De L' Eclairage 1970, quoted by Claude L. Robbins in

(A)

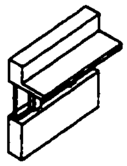
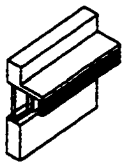
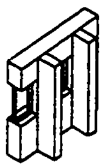
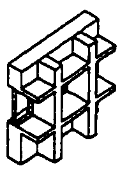
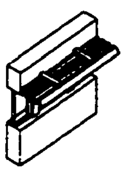
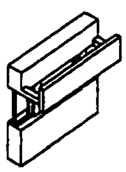
	Descripticve Name:	Best Orientation
	Overhanging Horizontal Panels	East West South
	Overhanging Louvers in a Vertical Plane	East West South
	Vertical Fins	East West North
	Eggcrate	East West
	Overhanging Louvers in a Horizontal Plane	East West South
	Overhanging Verticcal Plan	East West South

Figure 7A Common Shading Devices: (a) Fixed shading devices. Source Construction Illustration , 1991, pg. 1.11

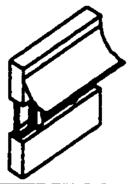
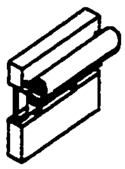
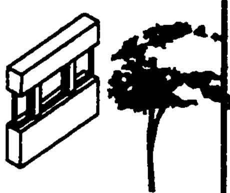
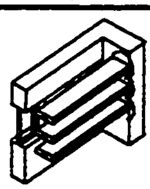
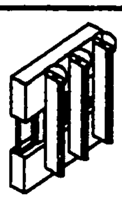
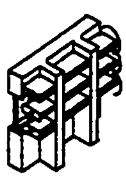
(B)		
	Descriptive Name	Best Orientation
	Overhanging Awnings	East West South
	Exterior Rolling Shade	East West Southwest Southeast
	Deciduous Plants Trees Vines	East West Southwest Southeast
	Overhanging Rotating Horizontal Louvers	East West South
	Fins Rotating Fins	East West
	Eggcrate Rotating Horizontal Louvers	East West

Figure 7B Common Shading Devices: (b) Moveable Shading devices. Source Construction Illustration , 1991, pg. 1.11

Daylighting, 1986, 157). Most methods fell into two general groups: (1) methods of analysis that determined absolute illuminance measured in lux or footcandles , and (2) methods of analysis that determined relative illuminance measured as a percentage of the exterior available illuminance. The Lumen Method and Flux Transfer Method were methods used to collect data for absolute illuminance. The Daylight Factor Method was a method used for establishing relative illuminance.

There were many organizations that produced valuable supplementary information to aid a designer. The National Oceanographic and Atmospheric Administration provided monthly summaries of climatological information of areas across the U.S. These summaries provided the designer with important data on the percentage of daylight, temperature, and precipitation levels available at a given site. This information was vital when a daylighting system was being designed for a given site.

The Illuminating Engineering Society (IES) provided guidelines on recommended illuminance levels in facilities. These guidelines were based on the task that was being performed, including the age of the participants, the importance of the task being performed and the reflectance of the task. However, these guidelines emphasized artificial lights and high uniform light levels, which provided a visual environment that lacked the visual stimulation that was a characteristic of areas that had a variation in lighting levels.

Daylighting Earth Integrated Structures

Natural light was considered beneficial to most built environments. The characteristics associated with natural light enhanced interior spaces and created a subconscious connection to the natural environment outside. The quality of natural light was often overshadowed by the disadvantages of using natural illumination in buildings. These included:

- Unwanted solar gain
- Blinding glare
- Energy loss through glazing
- Initial cost

All of these disadvantages contributed to the misconception that natural light was something from which one should have been protected and disregarded the more important advantages of a properly developed daylighting system that actually turned those disadvantages into energy benefits.

There were many other different strategies that provided a building's interior spaces with natural light. These strategies not only provided natural light as a primary source of illumination for the interior environment, but they also enhanced the exterior form and mass of the building.

Many of these strategies used techniques that were only used in structures that were placed above ground. When one integrated a building into its site, it limited a person to which of the systems or combination of systems one used as an effective means of projecting natural light into them.

To understand which daylighting systems were applicable to earth integrated structures, it was necessary to understand the different classifications of underground spaces. The following sections describe the different types of underground spaces as they pertained to this study and give a brief explanation on the differences between them.

The Classification of Earth Integrated Spaces

Since the 1970's, designers have rediscovered the benefits of earth integrated architecture (Carmondy 1985, 17). Over the years there have been several variations to the way in which architects and builders exploited the benefits of placing a building below grade. These variations have been categorized into two main groups:

- Deep-mined space
- Cut-and Cover earth sheltered space

Mined space was characterized by the excavation of earth through small openings from the surface by means of shafts or tunnels. Mined space was usually deeper and more isolated from the surface.

Cut-and-cover earth sheltered space represented the largest category of underground space. This type of space was characterized by buildings that were placed into the soil near the surface and were designed to support soil. This group was broken down into sub-categories of bermed and submerged types that were characterized by the building's relationship to the grade of the site and its openings to the surface (see figure 8 Carmondy 1983, 11).

The process of providing daylighting for subterranean structures was more complex than providing daylighting to their counterparts above ground. By exploiting

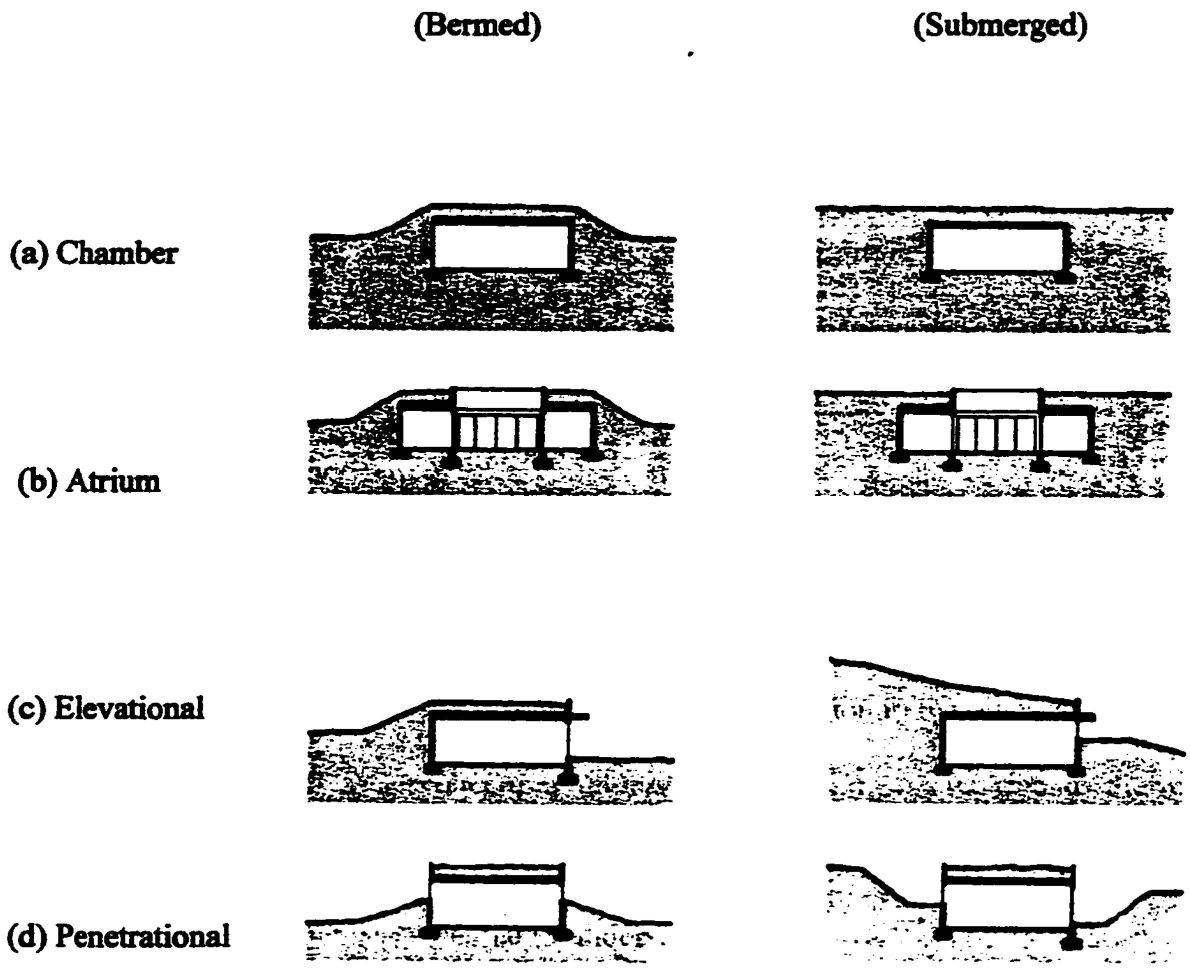


Figure 8 Classification of Earth Sheltered Structures, Source: Underground Space Design, 1983, pg. 49

the benefits that earth provided, one was limited to the amount of glazing used to provide natural light. Designers have used the following basic strategies to provide adequate natural light and exterior views to buildings that have been integrated into their sites:

- Vertical glazing

- Skylights
- Lightwells
- Interior / exterior courtyards

Vertical glazing, skylights, lightwells, interior and exterior courtyards, which have all been discussed in this study, have been used to illuminate the interior spaces of earth integrated structures (see figure 9).

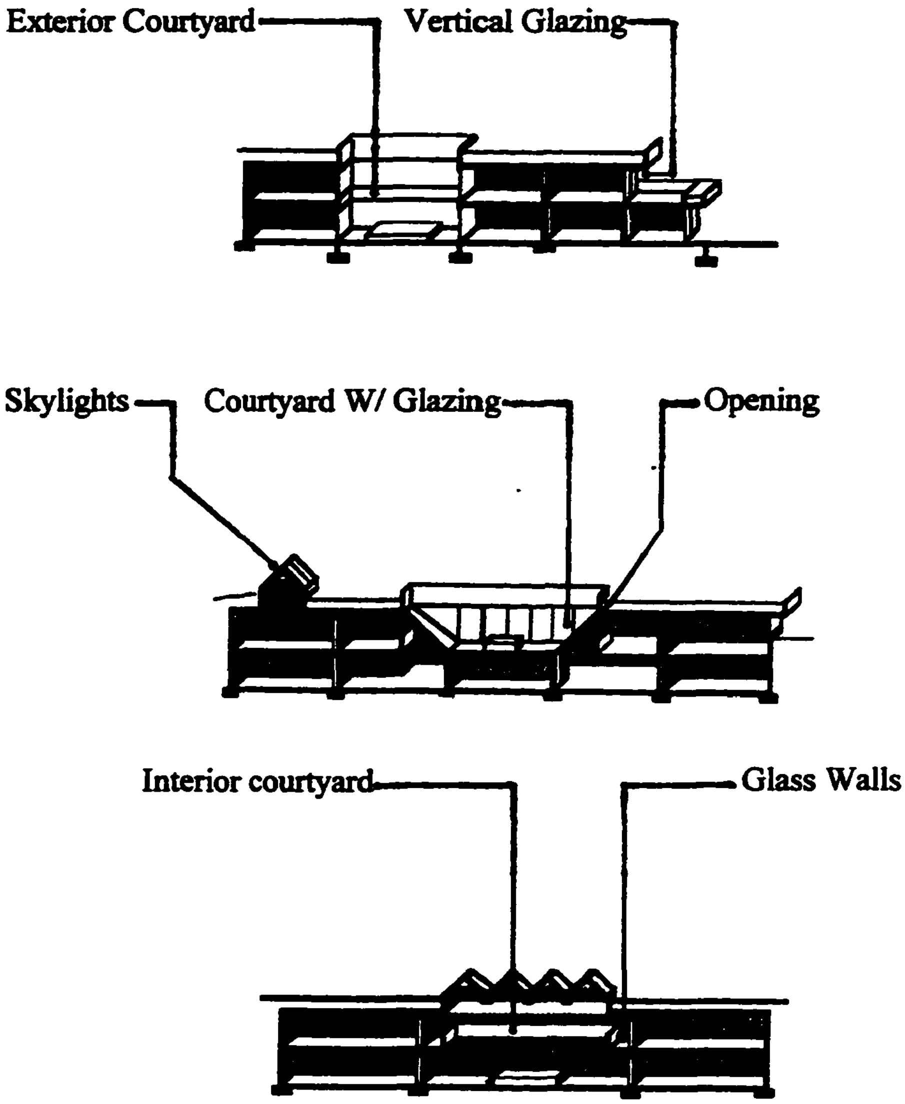
The use of these elements enhanced the form and aesthetics of a building and provided natural light. There were several factors that influenced where and when these elements were used. The following was a list of influences that determined which one or which combination of elements were selected. These included:

- Site topography
- Building orientation
- Size of structure
- Depth of structure
- Building function

Solar optical technology had been used on a limited basis as a means of projecting light into buildings. Theoretically, with a system of optical lenses and mirrors, sunlight and views could be captured and projected through small apertures within the structure to illuminate and provide views in areas that otherwise could not take advantage of natural light and views due to their location within the building.

Author Fuller Moore (1983) states that, "the aesthetic qualities of natural light are nearly universally recognized." Yet daylighting became widely presumed as a luxury

and difficult to justify to economically-conscious clients. However, subsequent research had now demonstrated certain economic advantages of daylighting for commercial buildings and its use was likely to spread.



(a) Building set into a sloping site.

(b) Bermed structure on a flat site.

(c) Below-grade structure on flat site

Figure 9 Daylighting approaches to Earth Sheltered Structures, Source: Underground Space Design, 1983, pg. 49

The economic advantages associated with the practice of daylighting were mainly from decreases in the energy usage of the building. This was the case of the Lockheed Missiles and Space Company Building in Sunnyvale, California, State Office Building in Sacramento, California and the St. Airy Public Library in Colorado. None the less, economic benefits should not have been the only determining factor to decide whether or not to incorporate adequate daylighting for earth integrated buildings.

The decision to use natural light as a source of illumination inside buildings should have taken into account the psychological and physiological benefits that accompanied the use of natural light as a primary source of illumination. These benefits became very important in cases where the building had been integrated into its site.

Psychological and Physiological Aspects of Underground Space

The many benefits gained by the utilization of underground space for storage, utility systems, and other types of facilities that required little or no human interaction were rarely overshadowed by concerns of the effects such a facility may have had on human occupants. Whenever facilities required human interaction for extended periods of time, concerns began to surface regarding the effect the underground facility might have had on the well-being of those individuals that worked in the space (Carmondy/Sterling 1993, 137).

The perception of caves and more primitive natural and human made spaces below grade, when combined with the power of the underground metaphor for the mysterious and unknown, provided reasons why many persons seemed apprehensive at

the idea of earth integrated architecture. The negative associations with underground space gave rise to many fundamental psychological issues such as claustrophobia, fear of entrapment due to structural collapse, and disorientation due to the loss of normal reference points (i.e. sky, ground, sun, and adjacent space) (Carmondy/Sterling 1993, 139). Physiological issues concerning the lack of natural light and poor ventilation also added to peoples' perception that underground space was dangerous and substandard (Carmondy/Sterling 1993, 50).

Relatively little research existed that was applicable to understanding the psychological and physiological effects of this type of environment. However, researchers had drawn from many related sources of information to hypothesize the pertinent psychological issues concerning underground environments (Carmondy/Sterling 1993, 141).

The research that was essential to understanding what effects earth integrated environments might have on human occupants had focused on windowless environments that were placed above ground. These windowless environments took on many of the characteristics that were common to earth integrated architecture. Most of the research that has been done on windowless environments focused on the values associated with windows.

One study (Wyon and Nelson) published in 1980 concluded that windows served several purposes. Windows allowed visual and acoustical information to be obtained from the outside environment, they influenced interior air quality and ventilation, and may further have served as an exit in the case of an emergency. These factors were important when a designer intended to limit the amount of useable glazing for a building.

Researcher Belinda Collins published a study of windowless environments in 1975 in which she concluded that in addition to admitting natural daylight, which provided a dynamic, changing character within the interior of a building, windows provided some contact with the outside environment. This contact with the outside environment provided knowledge of present weather conditions, time of day, and other changing events that happen within the natural environment. The study also stated that in some cases windows served as visual rest centers which allowed a person a change of focus and provided relief from the feeling of claustrophobia, monotony and boredom (Collins 1975, 1).

Jackson and Holmes (1973) stated that the contributions a window provided to an interior building environment were to be classed as qualitative. There was a marked difference perceived within a room that had been illuminated with natural light when compared to electric light.

By evaluating various research studies that had been conducted on windowless environments, it was revealed that peoples' attitude towards windowless environments were less then favorable. The strongest reactions seem to occur in restrictive and static spaces within buildings. This suggested that an essential function of a window was to provide for the dynamic lighting quality to an interior space that was contained in direct views to the exterior environment (Collins 1975, 2).

Beyond the psychological issues associated with natural light, there were many physiological issues associated with natural light as well. Although there was limited

evidence research has thus far proved that the relationship between natural light and a person's health was complex and multifaceted. Natural light affects the production of vitamin-D in humans. It also influences various biological functions such as the endocrine system's production of hormones and a person's biological clock. It has been proven that natural light relieved some of the effects of Seasonal Affective Disorder S.A.D. a disorder that affects a person's energy level and mood (Carmondy/Sterling 1993, 276).

With the knowledge of the contributions that natural light provided in the built environment, it was essential to understand that, by integrating a building within the its site, it was limiting a person's connection to the outside environment. Special attention must be given to this issue, in order to satisfy this important link to the outside and to fulfill the occupants' psychological needs associated with earth integrated architecture. From review of pertinent literature, research investigations, and an analysis of individual case studies of earth integrated buildings, it was expected that at least minimal levels of natural light could be determined for these types of spaces.

CHAPTER 3

RESEARCH METHODOLOGY

Research Approach for this Study

The purpose of this chapter was to provide procedures and methods for the systematic collection and analysis of information related to case studies of earth integrated structures and their use of natural light as a source of illumination.

The examples of earth integrated structures chosen for this study were represent state-of-the-art in underground developments in the United States and their use of daylight as a secondary source of illumination.

The information and data collected for this study was obtained through books, articles, and journals pertaining to the concepts of using daylight as a secondary source of illumination for underground environments. Plans, elevation, and sections are included with each case study to support the conclusions reached through the analysis of the written material.

The case studies chosen for this study were analyzed in two phases. The first phase analyzed the physical characteristics of the buildings to provide a thorough understanding of the design techniques utilized and to identify desirable design factors for technical parameters in designing daylighting strategies for underground spaces. The

second phase evaluated the selected buildings in reference to a set of proposed design hypotheses adapted from the previously published recommendations of John Carmody to apply to the specific issue of daylighting for underground spaces. The goals of this second phase of analysis were to (1) adapt previously proposed parameters to apply particularly to daylighting design, and (2) test the results of the revised guidelines when applied to existing buildings.

Analysis of Building Technical Features

The case studies that have been chosen for this study were analyzed on the basis of the following criteria:

- Type of facility (size, occupancy type)
- Type of underground construction
- Structural system as it relates to daylighting
- Solar orientation analysis
- Daylighting technology used
- Interior space (open, compact, scattered)
- Reflectivity of materials used
- Transition between exterior environment and interior environment
- Effective use of landscaping (berms, tiers, planters)
- Estimated minimum daylighting levels achieved

A brief description of each facility explaining the size, occupancy type, and type of underground space was given at the beginning of each of the case studies in order to

give the reader a general understanding of the type and function of the facility investigated and analyzed.

The structural system of any building played a major role in the development of the other supporting systems in a building. The shape and form of the structure depended on the material used in its construction. The placement and sizes of the openings throughout the building that provided natural light and views was limited by the choice of structural system used. Information on the structural system of each building was gathered through journals, professional magazines, and other case studies of these buildings. This information was analyzed on the basis of being either restrictive or nonrestrictive with regard to application of daylighting apertures. Restrictive structural systems usually incorporated planar elements including, load bearing walls and horizontal slabs, that enclosed spaces, making it difficult to reflect light throughout other interior spaces of the building. Non-restrictive structural systems incorporated linear elements, including columns and beams, that formed a skeletal frame which produced a sense of openness. This type of system allowed the interior walls to be manipulated in ways that allowed light to be reflected to other spaces in the facility.

Solar orientation was very important in the design and placement of any building. However, when using natural illumination, the solar orientation of the building became critical to the performance of the daylighting system. A solar orientation analysis was done to determine the effective placement of daylighting apertures in lighting the interior spaces of the facility.

Using Superlite 2.0 software, light levels were estimated and documented to establish the extent that natural daylight was an significant factor as a source of

illumination in specific areas within the facilities studied. These estimated light levels were then checked against universally recognized standard recommended light levels established by the Illuminating Engineering Society (IES) to establish how effective the daylighting approach was in providing natural daylight for illumination within each facility. At the conclusion of the case studies analysis, a comparison was tabulated with regard to the amounts of daylight that reached specific areas in each facility together with the daylighting strategies being utilized.

As information on daylighting expanded, new technologies were developed to better utilize available natural resources. Analysis of the placement and use of skylights, clerestories, and lightwells as an effective means to bring diffused light into a building was conducted to gain information which served as one basis of comparison for each case study. Atria and courtyard configurations were studied to determine if they were an effective way to allow parts of a building to access daylight. The effectiveness of the atria and courtyard configurations were based on the investigator's analysis of photos and diagrams of these spaces.

Evaluation of Design Parameters

While the evaluation contained in section above was used to develop the original design parameters which addressed the technical aspects of daylighting underground spaces, other researchers had developed additional parameters which addressed some of the problems that accompanied underground spaces. A comprehensive and well-organized set of design parameters for underground buildings was provided by Carmody & Sterling (1993). For the most part, these parameters stressed issues of aesthetics and

quality of interior environment rather than the technical building issues of daylighting underground spaces. The present study reviewed these parameters for the purpose of adapting them specifically to issues of daylighting design in underground buildings. These revised parameters were then used in evaluating the case studies of the selected buildings. The following procedure was used to adapt these parameters for daylighting requirements of underground buildings.

General Design Parameters:

Carmody & Sterling (1993) proposed numerous general design guidelines for underground buildings which addressed each of the following issues:

- exterior and entrance design
- layout and spatial orientation
- interior design elements and systems
- lighting
- life safety

These categories roughly followed a sequential process of building design which began with broader issues and subsequently to narrower concerns. In developing these design parameters, Carmody & Sterling claimed that the source studies on underground environment and any proposed design parameters derived from them would tend to be subjective. They stating that "the nature of research findings in the field of environment and behavior is 'suggestive' rather than 'conclusive' findings often document problems and behavior patterns but do not clearly tell designers what to do to resolve the problem" (Carmody & Sterling 1993, 154). In developing these guidelines, Carmody & Sterling

considered the well-documented problems of underground spaces discussed in Chapter 2 of this study, and the design hypotheses by previous researchers. Further, a comparison of design parameters for other building types with similar issues, and field observation of existing underground building solutions to typical problems encountered was undertaken. They presented their conclusions in the following form:

- statement of typical problems in each area
- proposed design objectives
- possible design responses ("patterns, " after Alexander's *A Pattern Language*)

The intent of the present study was specifically to evaluate the use of daylighting in underground building design. The design parameters addressed the overall design of underground buildings rather than daylighting specifically (Carmody & Sterling 1993, 154-155). However, many recommendations contained strategies that were well suited to being solved through effective daylighting design. These recommendations covered three major areas: aesthetic, psychological, and technical.

Aesthetic issues centered around providing a distinct image to an underground building to create a sense of place. The design recommendations included provisions for a visible building mass, a clear and legible building entrance, articulation of building boundaries, exposing building elements to clarify its location and extent, and creating a distinct image within the building to compensate for a lack of connection to the exterior (Carmody & Sterling 1993, 157-158).

Psychological recommendations focused on preventing the adverse occupant impressions of claustrophobia, lower status space, coldness, and lack of stimulation. Many of the recommendations centered around providing a feeling of spaciousness and

aiding occupants in orienting themselves within the space. To counter a feeling of being buried, they recommended providing a spacious and well-lighted entry, a graceful transition to lower levels, easy to understand patterns of circulation, and maintaining a visual connection with the exterior. To decrease the impression of underground space as low in quality, they recommended provision for a stimulating and varied interior environment, and use of high-quality materials that convey a sensation of color and warmth (Carmody & Sterling 1993, 157).

These recommendations by Carmody & Sterling were concerned with issues such as providing adequate lighting (natural or artificial) for the tasks being performed in a particular space, maintaining good quality air circulation, designing handicap accessibility into the main circulation areas, minimizing hazards, and establishment of effective emergency exiting.

The aesthetic and psychological issues listed above were the focus of the second phase of analysis in the present investigation. The technical issues evaluated in the present study were broader than those outlined by other investigations. These were addressed within the first phase of the analysis. The following section explains the application of general psychological and aesthetic parameters to the specific issues of daylighting.

Application of Aesthetic and Psychological Design Parameters to Daylighting:

Daylighting was an effective technique that met many of the underground building design concerns described above. Since skylights or atria occurred at ground

level and possibly extended downward into an underground building of considerable depth, such daylighting structures were useful in enhancing the user's feelings of spaciousness. Further, the studies have shown that daylit spaces that opened to the exterior environment were perceived as more desirable and certain daylighting structures such as skylights or atria could be useful in enhancing the perceived quality of the interior environment. Thus, windows or skylights provided a desirable visual connection to the exterior. Windows and skylights with various treatments allowed direct light, filtered light, bounced light, and patterns of shadows, and were especially effective in developing a stimulating, varied indoor environment. Prominent daylighting structures at ground level can be useful in developing a distinct image of an underground building and to demarcate its boundaries. Patterns of natural light were used to mark circulation patterns (such as a hallway) or nodes of activity, in order to make the spatial layout legible and clear.

One of Carmody & Sterling's basic recommendations was to "use natural light wherever possible." As shown in the previous paragraph, the available data contained many opportunities for the use of natural light in meeting general lighting design objectives (Carmody & Sterling 1993, 162). Accepting the idea that natural light is desirable wherever possible, and with the previous data supporting the application of natural light to the design issues described above, the investigator developed the following adaptations of their design objectives for the use of natural light to mitigate esthetic and psychological issues in underground buildings:

- Allow daylighting structures to create a distinct building image at ground level, including the demarcation of the building boundaries and a clear and inviting entrance.
- Use daylight to delineate circulation patterns, such as paths and nodes of activity.
- Provide daylight in important major spaces to convey a feeling of high quality space.
- Use natural light to provide visual complexity and variety and a distinct interior image.
- Use natural light to create a distinct interior image.
- Provide vertical open spaces beneath daylighting structures to create a sense of spaciousness.
- Provide a visual connection to the exterior.

Application of Proposed Parameters to Case Studies

Three steps were involved in compiling the following case studies with the above parameters. The first was to identify the particular use of the above parameters in the building design. This analysis was based on the information gathered for the first stage of analysis described in above. Next, any distinguishable design patterns along the lines of those described were identified. For example, "Sunken Exterior Courtyard" and "Interior Atrium Space" were design patterns identified by Carmody and Sterling as possible design responses to issues concerned with layout and spatial configuration (Carmody & Sterling 1993, 159). Lastly, any mitigating factors identified that changed the applicability of the design recommendations were identified. This could have been

spaces in which occupants performed monotonous work, with the need for a visually stimulating environment which was greater than when the activities performed in the space were more interesting (Carmody & Sterling 1993, 152). The next chapter of this study has summarized the results of these comparative analysis and offers other proposed design parameters that became apparent in evaluating the case study buildings.

CHAPTER 4

CASE STUDIES

A brief description of the building complex identifies the facility which was assessed from the viewpoint of the daylighting concept used, the type of earth integrated space, and the applicability of the previously proposed guidelines according to the criteria developed in the previous chapter.

Case Study One: Civil and Mineral Engineering Building, Campus of the University of Minnesota, Minneapolis

Project: .... Civil and Mineral Engineering building
Location: .... University of Minnesota, Minneapolis
Project Size: .... 150,000 SQ. FT. including 48,000 SQ. FT. deep mined space
Completion Date: 1983
Architect: .... BRW Architects Inc., Minneapolis, Minnesota
Type of Underground Space: .... Cut-and Cover
.... Mined Space
Type of Daylighting Strategies: .... Sidelighting
Toplighting
Passive/Active Solar optics
Estimated Daylighting Levels:
Circulation (bridge).. 36-57 fc
Structural Lab .... 13-16 fc
Rotunda.. 105- 167 fc

The Civil and Mineral Engineering (C/ME) Building on the campus of the University of Minnesota, Minneapolis represents one of the most innovative underground structures in the United States. This facility provided a unique opportunity to investigate how daylighting systems were implemented in earth integrated facilities. Investigating the daylighting systems that were used in this facility provided insight into which systems were appropriate to use in earth integrated facilities and how these systems were incorporated into guidelines for other earth integrated structures..

The Civil and Mineral Engineering Building was funded by the Minnesota State Legislature under the mandate that the facility demonstrate the latest techniques in earth sheltering and energy conservation. The construction on the facility was completed in January 1983 at a total cost of $12.9 million.

Facility Description

Serving as the gateway to the seven building complex known as the Institute of Technology, the Civil and Mineral Engineering Building incorporated 150,000 square feet of classrooms, lecture rooms, laboratory, and office space into a facility that was designed to demonstrate an energy conservative approach to building technology. Diverse program requirements and numerous site forces lead to placing 95 percent of the Civil and Mineral Engineering Building's mass below grade. The only visible portion of the facility was the upper level of the structures lab which provided a visual presence on the site that was representative of the building's purpose. The spiral shaped descending plaza, located in the western portion of the site, marked the main entrance into the facility

as well as forming the circulation pattern on the site. Within the facility, the major areas were organized on the basis of their relationship to the exterior environment (see figure 10).

Figure 10 Aerial view of the Civil and Mineral Engineering Building, Source: Best of Lighting Design 1987, pg. 217

Structural System:

The main structure was comprised of cast-in-place reinforced concrete in the portion of the facility that was classified as cut-and-cover earth integrated space. Self-supporting limestone and sandstone made up the structural system that was used in the portion of the facility classified as mined space.

Mechanical System:

Supporting systems included forced hot water to a forced air distribution system that was used to provide heat for the structure. For cooling a steam fired absorption water chiller with an outside cooling tower provided chilled water to variable-air-volume boxes.

Artificial lighting System

The artificial lighting system consisted of high pressure sodium and fluorescent luminaries that provided 100 footcandles in laboratories and 30-60 footcandles in corridors, offices and classrooms.

Energy System

To demonstrate energy efficiency in design, the Civil and Mineral Engineering Building incorporated a variety of innovative energy conserving systems to offset the energy requirements of this facility. These systems were described as being either passive or active systems. The active systems were those that were incorporated into the design of this facility and provided solar heating, solar electricity generation and ice storage cooling. These systems also relied on mechanical subsystems for supplementary energy. The passive systems that were used included: earth sheltered underground space, landscape microclimatology, hybrid solar heating, and solar optics and remote view optics.

The Civil and Mineral Engineering Building with its innovative energy components was an example of how technology and architecture together formed a unique facility that was both energy efficient and functional.

Type of Underground Space

The Civil and Mineral Engineering Building was a unique combination of underground space. As mentioned previously, 95 percent of the Civil and Mineral Engineering Building's mass was located below grade and combined both cut-and cover and mined space. Two-thirds of the facility's volume equaling 102,000 sq. ft. was categorized as being cut-and-cover earth integrated space. Only 15 percent of the building's roof structure was considered to be conventional. The remaining area of the roof structure was covered by earth ranging in depth from one to four feet or was considered to be plaza area. Only 10 percent of the building's wall area was located above grade and was not in contact with earth.

Interior Design Related to Daylighting

The interior design strategy for the facility focused on providing orientation to the surface, spatial variety, and natural lighting to public and circulation spaces. An example of this was seen in the placement of one of the building's interior visual focal points. A clerestory-banded rotunda, symbolizing the hub of the spiral shaped plaza, provided a public assembly space for the classroom and lecture spaces within the facility. The classroom and lecture spaces, which required total control over light levels, were located

two levels below grade in the west portion of the site. This two story rotunda, which provided ample amounts of natural light, also offered a critical visual link to the outside environment which was deemed necessary in this type of facility. The placement of the classroom and lecture spaces provided an opportunity for the development of the spiral shaped, gradually descending courtyard, which marked the main entrance into the facility. This courtyard also formed the hub for major circulation patterns on the site. It was interesting to note that an open air descending entrance into an earth integrated structure such as the one used at this facility, which allowed for a gradual descent outside the facility, had been suggested to offset the negative associations with going underground by evoking a feeling of a conventional entrance into an above ground building. The faculty offices were located along the southern portion of the main structures laboratory and step down into a sunken courtyard. This allowed for more of the offices to gain access to daylight. All laboratories, with the exception of the Environmental and Mineral Laboratories and the offices of the Underground Space Center, were located in the cut-and-cover earth integrated space.

The remaining one-third of the volume, equaling 48,000 sq. ft. of the facility, was classified as mined space. This part of the facility was located at the depth of 110' below grade and lies within a layer of soft sandstone. This portion of the facility, linked to the surface by only elevators and exit stairways, was completely isolated, and provided the Environmental and Mineral Laboratory and the offices of the Underground Space Center with a temperature stable and vibration free environment (see figure 11).

Structural System as it Relates to Daylighting:

As mentioned in the previous chapter, the structural system of a building played a major role in the development of the other supporting building systems. In the case of the Civil and Mineral Engineering Building, the structural system was comprised of two distinctly different parts.

The structural system that was used in the portion of the Civil and Mineral Engineering Building classified as being in cut-and-cover earth integrated space closely resembled conventional above grade construction. Cast-in-place reinforced concrete walls, columns and waffle slab floors made up the major components of the system. As an outward expression of structure, a steel truss system was used to span the structures laboratory, which was the only portion of the facility that was above grade. The linear nature of this structural system allowed the freedom to manipulate spaces and volumes within the structure. This was very important when designing earth integrated structures. This was evident in many areas within this facility. Main circulation areas terminated in large naturally lit spaces. Variations in ceiling heights found in classroom and office areas provided a variety of different spatial experiences within the facility.

Since the weight of the structure was carried by the columns, non-bearing partitions were manipulated to optimize daylight penetration. A good example of this was seen in the faculty office areas within the facility, clerestory glass partitions were used in office spaces that did not have direct access to natural daylight. These clerestory windows allowed natural light to enter these offices from corridors or public spaces that had exterior windows. Along with providing natural light in spaces that otherwise would

not have had access to natural light, the use of glass partitions were also successful in giving the building an open feeling.

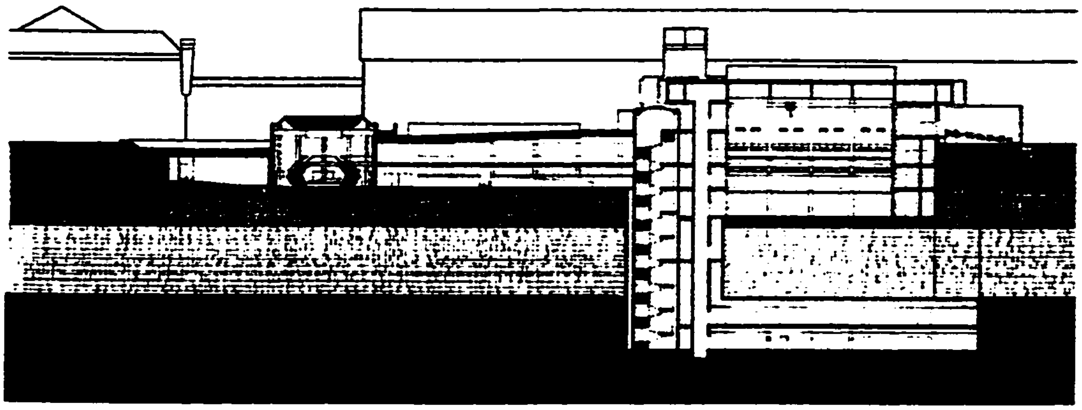


Figure 11 Section of the Civil and Mineral Building. Source: Underground Building Design, 1987, pg. 88.

The structural system used was categorized as being a non-restrictive system that allowed ample amounts of natural light to be distributed throughout the facility without any major problems.

The structural system that was used in the section of the facility classified as mined space was considerably different than that of the one previously described. It was important to note that the only natural light that reached this area was provided by the experimental solar optical system. This system was implemented in the design of the building and was not affected by the type of structural system that was used. The structural system in this section of the facility directly reflected the advances in mining technology. The roof structure was comprised of galvanized metal that was suspended from rock-bolted limestone. The walls were sandstone that had been reinforced by

concrete. The layout of the area was based on a room-and-pillar configuration that had a maximum span of 50 feet (see figures 12-14).

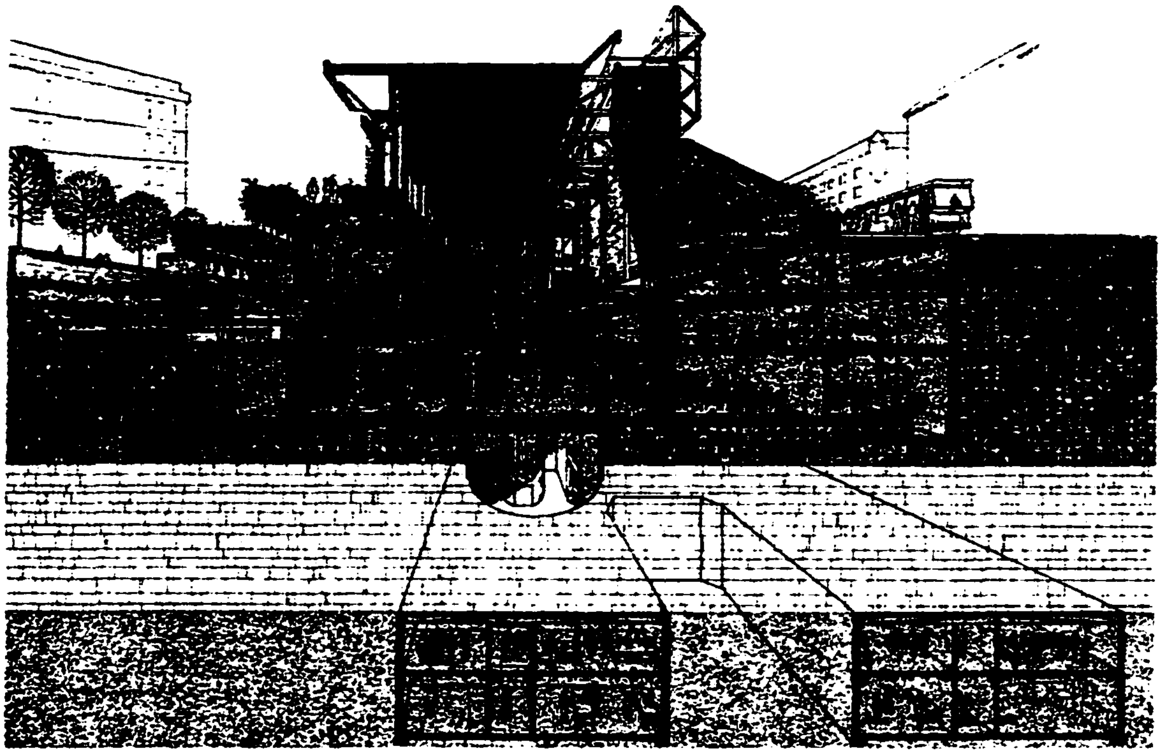


Figure 12 Cross section of the Civil and Mineral Engineering building. Source: Underground Building Design, pg., 312

The Civil and Mineral Engineering Building's major axis ran northwest to southeast. This orientation provided a balance between solar heat gain in the cold winter months and solar shading in the hot summer months. The spiral shaped descending plaza, located in the west portion of the site, formed the major entrance to the structure and defined the major circulation path across the site.

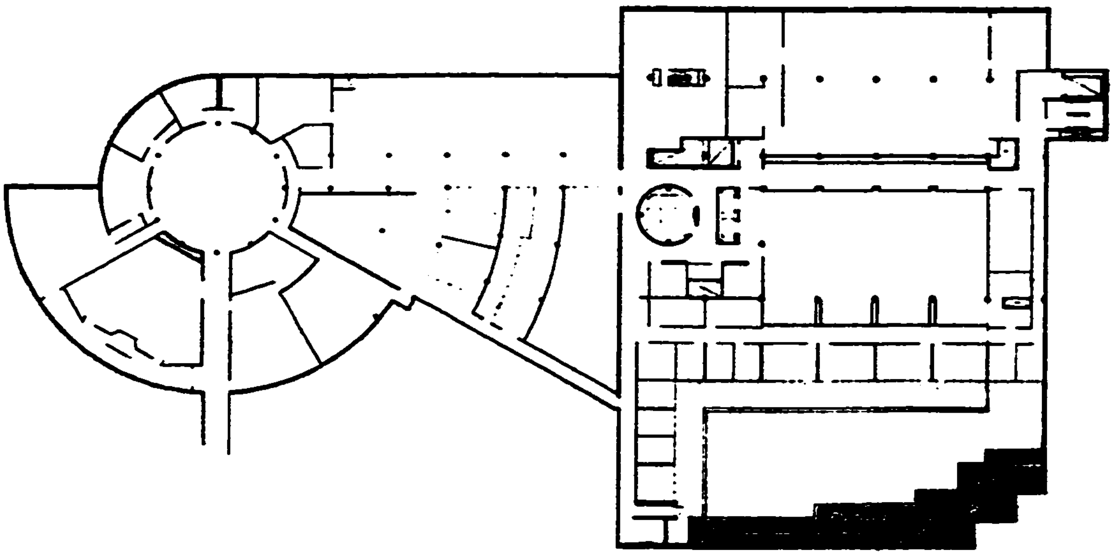


Figure 13 Floor layout of the portion of the facility that is classified as cut-and-cover space. Source: Undergound Building Design, pg. 90

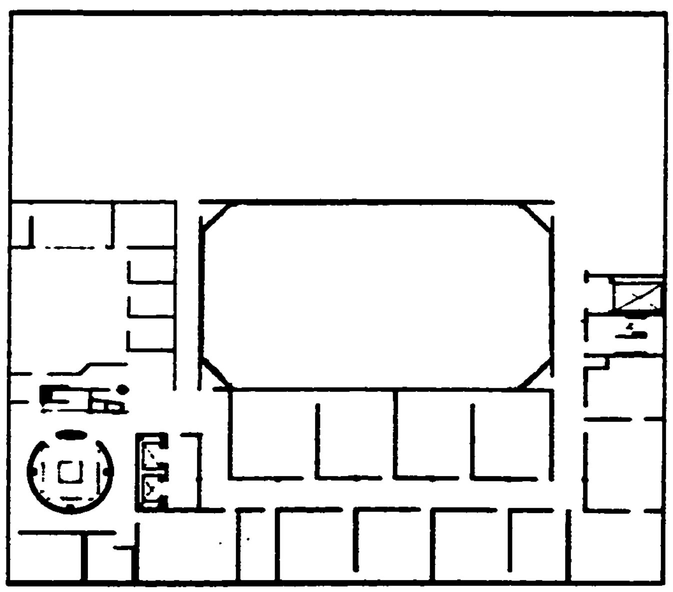


Figure 14 Floor layout of the portion of the facility that is classified as mined space. Source: Underground Building Design, pg. 313.

Solar Orientation

The two story Architecture building and six story Space Center located directly southwest of the plaza provided protection from blinding glare usually associated with low sun angles from this direction. The structures laboratory, the only section of the facility located above grade, was directly southeast of the plaza area. The structures laboratory provided a platform for many of the energy conserving systems.

The south facing wall of the laboratory was a translucent trombe wall and the components of the solar optical system used to project light into the mined space that lies 110' below grade were located on the roof of the laboratory. These systems were an outward expression of the building's energy conscious design. Another sunken courtyard was located to the south of the structures lab. Taking advantage of the shadow free portion of the site, the sunken courtyard allowed more of the faculty offices to gain access to natural light (see figure 15).

Daylighting Design Concept

The Civil and Mineral Engineering Building was designed to maximize the effectiveness of the available natural light. Windows in the facility were allocated on the basis of the specific function of the space. Special consideration was given to provide natural illumination in major public and circulation spaces.

Faculty offices were located in the southern portion of the site adjacent to the exterior sunken court yard and were provided with an exterior view into the courtyard.

The sunken courtyard allowed offices located two levels below grade to gain access to natural light. South facing windows provided unilateral lighting for most offices.

Permanent building overhangs and deciduous landscaping provided a balance between solar gain and shading on a seasonal basis. Offices that did not have access to natural light were provided with clerestory partitions that allowed natural light to enter from an adjoining public area that was naturally illuminated by roof monitors.

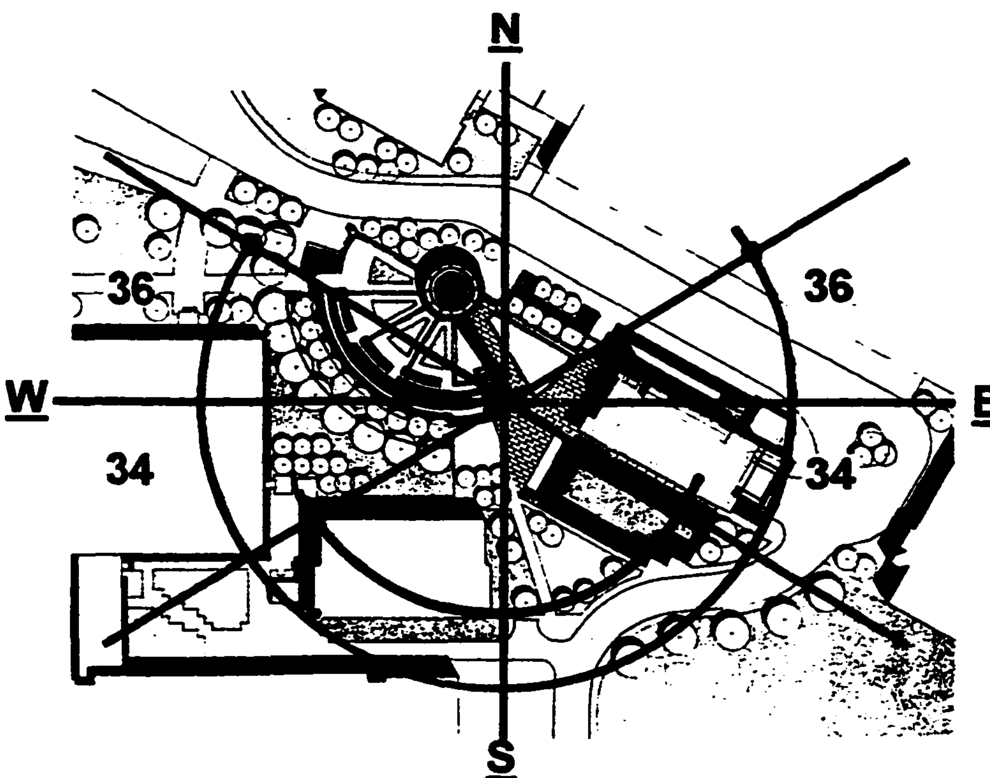


Figure 15 Solar Orientation Study. Source: Underground Building Design, 1987, pg. 86.

It was important to note, however, that during the mid-winter months the angle of the roof monitor and clerestory partition was designed so that it allowed direct sunlight to enter these offices, causing a significant glare problem.

The structures laboratory was another portion of the facility where the daylighting system was a major design element. Serving as a central atrium for the surrounding areas, it received natural light by two methods. First, natural light was projected into the facility via a passive solar optical system that was mounted on the roof of the facility. A fixed set of mirrors redirected daylight through a roof monitor to a suspended walkway that ran the length of the lab. The lab also received diffused daylight from a translucent trombe wall that ran along the southern wall of the structure.

The classroom and lecture spaces, mentioned previously, required total control over lighting levels and were placed two levels below grade in the western portion of the site. Directly above the classroom and lecture spaces was a descending spiral shaped plaza which marked the main entry into the facility. Due to the nature of the classroom and lecture spaces, daylight was only introduced into the large public area from which the classroom and lecture spaces were entered. Acting as the hub for the spiral shaped plaza, the two story rotunda was banded by clerestory windows and provided toplighting in this large public space. This large naturally lit public space also acted as a major focal point within the facility, which provided that important visual link to the outside environment.

Along with all the passive daylighting systems that were integrated into the design of this facility, the Civil and Mineral Engineering Building also had an active solar optical system used to project natural light into the portion of the facility that was located in deep mined space. With only a few minor problems with the sun tracking device which controlled the placement of the mirrors, the system has been quite successful and has spawned other systems to be developed for other applications.

As with many daylighting systems, the interior color scheme and finishes played an important role in the effectiveness of the entire system. The Civil and Mineral Engineering Buildings' interior surfaces were light in color value and hue to maximize the natural light that did enter the building. The major color scheme included rust red, tan and beige. These colors were used to provide warmth and visual interest. The interior finishes included painted concrete block and gypsum board walls, carpet and exposed aggregate floors, and metal rails and doors.

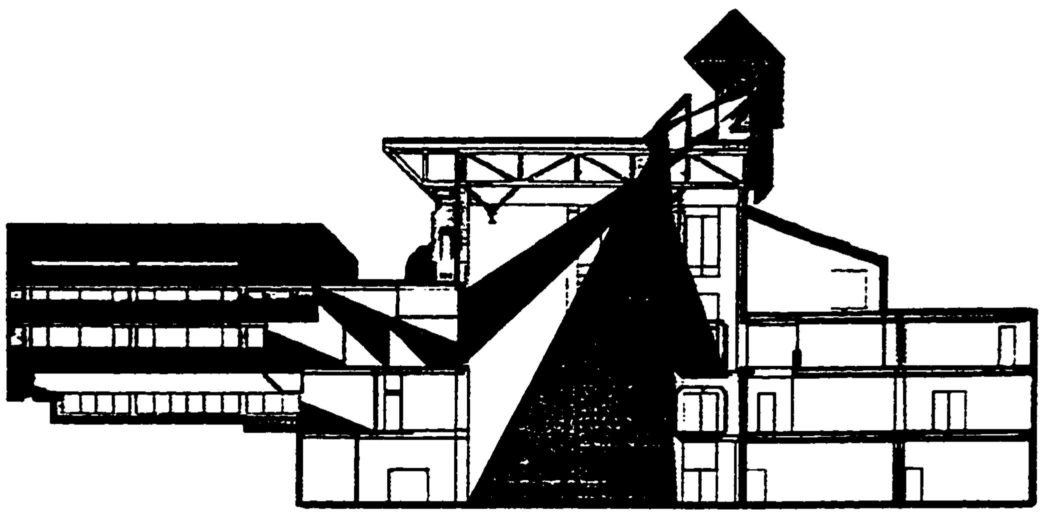


Figure 16 Cross section showing the active and passive daylighting systems. Source: Best of Lighting Design 1987, pg. 220.

The daylighting strategies that were used in the Civil and Mineral Engineering Building were not without their problems. The interior clerestory windows located in the faculty office area were positioned so they received light that entered the high light monitor that was across the corridor. The angle between the two windows was such that mid-winter sun was allowed to penetrate directly into the offices. This caused a

significant glare problem in these offices. Another problem centered around the angled glazing systems used in the facility. Besides not being readily accessible for cleaning , this glazing system contributed nagging leakage problems. These problems did not seem to be a serious detriment to the system's performance but they did affect people's opinions on the benefits of using natural light as a source of illumination (see figure 16).

Application of Proposed Daylighting Design Parameters

The Civil and Mineral Engineering Building used its major daylighting structure, the clerestory/rotunda with the descending courtyard, to provide a distinct building image at ground level. The courtyard and rotunda also clearly demarcated the entrance. This area and the above-ground portion of the structures lab provided an idea of the boundaries of the building underground. The rotunda incorporated the design principles of using daylight to emphasize an important focal point while providing a visual link to the exterior. The structures lab followed these same principles. The open faculty offices at the sunken courtyard also provided this visual link to the exterior. Glass walls at the interior follow the design principle of allowing natural light to penetrate the interior whenever possible, although this was done to avoid glare and solar gain problems. The solar optic system to the mined space provided the benefits of natural light even when no visual link to the exterior was possible. Daylight was intentionally excluded from spaces where it would have had a negative effect on their function.

The building demonstrated the following design patterns in response to daylighting underground space:

- A sunken courtyard to provide window areas with a visual link to the exterior environments
- The use of transparent interior partitions
- Design of vertical spaces at high daylighting structures as major circulation nodes
- active daylight transmission to deep underground spaces
- variety in the height and volume of interior spaces

These strategies may serve as precedents for designers to follow in addressing the same issues in future building designs.

Estimated Daylight Levels Achieved

As mentioned in chapter 3, lighting levels were estimated for June 21, the summer solstice, at 12:00 o'clock noon. Therefore the results achieved reflected the greatest amount of natural light that would reach the interior spaces within the facility. Lighting levels were estimated for key areas in the building that provided the best opportunity for using natural illumination in order to respond to the issues mentioned earlier with regard to daylighting underground space facility did in fact provide ample amounts of natural light that was used as a secondary source of illumination.

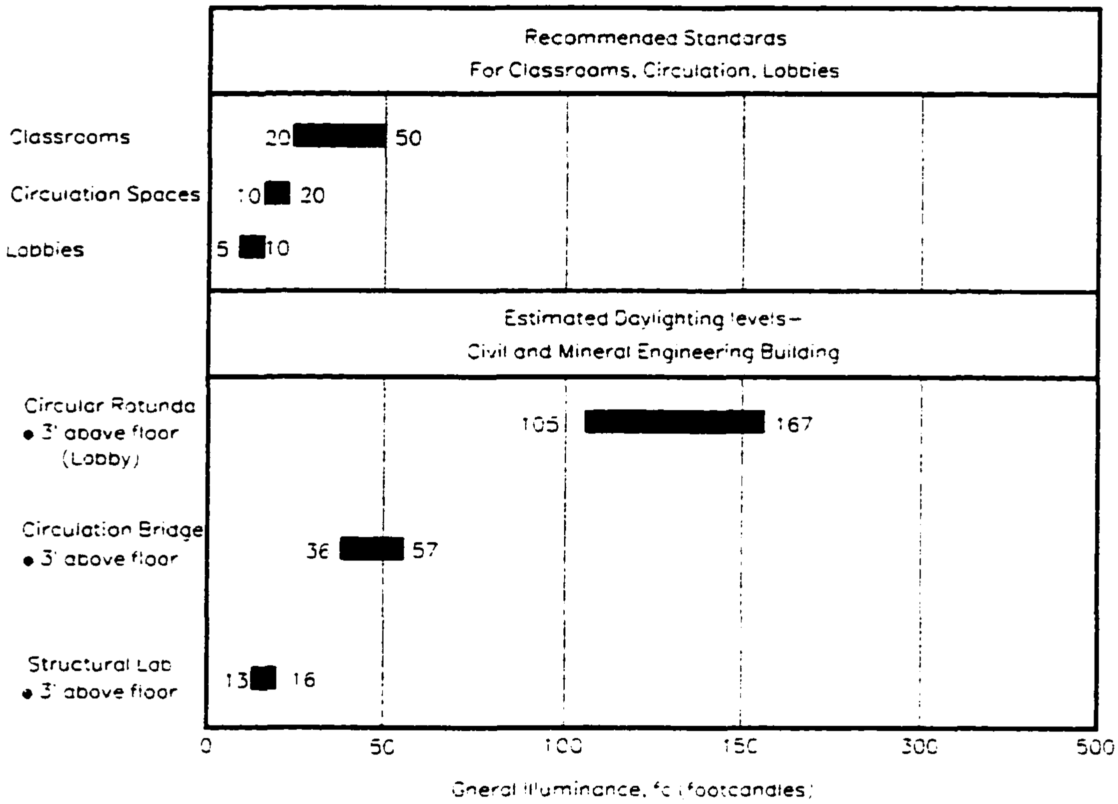


Figure 17 Estimated lighting levels in the Civil and Mineral Engineering Building These results indicated that the daylighting system implemented in the design of the

Case Study One Summary

The Civil and Mineral Engineering Building has effectively used the following daylighting strategies: Sidelighting, Toplighting, and Passive and Active Solar Optics This made it an outstanding example of how natural light was used as a design element in earth integrated facilities.

Case Study Two: Law Library Addition, University of Michigan, Ann Arbor

Project:	Law Library Addition, University of Michigan
Location:	Campus of the University of Michigan, Ann Arbor, Michigan
Project Size:	77,000 SQ. FT.
Completion Date:	1981
Architect:	Gunner Birkets and Associates, Birmingham, Michigan
Type of Underground Space:	Cut-and Cover
Type of Daylighting Strategies:	Sidelighting Toplighting
Estimated Daylighting Levels:	
Study Area	16-24 fc
2nd Flr. Circulation	12- 48 fc
3rd Flr. Circulation	90- 580 fc

The University of Michigan Law Library Addition, located in Ann Arbor, Michigan, has been cited as being one of the most aesthetically satisfying large underground structures built in the United States. The unique aspect of the addition was that it was neatly tucked away at the base of the old Gothic structure that housed the existing library. With only bronze railings around the major skylight elements, the addition was completely hidden from view and the historical character of the surrounding buildings was preserved.

Without any visually perceived above ground mass, the new addition provided insight into effective ways of directing natural light into facilities that had been completely integrated into their sites. The library addition was funded by the law school alumni and other private donors. Construction on the facility was completed in 1981 at a cost of $9.5 million.

Facility Description

In order to relieve the problem of overcrowding in the old facility and the need to preserve precious open space on campus, the new law library addition at the University of Michigan added a new unique character to the campus, while preserving the Gothic heritage of the old facility and the dormitories that were located in the area.

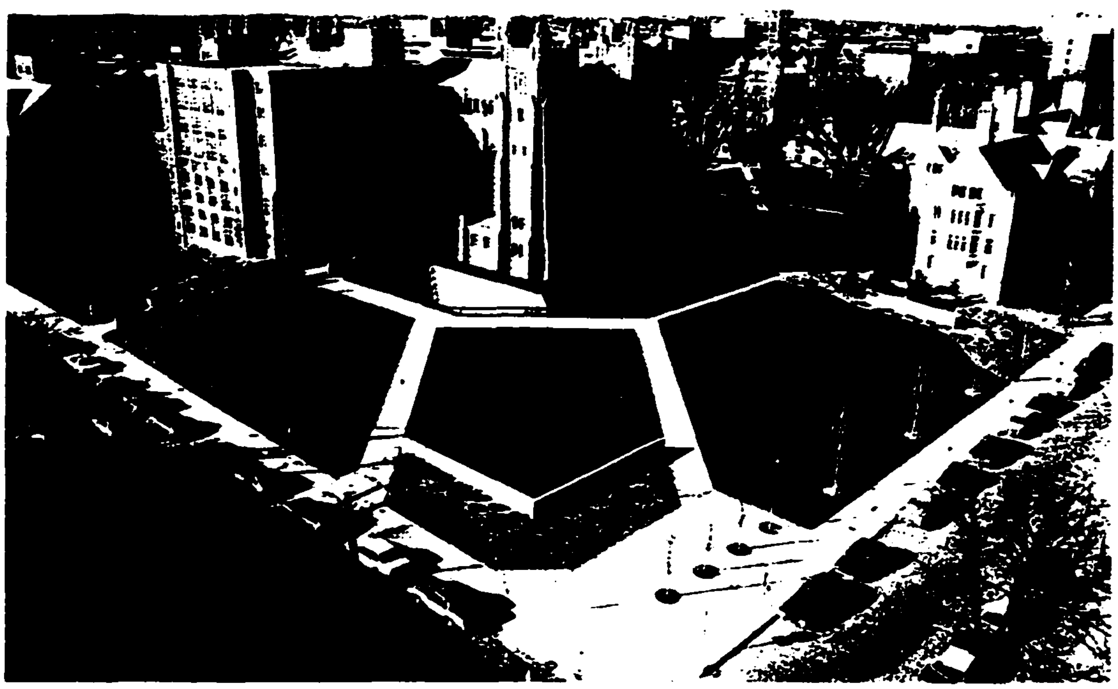


Figure 18 Aerial view of the University of Michigan Law Library Addition. Source: Underground Building Design, 1983, pg. 68

The new addition the Law library incorporated 77,000 square feet of stack area, administration offices, and casual student lounges into a unique underground environment. The facility was designed to handle 180,000 volumes in finished space and another 200.000 to 300,000 volumes in unfinished space. The main spaces in the facility were arranged around a dynamic one story high window wall that defined the inner edge

of the l-shaped facility. A smaller triangular skylight, located at the outside corner of the L-shaped facility, defined the outer perimeter of the facility (see figure 18).

The three story facility was designed as one big open space. Each floor stepped back away from the sloping limestone wall and glazed curtain wall which allowed diffused natural light to reach deep into the facility. The combination of the multi-level space created by stepping each floor away from the sloping wall and the diffused natural light diminished the feelings associated with being underground. Circulation space ran parallel to the glazed curtain wall in each wing of the facility. At the apex of the two wings of the facility, a grand stairway linked each floor and created an interior focal point within the facility.

Functions within the facility were arranged so that the more active spaces were located towards the dynamic window area. The busiest areas which included the card catalogs, offices, and reading areas were located on the first floor. The second floor was dedicated to book stacks and study carrels. The third and lowest level of the facility consisted of more book stacks, a student lounge and the offices of the university's Law Review and Journal (see figure 18).

Structure System

The main structure, like many earth integrated facilities, was comprised of cast-in-place reinforced concrete. The roof and intermediate floors were constructed of reinforced concrete waffle-slabs. The lowest level was also constructed of reinforced concrete slab on grade. The one story glazed curtain wall was supported by two major components. The first component consisted of three foot deep concrete pillars which

were used to support the glazing system. The second component consisted of concrete planks faced with white limestone. The planks sloped down from the base of the existing structure to the lowest level of the new addition. The sloping concrete planks and concrete pillars come together to form a 60' deep V-shaped trough that acted as a retaining wall to resist earth loads as well as providing natural illumination in the interior. The whole system was stabilized by pre-stressed tie-backs, which extended deep into the earth under the old Gothic structure.

Mechanical Systems

The heating system for the facility, like many institutional facilities, consisted of hot water that was provided from the university's central plant and was circulated through preheat coils in variable-air-volume distribution boxes located throughout the facility. The cooling system for the facility was unique in that it used low-pressure steam that was a byproduct of the university's central plant. Low-pressure steam that was generated from campus electrical generators and was piped to a single steam fired absorption chiller unit. The chiller unit provided chilled water to coils in the air distribution system.

Artificial lighting Systems

The Artificial lighting system in this facility consisted of one-by-four foot two lamp return air parabolic luminaries. Electrical lighting was augmented by natural illumination, both direct and diffused, from the one story glazed curtain wall and the smaller triangular skylight located on the outside corner of the facility. As an energy

conscious system, luminaries near the glazed curtain wall were connected to photocells which automatically turned off these lights when adequate levels of natural illumination were provided by the skylight. The design of the new addition the Law Library at the University of Michigan was a direct reflection of the architect's belief that natural daylight was a material that should be used for illumination as well as providing visual interest within a facility (see figures 19-22).

Type of Underground Space

The Law Library Addition was categorized as a cut-an-cover earth integrated space with the lowest level being 54 feet below the surface. The facility was completely covered by earth ranging in depth of 1.5 to 4.5 feet.

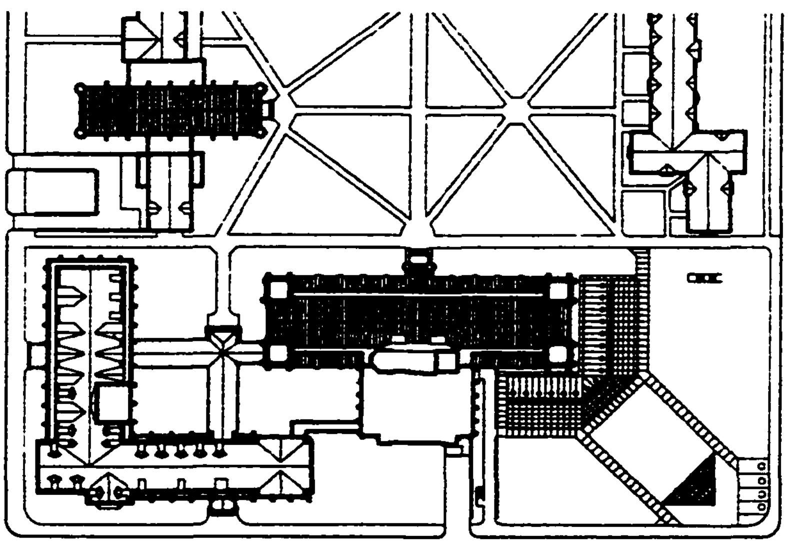


Figure 19 Site plan of the Law Library Addition. Source Underground Building Design, 1983, pg. 70

The exception was the glass curtain wall and triangular shaped skylight, which constituted just 10 percent of this facility's volume. To maximize the amount of natural

daylight that entered the facility through the skylight elements, the 77,000 sq. ft. L-shaped facility's interior was designed as one big open space that converged around a large glazed curtain wall and sloping limestone wall. The glazed curtain wall and limestone wall came together to form a V-shaped trough that ran 160' along inner edge of the two wings of the facility. The sloping limestone wall, which helped redirect natural daylight into the facility, continued down to the base of the addition. To allow natural light to reach the lowest level in the facility, the two intermediate floors stepped back away from the sloping surface. Each floor, in turn, formed a balcony that looked out over the multi-level space. The stepping back of each floor was categorized as a self-shading reentrant form that was discussed in Chapter 2.

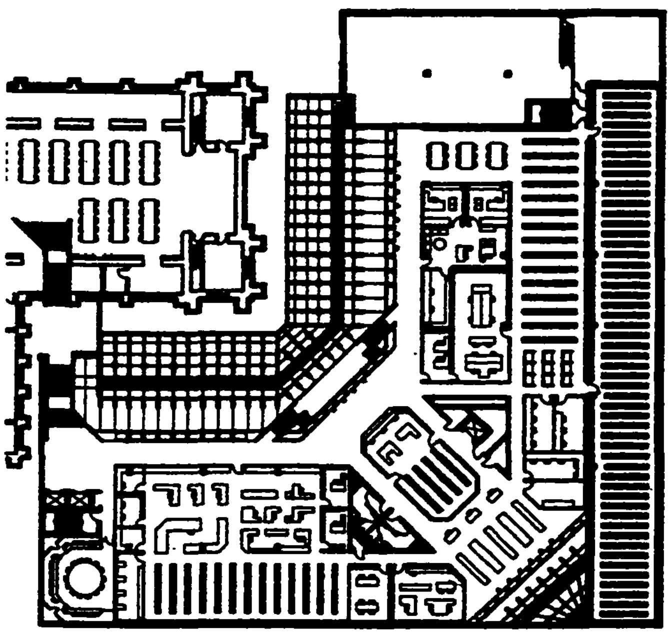


Figure 20 First floor plan of the Plan Law Library Addition. Source: Underground Building Design, 1983, pg. 72.

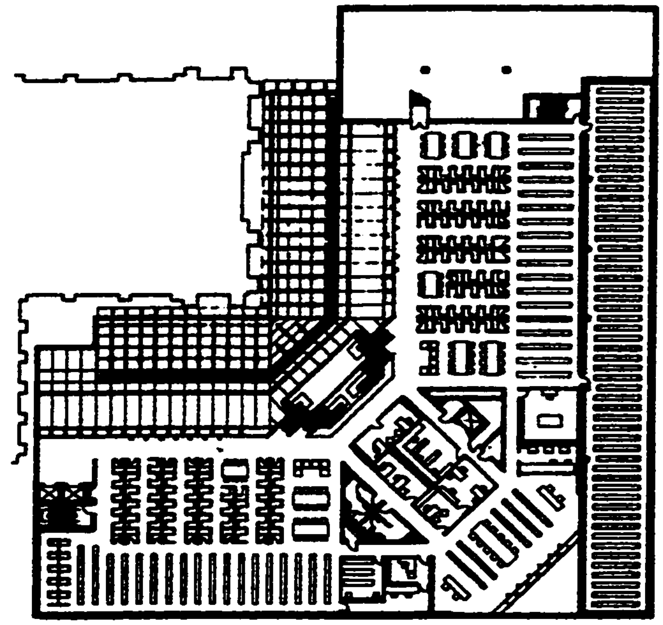


Figure 21 Second floor of the Law Library Addition. Source: Underground Building Design, 1983, pg. 73.

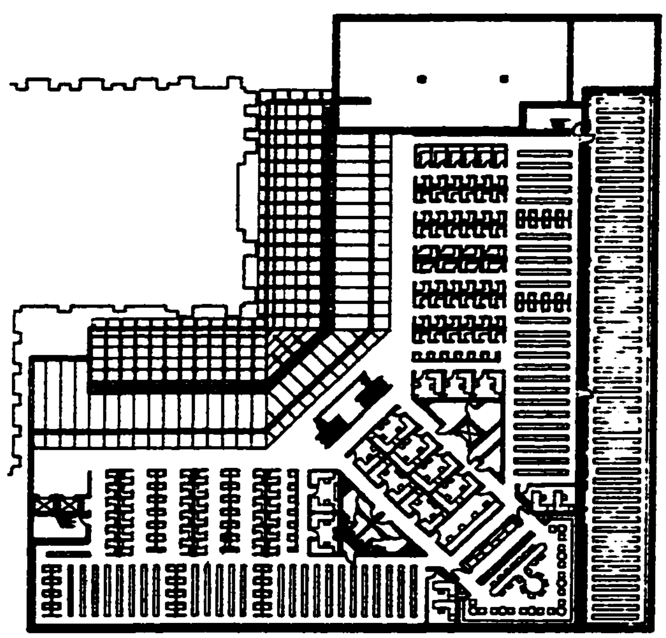


Figure 22 Third floor plan of the Law Library Addition. Source: Underground Building Design, 1983, pg. 73.

The idea of overlooking multi-level spaces in earth integrated facilities, in many cases, may have relieved the feelings of confinement that was often felt in this type of facility.

The new addition was intended to be integral part of the old Gothic structure. Therefore, the entrance to the new addition was located on the lower level of the older structure. A wide descending stairway led into the addition along one end of the dynamic window wall.

Structural System as it relates to daylighting

The structural system used for the addition, as mentioned previously, consisted of cast-in-place reinforced concrete. This type of system was easily manipulated to maximize the available natural daylight that entered the facility through the window wall and provided a variety of different experiences within the new addition. An example of this was the dynamic stairway connecting each floor together located at the apex of the L-shaped facility. Each individual run of the stairway was cantilevered away from each floor, creating a grand vertical circulation path that became a major interior visual focal point. The multi-level space that was created by the stairway further reduced the uneasy feeling of being underground. The multi-level space also allowed natural light to penetrate deeper into the facility. The sloping limestone faced wall, which acted as a retaining wall to resist lateral earth loads, helped redirect natural light into the earth integrated structure as well as providing a visual focal point within the facility. The opposing pillars that supported the glazed curtain wall played a major role in the daylighting system. These pillars acted as baffles to reduce the amount of direct sun and direct glare that entered the facility. In addition to providing protection against direct

sun and glare, the pillars also provided a fragmented reflection of the old Gothic structure as well as of the sky and clouds. These reflections further reduced the negative feeling associated with being underground.

Not unlike the Civil and Mineral Engineering Building on the campus of the University of Minnesota, the weight of the Law Library was supported by columns, which allowed the use of nonbearing partitions that were located in areas that did not block incoming daylight. Partitions that were located near the window wall had clerestory windows to allow light to be reflected deep into the facility along the ceiling.

The structural system used was a non-restrictive system that allowed natural light to enter the facility and be distributed throughout without any major problems (see figure 23).

Solar Orientation

The addition was located in the southeast corner of the historic Gothic quadrangle, formed by the old library and surrounding dormitories. The two major axes of the L-shaped facility ran north to south and east to west along the base of the old Gothic structure. The major daylighting element, a 160' x 26' trough, defined the inner edge of the facility, and ran along the base of the old structure. The trough, created by the sloping limestone faced wall and the opposing glazed curtain wall, redirected natural diffused daylight into the facility. The limestone wall slopped towards the south, southeast, and east as it wrapped around the base of the old structure.

The wall took advantage of the direct sunlight throughout the day and provided diffused daylight on all three levels. The glazed curtain wall was protected from glare associated

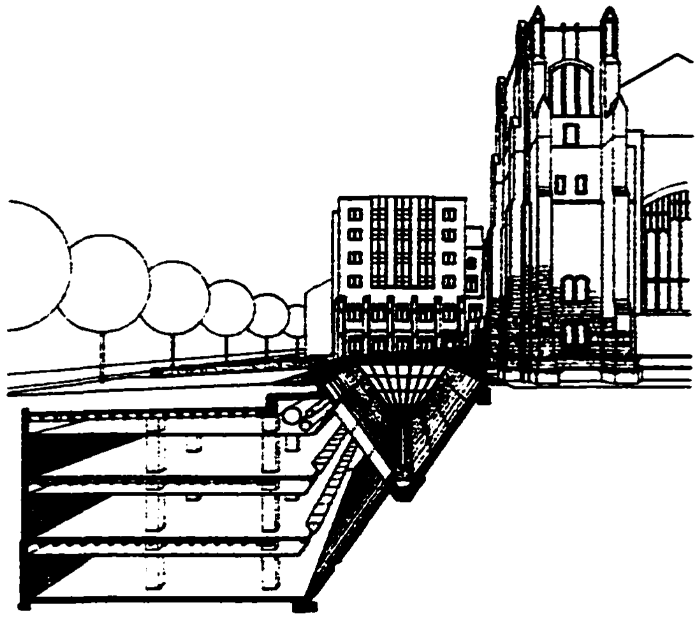


Figure 23 Cross section Law Library Addition. Source: Underground Building Design, 1983, pg. 74.

with low sun angles coming from the west by the old library. The concrete pillars that supported the glazed curtain wall acted as baffles to protect against direct sun and glare throughout the day. Evidence of the their effectiveness to protect against glare associated with overhead glazing was indicated by people reserving spaces along the balconies and working there throughout the day. The smaller triangular skylight that was located in the southeast corner of the facility took advantage of daylight throughout the day and was protected against direct sunlight in much the same way as the major window wall was. .However, during the late afternoon hours, the skylight was protected by the direction in which it was sloped, and at the surface by a high concrete wall around the opening which cast its shadow across the glazing (see figure 24).

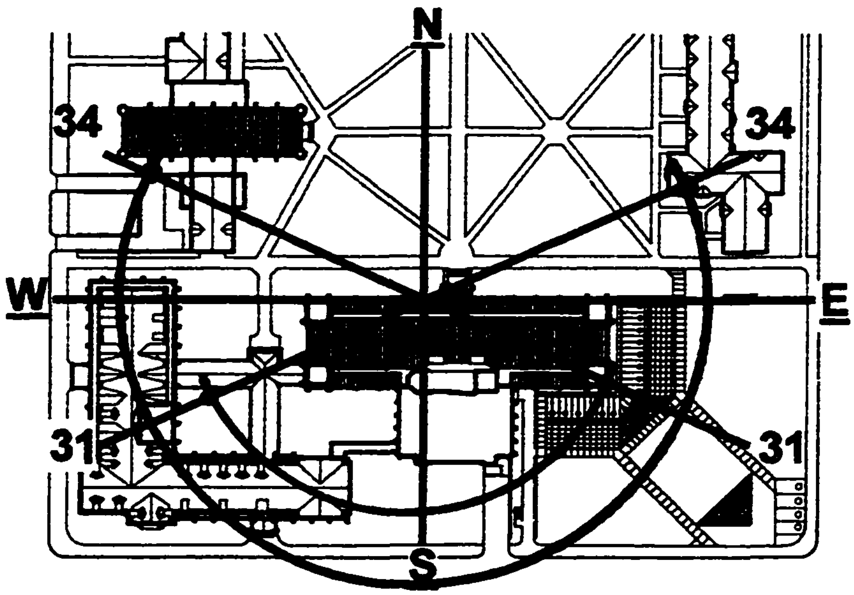


Figure 24 Site plan showing solar angles. Source: Underground Building Design, 1983, pg. 70.

Daylighting Design Concept

Since the addition was completely integrated into its site, providing enough natural daylight and views to the outside, became a major concern. The daylighting system used to provide natural light and views was a integral part of the design of the facility and natural daylight entered the facility in a dynamic fashion through the glazed curtain wall that ran along the inner edge of the facility. The glazed curtain wall and opposing limestone wall came together to form a 60' deep trough that allowed natural light to enter the facility from above.

The limestone wall which stretched from the base of the old structure to the lowest level of the addition captured natural light throughout the day and redirected it through the glazed curtain wall into the facility. The major supports of the glazed curtain

wall also acted as baffles to protect it against unwanted direct sunlight and glare, which was often associated with large amounts of overhead glazing. This unique system also provided views to the outside and other parts of the interior by the use of mirrors. Three foot deep mirrors were attached to each side of the supporting members. These mirrors provided fragmented views of the changing environment outside along with views of the different interior spaces within the facility. Mirrors also provided a stimulating visual effect that was seen throughout the facility. As natural light struck the mirrors, it was redirected downward onto the sloping limestone wall. The position of the mirrors created a criss-cross pattern of reflected light on the sloping surface that changed throughout the day.

To allow the natural light that was reflected down into the facility in order to reach the lower levels, each floor slab was pulled back away from the sloped surface. By pulling each floor back, a multi-level naturally lit interior space was created. Most of the activity in the library centered around this dynamic space, which was an indication that natural light was an important component within the structure. In addition to the large glazed curtain wall, there was a smaller triangular shaped skylight located at the southeast corner of the facility. This provided natural light to enter along the outer edge of the facility. This skylight also provided natural light to reach the student lounge located on the lowest level directly under the small skylight. The glazed curtain wall and smaller triangular skylight allowed enough natural light to enter the facility so that a person was conscious of being surrounded by natural light in most areas well within the structure. Fifteen foot ceilings also provided ample open space within the facility to reflect light above most of the activities. Partitions located near the window wall had

clerestory windows, which allowed light to be reflected beyond the partitions along the ceiling deeper into the facility.

Interior Design

The interior color scheme for this facility, like with daylighting system, played a major role the in the overall performance of the system. The interior scheme for this facility consisted of white walls and ceiling panels to insure that light was reflected deep into the facility. The white limestone faced panels made sure light was reflected into the facility. Dark green carpet was used in the more active areas within the facility and quieter tannish-brown carpet was used in the less active spaces. Throughout the facility red oak along with polished aluminum four pipe railing were used as accents

A true indication of the success of the daylighting system was expressed by comments from people who worked in the facility. Margaret Leery, the associate library director when the new addition was completed, said, "We really like the open stacks, the carrels, the space is light and airy and comfortable and engender a good feeling." Bruce Johnson, the reference librarian said, "We were afraid we'd be trapped in a basement, but I don't feel the least entombed. It's a spectacular setting to work in" (Dean, 1983, 54).

Application of Proposed Daylighting Design Parameters

The Law Library is an example of a building where the designer chose appropriately not to use exterior daylighting structures to create a distinct exterior image

for the building. In this case, preserving the context of existing Gothic buildings weighed more heavily than the need to emphasize the new building. Those portions of the daylighting system that were exposed at ground level were designed to appear low-key and of high quality (the triangular skylight with its brass railings). The major daylighting structure of the 60' trough with sloped limestone walls was, however, used to create a distinct image for the interior of the building. This pervasive feature was an application of the principle of allowing deep vertical lighting structures to provide a sense of spaciousness. Visual variety and stimulation were provided in this building by the shadow pattern effect provided by the major support columns, the mirrors, and the reflected light from the sloped wall. The stairway at the intersection of the two linear light troughs uses daylighting structures to emphasize the major circulation pattern. The large glass curtain wall at the light troughs allows a visual connection to the exterior, not only to the sky but to the Gothic buildings above.

Daylighting design strategies exhibited by this building included:

- A two way light trough penetrating the earth around building perimeter
- The use of structural elements as light-patterning element
- Introducing bounced light from sloped reflective surface
- The Use of high floor-to-floor space to increase light penetration to interior
- Reducing interior walls to a minimum

Estimation of Daylighting levels Achieved

As mentioned previously, lighting levels were estimated for June 21 at 12:00 o'clock noon. The results achieved reflected the greatest amount of natural light the

would reach the interior spaces within the Michigan Law Library Addition.. The following chart shows the range of available levels of natural illumination in three key areas in the facility (see figure 25). These results proved that a properly designed daylighting system did provide ample amounts of natural light in a facility that was totally integrated into its site.

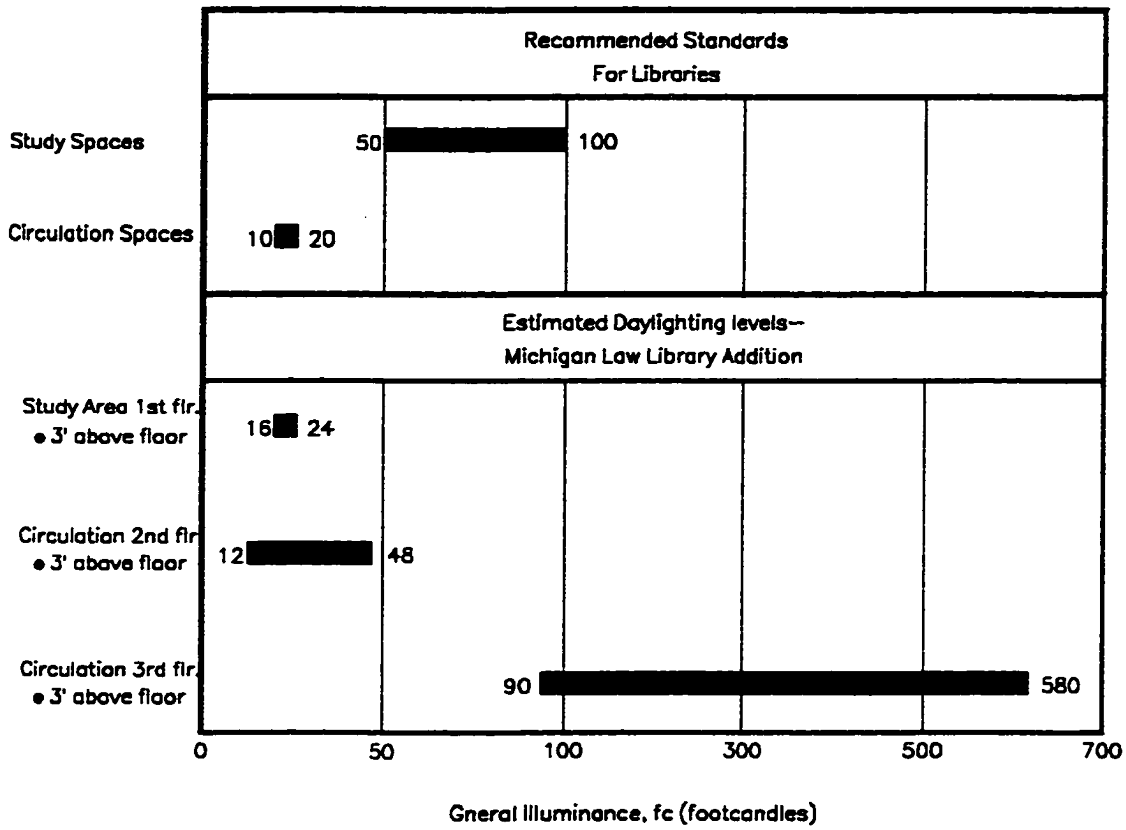


Figure 25 Estimated lighting levels at the Michigan Law Library Addition

Case Study Two Summery

With any new facility, some small problems need to be worked out. The law library addition was no different. There were no serious leaks in the main structure, however there has been some minor leaks through the curtain wall itself that had to be repaired. Acoustics in the building was a problem and there was little that could be done to solve the problem. Due to the large open space and high ceilings in the facility, voices on the lowest level were heard throughout building. There was a more serious problem with the ventilation system when the facility was completed. Metal veins used to direct air within the circulation ducts produced a high pitched whining sound when the air reached certain temperatures and speeds. The high pitched sound made it impossible to work in the facility (Dean, 1983 54).

However, The Law Library Addition at the University of Michigan successfully demonstrated how a daylighting system could be used to provide natural illumination in the facility that was completely integrated into its site. The hybrid system combining both sidelighting and toplighting strategies redirected natural light down into a facility in a dynamic fashion. The estimated lighting levels showed that natural illumination was possible in a facility that was completely integrated into its site. This facility was a good example of how natural light was integrated into the building's overall design.

Case Study Three: Williamson Hall, The University of Minnesota, Minneapolis

Project: ....Office of Admissions and Records, Student Bookstore
Location: ....University of Minnesota, Minneapolis
Project Size: ....86,500 SQ. FT. (includes 1982 addition)
Completion Date: ....1977 (addition 1982)
Architect: ....BRW Architects Inc. Minneapolis, Minnesota
Type of Underground Space: ....Cut-and Cover
Type of Daylighting Strategies: ....Sidelighting
Toplighting
Estimated Daylighting Levels:
1st Floor Work Surface: ....36- 394 fc
2nd Floor Work Surface: ....6-72 fc

Williamson Hall, located on the campus of the University of Minnesota, represented one of the first large scale underground facilities built in the United States. The 86,500 square foot. multi-use facility designed to house the university's admissions and records offices and the campus bookstore was 95 percent earth integrated. Williamson Hall provided another good example of how daylighting and earth integration was combined to provide a well balanced facility. The initial cost of the facility was $3.5 million and construction was completed in 1977. A 6000 square foot addition was completed in 1981 for an additional cost of $800,000

Facility Description

The overall design concept for Williamson Hall, like many earth integrated structures, developed out of a need to preserve scarce open space, preserve views of historic buildings, and preserve the established pedestrian circulation pattern that

diagonally bisected the site. The driving force behind the design of the two story facility was to achieve a balance between energy conservation and user satisfaction. The 86,500 sq. ft. facility incorporated the university's admissions and records offices and the campus bookstore into a two story facility that was 95 percent integrated into its site, with only a small lounge and the entry way giving one a hint of the two story structure that lay below. Williamson Hall's entire building mass was hidden below grade. Two of three main entrances to Williamson Hall allowed pedestrians to enter to the building one level below grade. A sunken courtyard at one end of the site allowed pedestrians to enter the facility horizontal. The change in grade across the site made it possible to enter the facility horizontally on the other side of the site.

Figure 26 Aerial view of Williamson Hall. Source: Underground Building Design, 1987, pg. 119.

The interior of the facility was designed to evoke a feeling of openness and to emphasize the available natural light and views. The campus bookstore was located on the lowest level in the southwest portion of the facility. The bookstore was designed as one large open space. The offices of admissions and records, located in the northeast portion of the facility, were arranged in a typical open office format with private offices located along the back walls. The two quadrants of Williamson Hall were bisected diagonally by a pedestrian walkway at grade level. A central concourse, which acted as the facility's main circulation spine, was located one level below grade. A sunken courtyard, located one story below near the offices of admissions and records, was used to allow more natural light to reach the interior spaces of the facility. Since the majority of the building was located below grade, the roof of Williamson hall was used as urban plaza area (see figure 26).

Structural System:

The main structure of Williamson Hall was composed of cast-in-place reinforced concrete. Cast-in-place reinforced concrete waffle slabs were used for the roof and the intermediate floor. The lowest floor was reinforced concrete slab on grade. The column supports and walls were also cast-in-place concrete. The major components of the structure were exposed in the interior of the facility, which created complex geometric patterns that provided visual interest within the facility.

Mechanical Systems

As another example of energy efficiency in design, Williamson Hall incorporated a variety of energy conserving features that included both active and passive systems. Williamson Hall received its energy, in the form of steam, from the campus central plant and used it for both its heating and cooling cycles. The steam was piped through a low-pressure variable air volume distribution system that ran throughout the building. The system was also offset by the use of direct solar gain (daylighting) through the glazing system and an active solar collection system that was added in 1980.

Artificial Lighting System:

The artificial lighting system used in Williamson Hall was a combination of metal halide lamps that were used for general lighting throughout the building and movable ceiling mounted fluorescent fixtures used for task lighting. Estimated lighting levels were 70 fc for task lighting and 35 fc for general lighting. The lighting system was offset by the use of passive daylighting (see figures 27-29).

Type of Underground Space:

Although only 7 percent of Williamson Hall's roof structure actually supported soil, it was still categorized as being a cut-and-cover underground space. The facility itself stepped down two levels below grade and took the form of a square that was bisected diagonally by pedestrian circulation both inside and outside the facility. Seventy five percent of the roof structure was covered with concrete pavers that formed a urban plaza that Williamson Hall. The remaining portion of Williamson Hall's roof was

comprised of conventional built-up roofing. Only 2 percent of the facility's exterior walls were not covered with earth.

Due to the nature of this type of facility, special emphasis was placed on three key areas of the design: the entry, interior design and exposure to natural light and view. All three areas are very important in any successful underground facility. To maximize the amount of natural daylight light that entered the facility, 80 percent of the building's interior space was laid out in an open office plan. The remaining 20 percent of the building consisted of private offices that were placed around the perimeter.

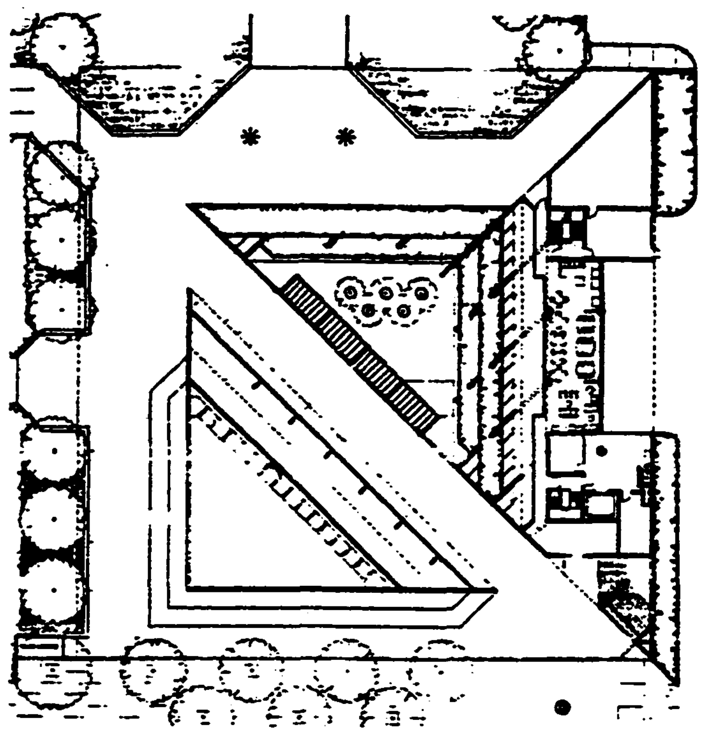


Figure 27 Ground level of Williamson Hall. Source: Underground Building Design, 1987, pg. 121

The offices of Admissions and Records, located in the northeast portion of the facility, were arranged around an exterior courtyard that was located one story below grade. The courtyard allowed more offices to gain access to natural light and views outside. The bookstore, designed as a big wide open two story space, was located on the lowest level in the southwest portion of the facility. The bookstore gained access to natural light though high angled clerestory windows

The bookstore was bisected diagonally by a mezzanine level that acted as the main circulation system inside the building. The mezzanine level looked out over the bookstore below and created a feeling of openness within the building. The complex shapes within the structure, created by the exposed structural system, provided the user with a unique underground experience that rivals any above grade facilities.

Structural System as it Relates to Daylighting

The structural system that was chosen for Williamson Hall, as mentioned previously, consisted of cast-in-place reinforced concrete. This type of system was chosen because of its ability to handle extreme earth loads as well as being easily manipulated to create large open areas and provide large openings for natural daylight to enter the facility.

Since the main objective for the design of the interior was to create a feeling of openness and maximize the available light and views, cast-in-place was a natural choice. In the initial stages of the design it was decided that the bookstore employees and visitors, due to the dynamic nature of the function, needed less sun, light and stimulation from the outdoors than office workers. As a consequence, the bookstore main sales floor

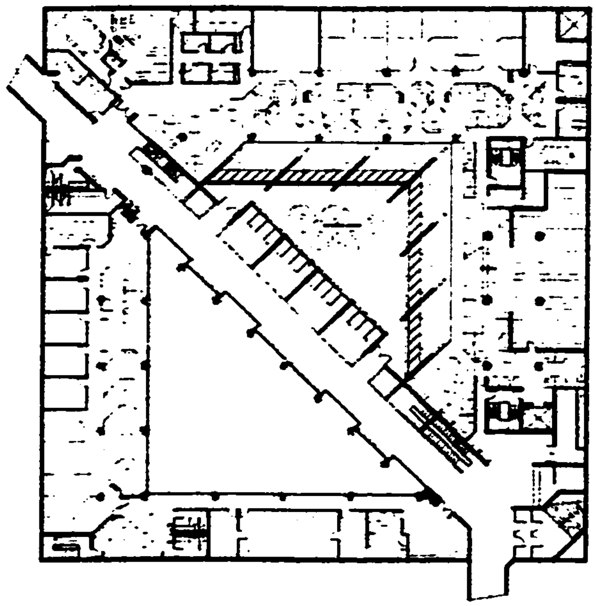


Figure 28 First level plan of Williamson Hall. Source: Underground Building Design, 1987, pg. 122

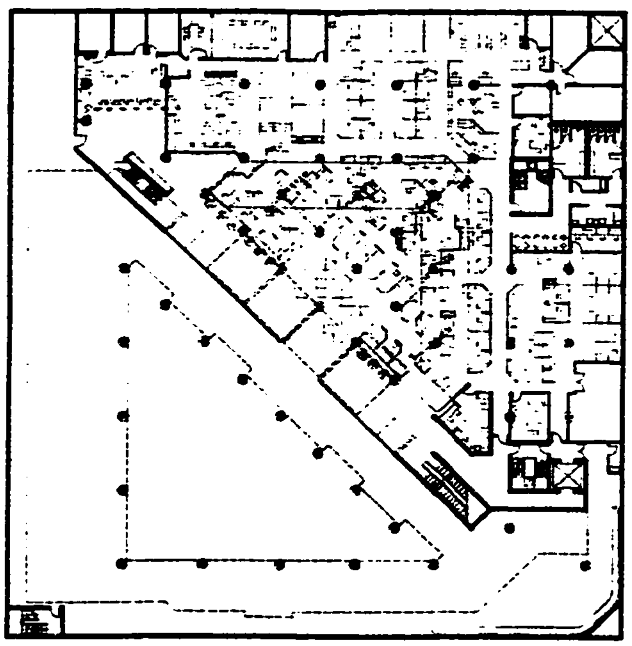


Figure 29 Second level plan of Williamson Hall. Source: Underground Building Design, 1987, pg. 123

was located on the lowest level of the two story structure. The circulation concourse, which provided a panoramic view down into the bookstore and bisected the building, was located one level above the main floor of the bookstore. The first level of Williamson Hall was designed as a mezzanine, which allowed more natural light to reach the lower level through the angled glazing system. The sloped glazing system was used to permit a greater amount of light to reach the lower level while it provided views outside. On the other side of the building, the office of Admissions and Records were laid out in a typical open office format and were arranged around a sunken courtyard. The first level was stepped back away from the glazing area which allowed natural light to reach the offices on the lowest level. The low partitions in the office area provided flexibility and a sense of spaciousness, but also allowed natural light to reach deep into the facility. Private offices were placed along the perimeter of the building to provide more privacy. Throughout the facility, concrete walls and structural elements were exposed, reducing the feelings associated with being in a typical basement. This association was further

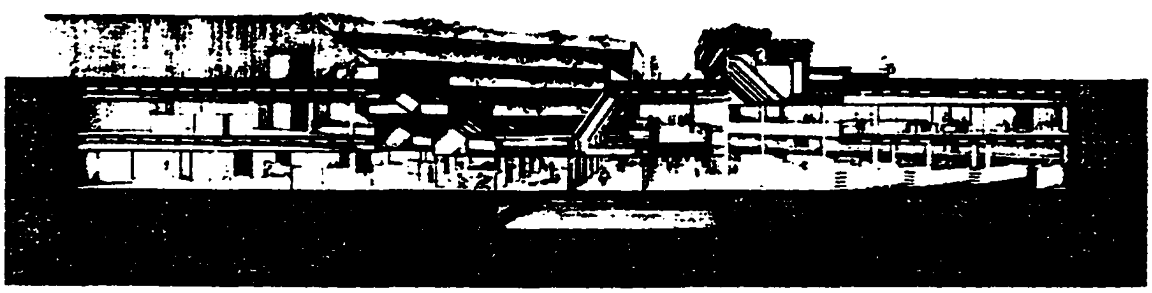


Figure 30 Section through Williamson Hall. Source: Underground Building Design, 1987, pg. 125

reduced by complex geometric patterns formed by the structure itself, the fluted texture of the concrete, and the extensive use of color. The rough textured cast-in-place concrete structure was also softened by using natural birch wood detailing, and the abundant use of plants. The structural system that was used at Williamson Hall was categorized as being a non-restrictive structural system that allowed natural light to enter and be distributed throughout the facility without any major problems (see figure 30 Carmody, 1983, 121).

Solar Orientation

Williamson Hall used only 3 percent of the total floor area for glazing to allow natural light into the facility. Solar orientation became critical when such a limited amount of glazing was used for this size of building. As mentioned previously, Williamson Hall was designed as a square building that was bisected diagonally on its north-south axis by pedestrian circulation, both on the surface as well as inside the facility itself. Most of the glazing in the facility was oriented to the south and west. Due to the location of the glazing, the facility was supplied with ample amounts of unobstructed daylight throughout the day, even in the winter months. The south facing glass areas were shaded in the summer months by tiers of planters which contain ivy.

In the winter months, the ivy loses its leaves and allowed more natural light to enter the facility. Due to their size, the buildings that surrounded the site did not affect the amount of natural light that reached Williamson Hall (see figure 31).

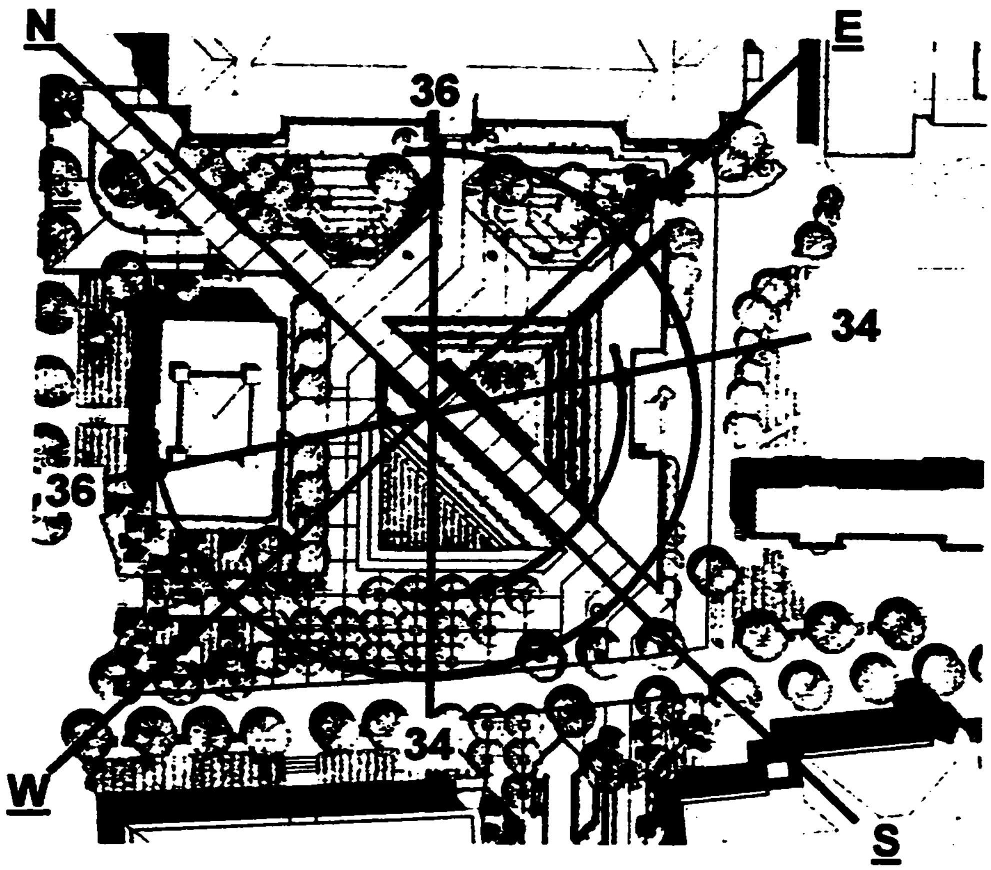


Figure 31 Solar Orientation study of Williamson Hall. Source: Underground Building Design, 1987, pg. 121.

Daylighting Design Concept

Psychological benefits gained by the use of natural light, not energy conservation, was the fundamental motivation for the use of natural daylight in the facility. The daylighting system used at Williamson Hall was an integral part of the overall design of the facility. The concepts that were implemented into the design of facility included the use of side-lighting, in the form of angled clerestory windows, and the use of an exterior sunken courtyard. Both provided ample amounts of natural light and views to reach inside the facility. The first floor of the facility was designed as a mezzanine and was

stepped back away from the glazing areas to allow more natural light to reach the lowest level. Oriented towards the south and west, the clerestory glazing areas were set at a 45 degree angle to provide more light inside the facility while still providing horizontal views from inside the building. By using sloping glazing the architect created a more open effect than would have been achieved by using the skylight strategy that was first proposed with the design. The office areas were laid out in a typical open office plan and used low partitions to divide up the space. The use of low partitions rather than walls to divide up the areas allowed natural light to reach further into the facility without being obstructed. This strategy allowed major spaces within the building to feel large and airy. The bookstore, located on the lowest level, was again designed as a large open space to allow natural light to reach the main floor through high clerestory windows. Employees of the bookstore have said, "there is so much light you can look out and you don't have the feeling of being underground or crowded". Throughout the facility, the passive daylighting strategy used in conjunction with fluorescent task lighting and metal halide general lighting provided ample amounts of light to produce a bright and comfortable interior, even though it was underground.

To protect the facility against solar heat gain while still allowing diffused light to penetrate the building, tiers of planters were placed over the major areas of south and west facing glass. Engleman ivy hung from these planters and shaded the glazing area in the summer months, but in winter months the ivy drops its leaves and allowed the facility to gain more solar radiation.

The interior color scheme for this facility played an important role in the overall acceptance of people who used it. The rough textured cast-in-place reinforced concrete

exposed structural system dominated the interior. The appearance of the concrete was softened by natural birch wood detailing. The cold appearance of the structural system was offset by the use of bright primary colors on the exposed building systems and the furnishings in the office areas, which over time has given away to a more muted pastel color scheme (Dean, 1978, 48).

Application of Proposed Daylighting Design Parameters

The vast sloped glazing and the sunken courtyard were an outstanding examples of a building that used the exposed daylighting elements to produce a distinct building image, both for the exterior and the interior. This daylighting system also provided a broad visual connection to the outside and a feeling of spaciousness. The spaciousness was enhanced by the avoidance of full interior partitions. The major circulation pattern, including the diagonal path of the mezzanine, is emphasized by its alignment with the daylighting structure. The considerable daylight transmitted through the large window areas was one of many elements that contributed a sense of the high quality to the space. Natural light was de-emphasized in the bookstore area, a decision of the designer that the dynamic nature of the activity there would lessen the need for natural light. As noted below, this was a decision that led to decreased occupant satisfaction in this space.

The design response exhibits the following daylighting design strategies:

- A sunken courtyard
- Minimal use of full interior partitions
- The use of stepped levels
- The use of deciduous plants to allow seasonably controlled daylight penetration

Estimation of Daylighting levels Achieved

As mentioned previously, lighting levels were estimated for June 21, the summer solstice, at 12:00 o'clock noon. The results achieved reflected the greatest amount of natural light that would reach the interior spaces within Williamson Hall. The following chart shows the range of available levels of natural illumination for two key areas in the facility (see figure 32). These results proved that a properly designed daylighting systems provide ample amounts of natural light in a facility having two floors below grade.

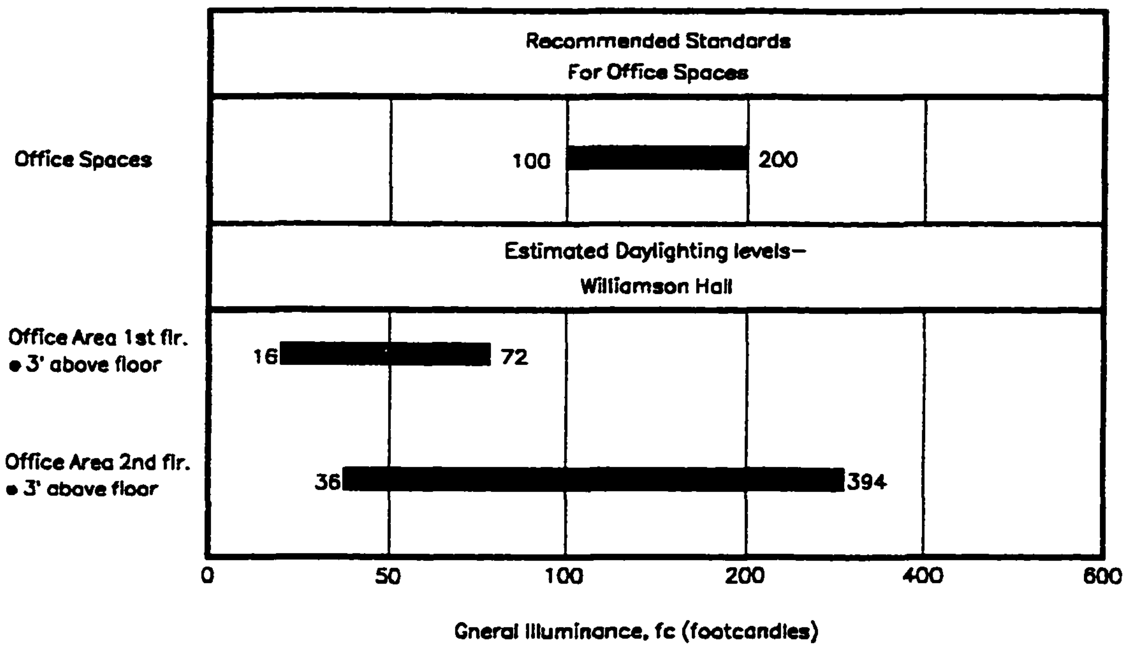


Figure 32 Estimated lighting levels at the Michigan Law Library Addition

Case Study Three Summery

Williamson Hall has shown the effective use of the following daylighting Strategies:

- Sidelighting
- Toplighting
- Active / passive solar collection systems

These made it another good example of how natural light was used as an integral design element in earth integrated facility. It proved that with a very limited amount of glazing one could provide an ample amount of natural light to relieve fears that were usually associated with being underground. The facility proved by effectively integrating an active solar and conventional HVAC components one could also enhance attainable energy savings through earth sheltering. This project provided valuable knowledge that helped in the development of future earth integrated facilities.

However, the facility was not without its faults. Leaks had developed around the sloped glazing system, an inherent problem with this type of glazing. Another problem concerned the performance of the sloped glazing system, which caused greater heat loss through its sloped glazing than through vertical glazing. There were complaints from office workers that it was too noisy in the facility which reflected a common problem with open office layouts. There was not much that could be done to fix this problem. The tiers of planters that were used to shade the south and west facing glass also caused problems. The landscaping was not maintained properly and as a result direct sun light was able to penetrate through glass areas and increased solar gain in summer months.

Architects originally planned for a louver system but this proposal was turned down by the building committee. However, It was interesting to note that the building, with all the problems, still used less energy than larger above ground facilities on campus.

Case Study Four: California State Office Building No. 3,

Sacramento California

Project:	California State Office Building Site No. 3
Location:	Sacramento, California
Project Size:	264,000 SQ. FT.
Completion Date:	1982
Architect:	The Benham Group Oklahoma City, Oklahoma
Type of Underground Space:	Cut-and Cover
Type of Daylighting Strategies:	Sidelighting
Estimated Daylighting Levels:	
Work Surface by East Facing Glass:	23-358 fc
Work Surface Between North & South facing Glass:	6-28 fc
Work Surface by East & West Facing Glass:	92-450 fc

The design for the California State Office Building in Sacramento, California was the result of a national design competition concerned with energy conservation. The 264,000 square. foot complex, covering one-and-a-half city blocks, was designed with many innovative energy efficient systems. The most predominant energy efficient features of this facility were the use of earth sheltering and solar technology.

The facility, which formed part of the Sacramento Capital Area plan, was developed in two components to maximize energy efficiency and to resolve many of the site constraints. The first component of this facility consisted of a six story office building located at the north end of the site. With its sloping facade and the 25,000 square feet of concentrating solar collectors, the six story office building was provided with a dominate visual image. The second component consisted of 75,000 square feet. of office space and an auditorium. This portion of the facility, located at the south end of the site, incorporated the use of earth sheltering technology. The two components of

the facility were linked together by a open air subterranean commons. This facility provided an opportunity to investigate how a variety of energy efficient systems were implemented into a facility that incorporated earth sheltering and standard on grade construction. Construction of the facility was completed in 1982 at a cost of $18.5 million (see figure 33 Kosaa 1987, 128).

Figure 33 Aril view of the California State Office Building Site No. 3. Source: Underground Building Design 1983, pg. 129

Facility Description

The primary force behind the design of the California State Office Building was to conserve energy. The 264,000 square foot facility, which incorporated 1.5 city blocks, demonstrated an aggressive approach to energy conservation. The 264,000

square foot facility was programmed to house governmental offices and an 150-seat auditorium.

To accommodate the site being bisected by a public street, the facility was developed in two distinct components that were typical of most office buildings with a few exceptions. The major exception was that 75,000 square feet of this facility, which included office space and an auditorium, was integrated into the site. The earth integrated component of the facility encompasses a complete city block and was located in the southern half of the site.

The other 189,000 square feet component of the facility, located in the northern half of the site, consisted of a six story structure that was designed to maximize the use of solar energy. Each floor of the six story structure stepped back at a 45 degree angle which gave the building its distinct image. By sloping the southern facade of the six story structure, the architect was also able to visually connect the two different components of the facility.

The main entrance gallery to the California State Office Building was centrally located within the six story structure at the north end of the site. Access to the earth integrated portion of the facility was provided by an open-air subterranean commons that was an integral part of the main entrance of the six story structure. At the southern end of the site, long sloping ramps provided access to the central sunken courtyard. This sunken courtyard served as the main entrance for the office spaces below grade and also linked the two separate components of the facility together. The central sunken

courtyard also provided the major sense of orientation from both the exterior and interior spaces below grade (see figure 34)

Interior Design

The interior of the facility was designed to capture the available natural light and views, while protecting against solar heat gain. The interior of the six story structure was laid out to maximize the penetration of natural light into office and circulation spaces within the structure while minimizing solar heat gain. In the portion of the facility that was integrated into the site the office areas were laid out in close proximity to the exterior sunken courtyards. This allowed the majority of the office areas to be located within view of the windows.

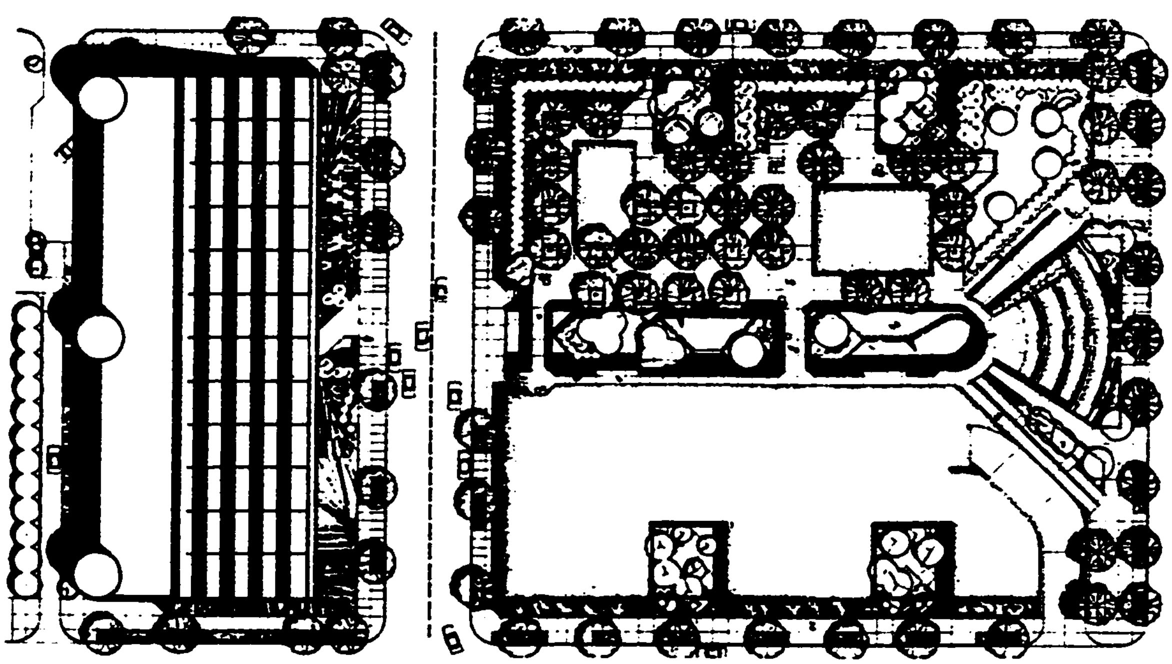


Figure 34 Overall Site Plan of the California State Office Building Site No. 3. Source: Underground Building Design 1987, pg. 131

Structural System

The structure system for the California State Office Building further reflected the differences in the two sections of the facility. The 75,000 square foot section that was integrated into the southern portion of the site had a structural system typical of this type construction. The main component was comprised of cast-in-place reinforced concrete. A cast-in-place reinforced concrete waffle slab was used for the roof. The floor system in this portion of the facility was a reinforced concrete slab on grade. The column supports and walls were also cast-in-place concrete. It was interesting to note that the structural system in this portion of the facility was designed to support a future housing development proposed on a part of the site.

A steel skeletal system was used in the six story portion of the facility. This type of structural system, typical of conventional construction, allowed more flexibility in the design of the interior spaces within the six story structure.

Mechanical Systems

Since the driving force behind the design of the California State Office Building was energy conservation, the facility incorporated a variety of energy conserving features that included both active and passive systems. The California State Office Building's entire HVAC system was controlled by computers that monitor and select the most efficient way to heat and cool the facility. During the winter months heat pumps supplied hot water from concentrating solar collectors and reclaimed heat generated from various building functions to baseboard fin tubes and the variable-air-volume distribution system that ran throughout the building.

During the summer months, the same hot water from concentrating solar collectors was used to drive an absorption machine that produced chilled water which was then fed to the variable-air-volume distribution system. This system was supplemented by nighttime cooling of the facility with the HVAC systems' economizer cycle. A rotary screw compressor and a brine chiller, which made and stored ice during nighttime hours, provided additional energy for peak daytime use.

Artificial Lighting System

Extensive testing was done before a lighting system was integrated into the California State Office Building. The system that was ultimately selected incorporated three foot by three foot fixtures with two pair of criss-crossing fluorescent lamps within each fixture. The fixtures were set into a five foot by five foot ceiling module and used for general lighting throughout both sections of the building. The lighting system was offset by the use of task lighting and passive daylighting. To capitalize on the potential energy saving associated with using natural light within the building, the lighting system was linked to photoelectric cells near each light court. The photocells automatically turned off a portion or the entire lighting system when adequate levels of natural illumination were provided by the light courts (Kosaa 1987, 135).

Type of Underground Space

The California State Office Building was unique in that the facility incorporated both an above grade structure and an earth sheltered structure which were both linked together by an open-air circulation spine centrally located one level below grade. The

75,000 square foot portion of the facility that was integrated into the site was categorized as being a cut-and-cover underground space. One hundred percent of the walls of the facility were in contact with earth. Of course, this figure didn't include the sunken courtyards located around the perimeter or the centrally located sunken circulation spine. One hundred percent of the exposed roof was covered with earth ranging in depth from 9 inches to 3 feet. The portions of the roof not exposed were developed into a city park and plaza area.

Like most earth integrated facilities, special emphasis was placed on three key areas of the design: the entry, interior design and the exposure to natural light and view. To maximize the amount of natural daylight that entered the facility the majority of the building's interior office spaces were arranged around exterior courtyards. The courtyards that were located along the east and west sides of the facility and the central open air subterranean commons used for circulation. These sunken courtyards, accented with plants and fountains, also created a transition area to the below grade space. The open-air subterranean commons, which divided the earth integrated office space into two sections, acted as the main entrance for the facility. Two diagonal ramps, located at the south end of the site, allowed pedestrians to gain access to the open air subterranean commons. Exterior stairways located in each of the sunken courtyards provided secondary entrances to the facility. Each section of the facility was designed with windows that faced this centralized exterior open space which provided more office spaces with views to the exterior. These windows provided the user with a visual link to the outside that was so important in this type of facility (see figures 35-36).

Structural System as it Relates to Daylighting

The structural system that was chosen for the California State Office Building, as mentioned previously, consisted of two distinct types of systems that were related to each type of building. The structural system that was used in the underground portion of the facility was cast-in-place reinforced concrete. This type of system was chosen, as mentioned in earlier case studies, because of its capacity to handle earth loads as well as its ability to be easily manipulated to provide large openings which allow natural daylight to enter the facility.

In the initial stages of the design it was determined that office workers needed stimulation to provide a relief from the otherwise monotonous environment typical of most offices. This issue became critical when placing office areas below grade. Courtyards were incorporated into the design to alleviate this problem

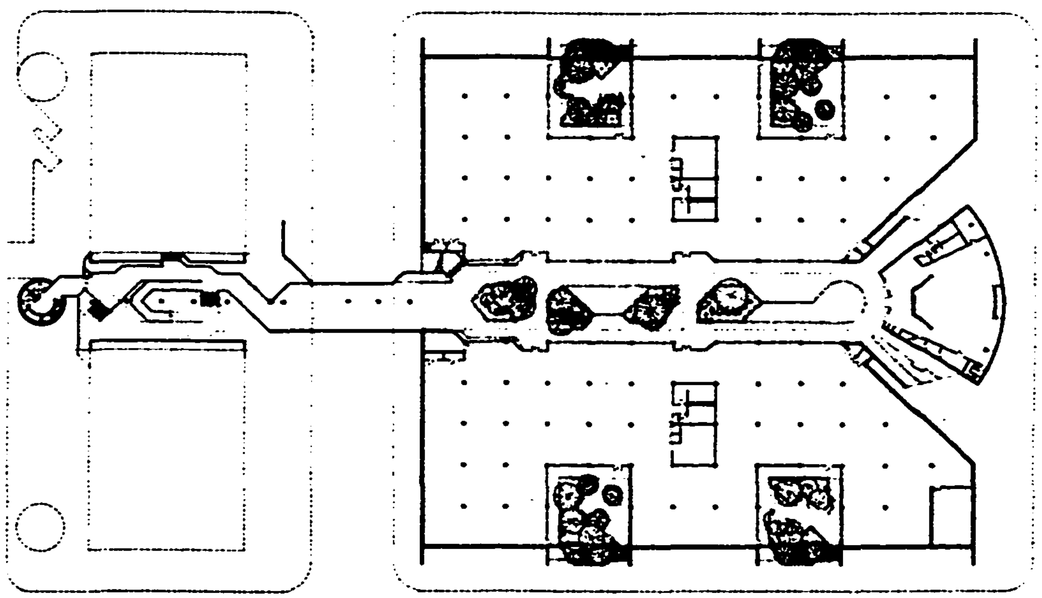


Figure 35 Floor plan of below grade portion of the California State Office Building Site No. 3, Source: Underground Building Design 1987, pg. 133.

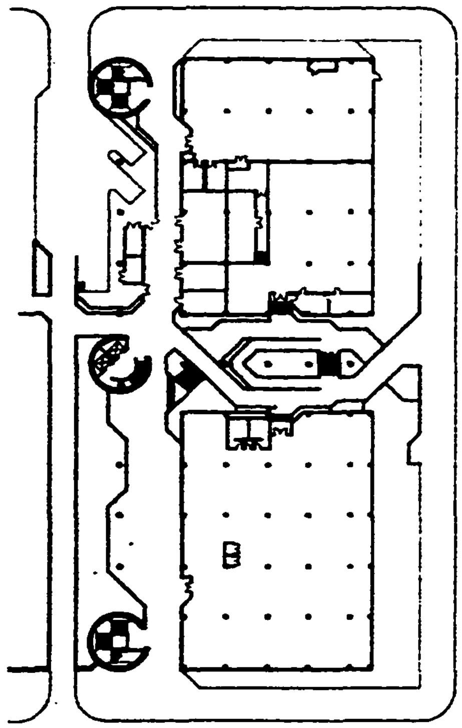


Figure 36 Typical floor plan of above grade portion of the California State Office Building Site No. 3. Source: Underground Building Design 1987, pg. 132.

They were also located around the perimeter and in the center of the underground facility. These courtyards were located in areas that allowed the majority of the underground office space to be within view of an exterior window. These windows also allowed natural daylight to enter at different points throughout the facility so the occupant was consciously aware of being surrounded by natural daylight in most areas.

A steel skeletal frame was used in the six story above grade portion of the facility. This type of structural system allowed more flexibility in the design of its exterior facade and interior spaces. The north facade of the six story portion of the facility was designed as a self shading reentraant (discussed in Chapter 2). This allowed natural light to enter the facility while protecting it against direct heat gain. The placement of solar collectors and large building overhangs on the sloping south facade protected south facing windows

from direct sunlight but allowed diffused light to enter the facility.

Both structural systems used at the California State Office Building were categorized as being a non-restrictive structural system that allowed natural light to enter the facility and be distributed throughout without any major problems (see figure 37 Kosaa 1987, 128).

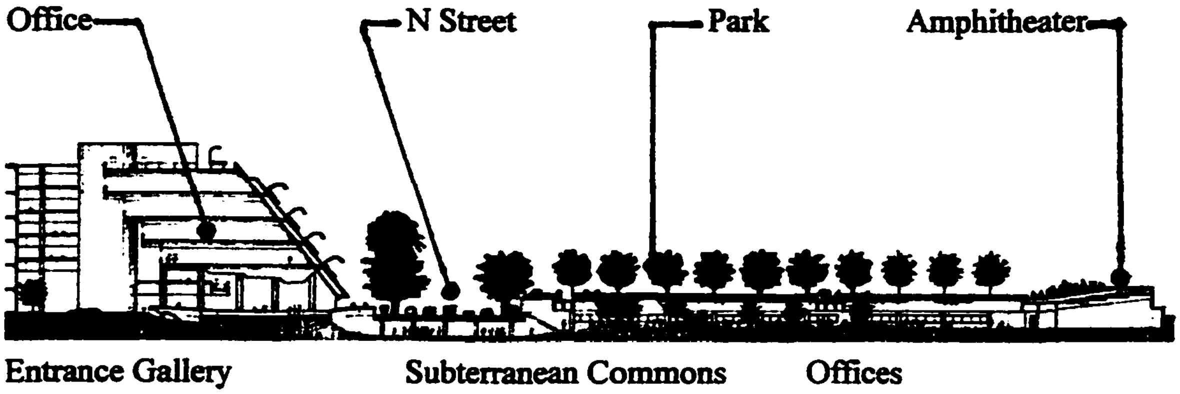


Figure 37 Section through the California State Office Building Site No. 3, Source: Underground Building Design 1987, pg. 130.

Solar Orientation

Since the primary force behind the design of the California State Office Building was energy conservation, the buildings overall form of the facility reflected the importance of solar technology as a way of conserving energy. The six story structure's major axis ran east to west thus maximizing the exposure of the solar collectors located on the sloping southern facade. By placing the major axis of the structure in the east to west direction, direct solar exposure to the east and west facades of the structure was minimized. Most of the glazing in the six story structure was oriented to the south. The

south facing glass areas were shaded by the placement of solar collectors and large building overhangs. The north facing glazing was completely protected from direct solar exposure by the structure itself.

The major axis of the portion of the facility that was integrated into the site ran north to south. Even though the glazing in this portion of the facility faced east and west, the glazing was protected from direct exposure by large overhangs and the use of landscaping in the perimeter courtyards.

Due to the location of the glazing areas, both portions of the facility were supplied with ample amounts of unobstructed daylight throughout the day, even in the winter months. Due to their size, the buildings that surrounded the site did not affect the amount of natural light that reaches either portion of the facility (see figure 38).

Daylighting Design Concept

The psychological benefits gained by the use of natural light was a major motivational factor for the use of natural daylight in the facility. The daylighting system used at the California State Office Building was an integral part of the overall design of the facility. The concepts that were implemented into the design of the facility consisted of sidelighting and borrowed lighting. Sidelighting took the form of windows that looked into exterior sunken courtyards. Borrowed lighting came in the form of glass partitions in areas not directly adjacent to windows. Both provided ample amounts of natural light and views for the facility. The layout of office space and the exterior courtyards was designed to place the majority of the office areas within view of the windows. The use of glass partitions allowed natural light to reach further into the

facility without being obstructed. The passive daylighting strategy in conjunction with fluorescent general lighting and task lighting provided ample amounts of light to produce a bright and comfortable interior.

To protect the six story portion of the facility against solar heat gain while allowing diffused light to penetrate the building, solar collectors and building overhangs were designed to protect major areas of south facing glass. The north facade, which was designed as a self-shading reentrant, protected north facing glass from direct solar heat gain, while it provided ample amounts of natural light to reach the interior of the facility.

As mentioned in the earlier case studies, the color scheme for this facility played an important role in the overall acceptance of people who used it.

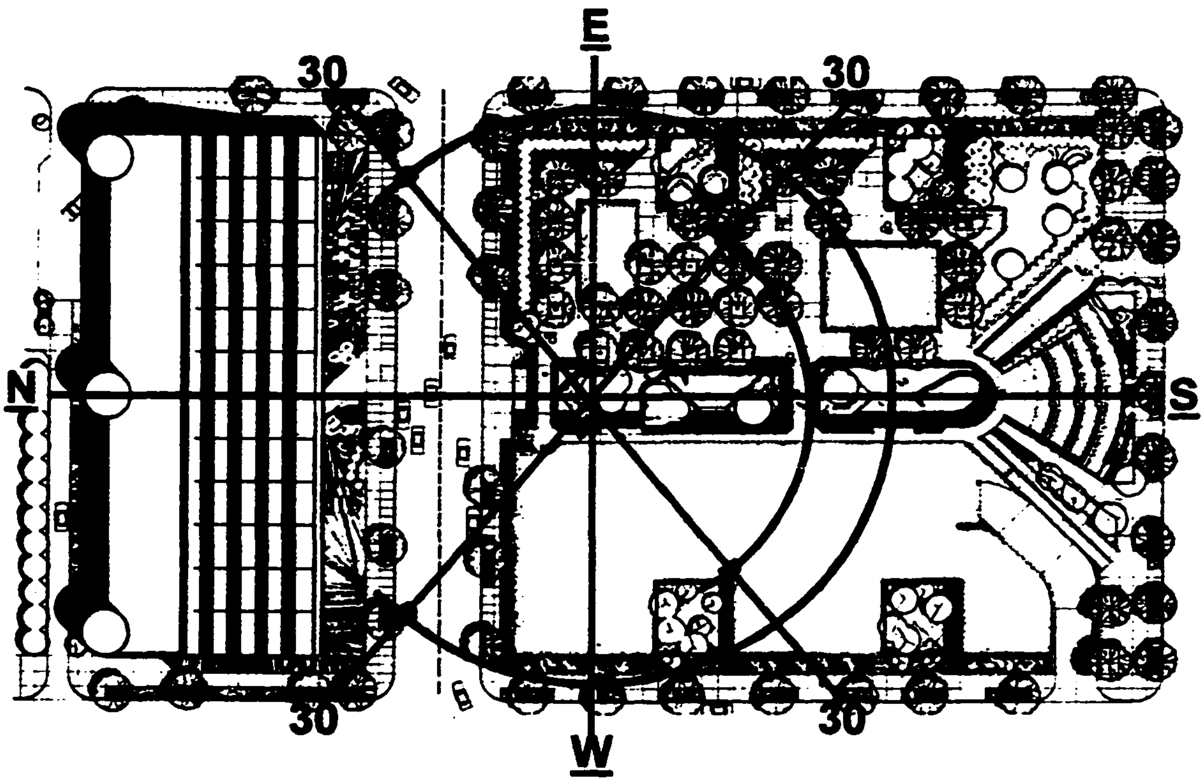


Figure 38 Solar Orientation study of the California State Office Building, No. 3.
Source: Underground Building Design 1987, pg. 130.

White stucco walls and light-colored concrete paving were used in the courtyards to maximize the amount of natural light that was projected into the facility. The interior of the building also used light colors to help reflect natural light deeper into the facility.

Application of Proposed Daylighting Design Parameters

The California State Office Building was another sunken courtyard building that used its above-ground glazing to create a distinct building image at ground level. The exposed courtyard windows also provided a visual connection to the exterior. As the main interior circulation pattern was along the exposed windows, the circulation and daylighting structure were also integrated into one another. This facility exhibited the design strategies which consisted of:

- The use of sunken courtyard for daylighting
- Circulation paths aligned along the vertical daylighting structure
- Occupied areas aligned along the vertical daylighting structure
- The use of transparent partitions to transmit natural light deep into interior

Estimation of Daylighting levels Achieved

Lighting levels were only estimated in the portion of the California State Office Building that was below grade. Using June 21 at 12:00 o'clock noon as a standard, the results reflected the greatest amount of natural light the would reach the interior spaces within that portion of the California State Office Building #3. The following chart shows

the range of available levels of natural illumination in three key areas in the facility (see figure 39).

Case Study Four Summery

The California State Office Building demonstrated the effective use of the following daylighting strategies:

- Sidelighting
- Borrowed light
- Active and passive solar collection systems

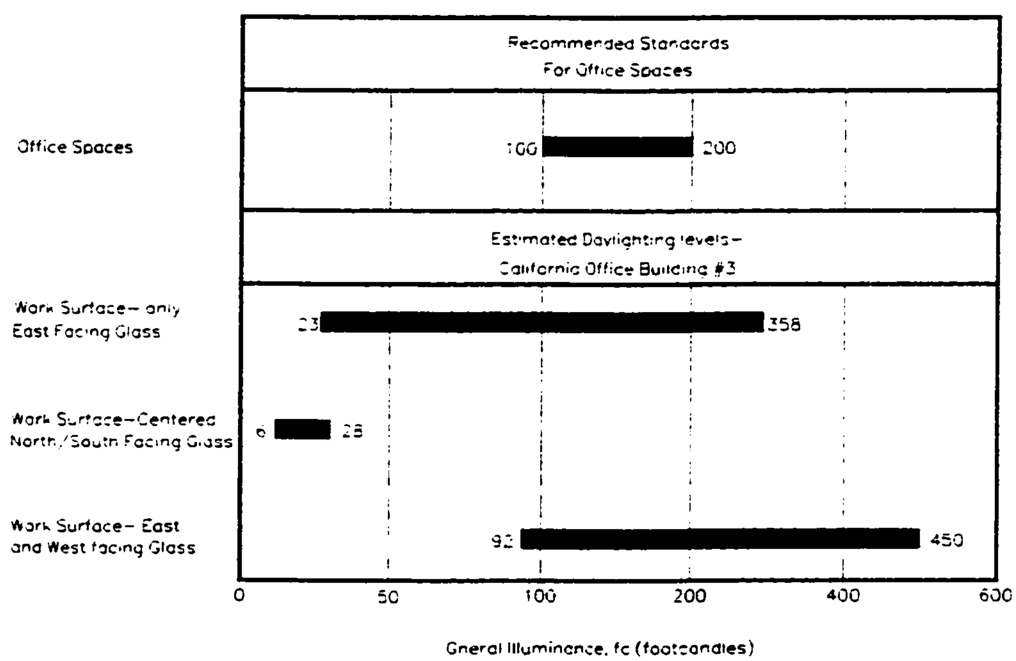


Figure 39 Estimated lighting levels at the California State Office Building No. 3

California State Office Building No. 3 another good example of how natural light was used as an integral design element in an above ground facility that also incorporated earth integrated areas. The facility proved that by effectively integrating active solar and conventional HVAC components to enhance energy savings attained by earth sheltering techniques. This project provided valuable information that could aid in the design of future projects that planned to incorporate above ground facilities with areas integrated into the earth.

Comparative Summary of The Four Case studies

Data that was collected during the case study investigations provided information that was conclusive to the idea that natural daylight could be used as a primary design element in earth integrated structures (see figure 40). Natural daylight was an integral element in the building designs that were investigated in this study and, as a result, natural illumination levels within these facilities were in fact significant. In many of the cases the estimated lighting levels met or exceeded the Illuminating Engineering Society (IES) standards for that type of space and activity. The Civil and Mineral Engineering Building's circulation spaces, with an highest estimated lighting level of 167 footcandles suggested that on average about 50% of the recommended lighting levels were met by using natural daylight in those spaces.

The circulation spaces within the Michigan Law Library Addition, with the highest estimated lighting level of 580 footcandles, exceeded the recommended requirements needed to perform visual tasks associated with this type of space. Both facilities incorporated the use of top lighting concepts, one could draw the conclusion

that toplighting concepts were a good device to be used in circulation spaces within earth integrated facilities.

Estimated lighting levels for work spaces in Williamson Hall and The California State Office Building #3 were also significant. IES recommends a range from 500-700 footcandles for office spaces. The highest estimated level achieved at Williamson Hall was 394 footcandles and the highest estimated level achieved at The California State Office Building #3 was 450 footcandles. About 70 % of the recommended lighting level was achieved in these two facilities with natural daylight illumination. This suggested that sidelighting concepts provided the needed levels of illumination in those types of spaces.

It was important to note that the data collected throughout the case study investigations did provide enough information that could be organized to generate realistic parameters to provide daylighting strategies for initial stages of designing earth integrated facilities.

The case studies showed that the originally proposed set of design parameters did in fact appear as important elements in the buildings studied. The appearance of these elements in buildings specifically selected for their success in providing daylighting for earth integrated structures supported the validity of the proposed parameters as methods to achieve a successful building design.

An additional set of proposed parameters and techniques was developed out of the knowledge and understanding that was gained by investigating earth integrated facilities that incorporated the use of natural daylight as a source of illumination. Many

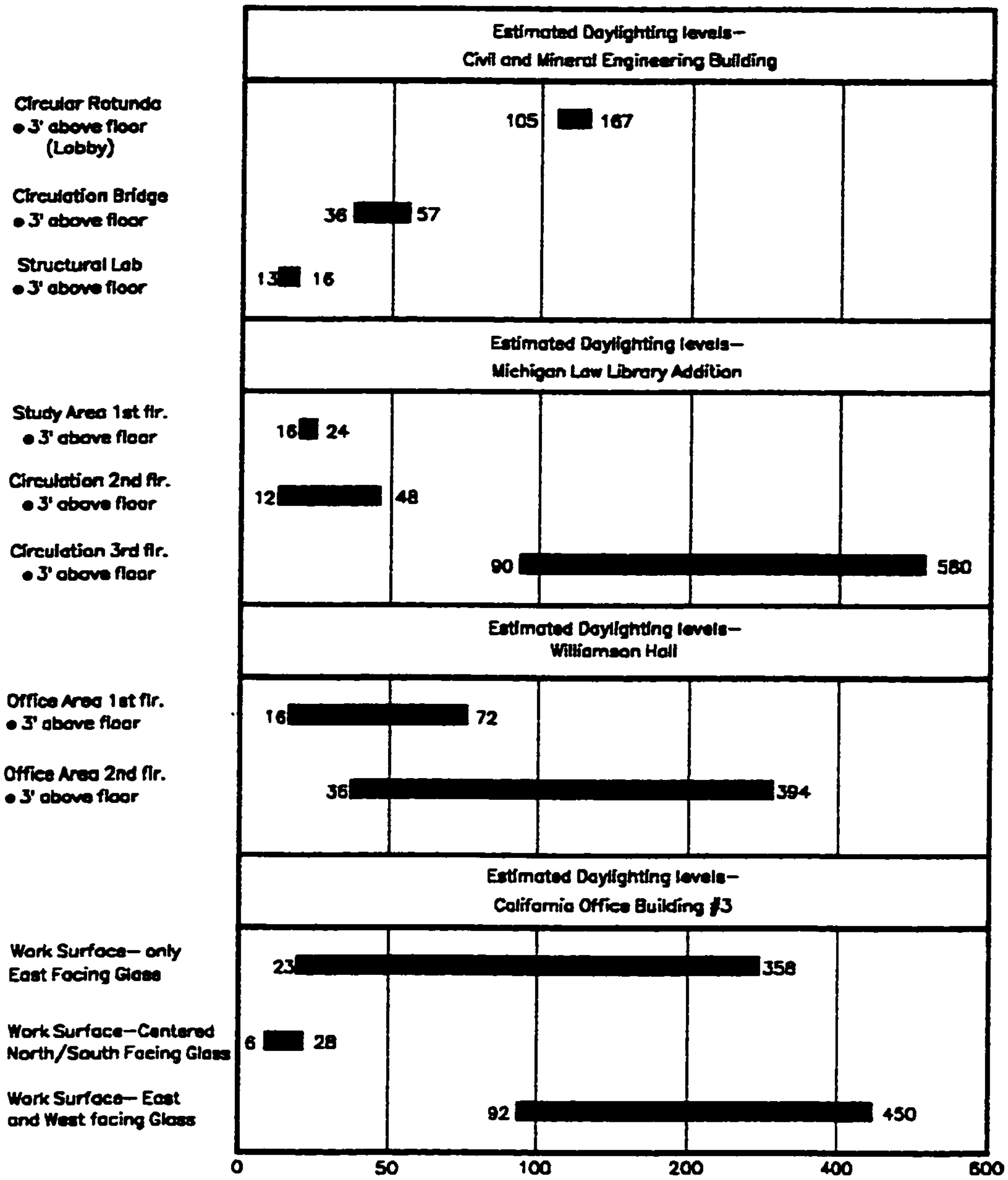


Figure 40 Comparative chart of estimated lighting levels achieved.

of these parameters came from observing the design strategies identified in the case study buildings. The design techniques observed were:

- Sunken courtyard to provide window area and visual link to exterior
- Transparent interior partitions to transmit natural light deep into interior
- Vertical spaces at high daylighting structures as major circulation nodes
- Active daylight transmission to deep underground spaces
- Variety in height and volume of interior spaces
- Two way light trough penetrating earth around building perimeter
- Use of structural elements as light-patterning element
- Introducing bounced light from sloped reflective surface
- Use of high floor-to-floor space to increase light penetration to interior
- Minimal interior walls
- Use of stepped levels
- Use of deciduous plants to allow seasonably controlled daylight penetration
- Circulation paths aligned along vertical daylighting structure
- Occupied areas aligned along vertical daylighting structure
- Other proposed techniques came from noting the problems or benefits observed from other aspects of daylighting or underground space in the case studies.

Originally Proposed Techniques

- Allow daylighting structures to create a distinct building image at ground level, including demarcation of the building boundaries and a clear and inviting entrance.
- Use daylight to delineate circulation patterns, such as paths and nodes of activity.
- Provide daylight in important major spaces to convey a feeling of high quality space.

- Use natural light to provide visual complexity and variety and a distinct interior image.
- Use natural light to create a distinct interior image.
- Provide vertical open spaces beneath daylighting structures to create a sense of spaciousness.
- Provide a visual connection to the exterior.

Additional Parameters and Techniques

The parameters developed provided a designer with basic rules to follow when designing an environment that is integrated into its site. The parameters were developed in relation to four fundamental aspects of the designed environment. The four aspects were:

- Climate
- Site topography
- Building mass and orientation
- Building organization

The purpose of these parameters was to provide the basic parameters on ways that natural light was used as a primary design element in earth integrated architecture. These parameters were by no means the only way of providing this type of environment with natural illumination. They were meant to provide a sample of the techniques that could be used to enhance the interior environment of building that used the earth as a primary design element.

Climate

- Use deciduous plants to allow seasonably controlled daylight penetration if proper future maintenance is assured.
- Where seasonal direct light reaches interior spaces, ensure that glare is avoided.

Site Topography

- Use a sunken courtyard for a distinct building image, light transmission to the interior, a horizontally-directed entrance, and a visual link to the exterior when surface space or building visibility are not a problem.
- Use prominent exterior daylighting structures when a distinct building image is desired but space at ground level is limited.

Building Orientation and Surface Appearance

- Where privacy is not an issue, avoid the use of full-height interior partitions to allow daylight to penetrate into the interior.
- Where privacy or light control are not an issue, use transparent interior partitions to allow daylight to penetrate into the interior.
- Consider active optic systems to transmit light to underground spaces having no connection to the surface.
- Provide trough along building perimeter as sunken perimeter atrium.

Building Organization and Structure

- **Use exposed building structure to provide visual stimulation and variety to interiors**
- **Emphasize major circulation areas with prominent daylighting structures.**
- **Align circulation patterns with linear daylighting structures.**
- **Vary height and proportions of interior areas to provide visual stimulation.**
- **Use building's structure as pattern producing elements within daylit spaces to provide visual stimulation.**
- **Use high floor-to-floor space to increase light penetration to interior.**
- **Allow successive levels to step back to increase light penetration to interior.**

CHAPTER 5

CONCLUSIONS AND PROPOSALS

Psychological and physiological benefits natural light have been well documented, Yet it seemed that utilization of natural light as a primary source of illumination in the built environment was kept to a minimum. However, the importance of using natural light was summed up in a quote by architect Louis I. Kahn, respected as one of the masters at using and manipulating natural light. He said,

> "A space can never reach its place in architecture without natural light. Artificial light, the light of night expressed in positioned chandeliers, not to be compared with the unpredicted play of natural light. The structures a design in light, the vault, the dome, the arch, the column are structures related to the character of light. Natural light gives mood to space by the nuances of light in the time of day and seasons of the year as it enters and modifies the space."

This investigator examined daylighting techniques used in four contemporary and existing underground facilities, which provided knowledge of the technology used in daylighting subterranean environments. The insights gained by analyzing these four commercial facilities for different regions of the country provided the justification for concluding that an detailed analysis of previously reported data on earth integrated

facilities could be utilized to provide effective initial daylighting design strategies for these types of buildings.

As the technology of daylighting grows, designed human environments will benefit and become more sensitive to the needs of their users. The following additional conclusions were drawn from the analysis of case studies in this investigation.

Conclusion and Proposals

As described in chapter 1, the purpose of the study was to determine if the following hypothesis was supported.

Would a thorough analysis of four building case studies generate sufficient data to provide realistic design parameters that could be used by a professional engaged in the initial stages of the design process to insure appropriate daylight design strategies for a particular earth integrated structure

After a thorough analysis of the building case studies and compared with the lighting levels of natural illumination that were estimated using Superlite 2.0 software as a check against the written data analyzed, it was concluded by this investigator that this method would provide adequate information for the initial stages of the building design process to better insure an appropriate daylight design strategy an earth integrated structures. The following proposals relating to particular daylighting strategies were generated from the case study investigations:

(1) The use of top-lighting concepts were a very effective means to bring natural light into a building. Many of the architectural forms used in this type of daylighting scheme

can enhance the building's overall exterior aesthetics as well as the particular spatial environments within the building.

(2) The use of sidelighting concepts were an effective means to bring natural light to areas that did not have direct access to exterior windows or views.

(3) Natural light was best used as a "building material" and manipulated in techniques that took advantage of the good qualities of light while reducing its harmful effects.

(4) The proposed design parameters outlined in Section 3.3 correlated with user responses for the earth integrated buildings analyzed in the case studies. As such, they were effective statements of design parameters and subsequent strategies utilizing natural light as a solution to aesthetic and psychological problems related to prolonging activities in underground environments.

However it was important to note that the design parameters that were generated by the case study investigations in this study only provided information that was to be used for the initial stages of design. To insure the selection of an appropriate daylighting system for implementation in the final design of a earth integrated facility, further in-depth investigations into particular daylighting systems and how they enhance the overall design and function of each individual facility and its spaces should be undertaken to insure the use of the most appropriate daylighting design strategies and techniques.

REFERENCES

Anderson, Bruce. 1981. Passive Solar Energy. Andover: Brick House Publishing Co.

Anderson, Grace. 1982. Architecture Beneath the Surface. Architecture Record. (March): pgs 77-85

Antoniades, Anthony C. 1986. Architecture and Allied Design. Dubuque: Kendall/ Hunt Publishing Co.

Bennett, D., and D. A. Eijadi. 1980. Solar Optics: Projecting Light into Buildings. The American Institute of Architects Journal. (March): pgs. 72-75

Boyer, Lester L. 1987. Earth Shelter Technology. College Station: Texas A&M University Press.

Carmody, John. 1983. Underground Building Design. New York: Van Nostrand Reinhold.

Carter, David. 1982. Build it Underground. New York: Sterling.

Cook, Jeffrey. 1984. Award-Wining Passive Solar Designs. New York: McGraw-Hill book Company.

Dean, Andre O. 1978. Underground Architecture. The American Institute of Architects Journal. (April): pgs. 34-43

__________. 1978. Evaluation: Bright Bookstore Cut into the Earth. The American Institute of Architects Journal (April): pgs. 46-51

__________. 1982. .Earth Sheltered Residential Design Manual. New York: Van Nostrand Reinhold.

__________. 1983. State-of-the-Art Underground Design. The American Institute of Architects Journal. (January): pgs. 64-67

__________. 1983. Splendor Beneath the Grass' in Michigan. The American Institute of Architects Journal. (January): pgs. 51-55

__________. 1986. Library Addition Inserted into a Hill. The American Institute of Architects Journal. (February.): pgs. 50-53

Darl Rastorfer. 1989. Building with the Sun. Architectural Record (May) pgs. 153-159

Debord, David Douglas. Earth Sheltered Landscapes. New York: Van Nostrand Reinhold Company.

Evans, Benjamin. 1981. Daylight in Architecture. New York: McGraw -Hill Book Company.

__________. 1984. Energy and Design. Progressive Architecture. (April): pgs. 85

__________. 1987. Basics of Daylight Design. The American Institute of Architects Journal. (February): pgs. 78-85

Fisher, Thomas. 1984. Energy and Design. Progressive Architecture. (April): pgs. 85

__________. 1986. Energy Past and Future. Progressive Architecture. (April): pgs. 114-123

Frenette, Edward R. 1981. Earth Sheltering. New York: Pergamon Press.

Gardner, James . 1984. Daulight Cuts Energy Use to 19,600 BTU Per Sq. Ft. Per Year. Architectural Record. (January): pgs. 139-143

Golany, Gideon. 1988. Earth Sheltered Dwellings in Tunisia. Newark: University of Delaware Press.

__________. 1990. Design and Thermal Performance. Newark: University of Delaware Press.

Greer, Norm R. 1983. Measuring Performance of Energy Design. The American Institute of Architects Journal (January): Pgs. 64-67

__________. 1983. Lighting Design: State of the Art. The American Institute of Architects Journal. (January): Pgs. 64-67

Holthusen, T. Lance. 1981. The Potential of Earth-Sheltered and Underground Space. New York: Pergamon Press.

James S. Russell. 1989. Living on Borrowed Light. Architectural Record (May) pgs. 150-153

Jankowski, Wanda. 1987. The Best of Lighting Design. New York: PBC International Inc.

Kurtich, John - Eakin, Garret. 1993. Interior Architecture. New York: Van Nostrand Reinhold.

Kosaa, Burt-Kantrowitiz, Min. 1987. Commerciial Building Design. New York: Van Nostrand Reinhold.

Lechner, Norbert. 1991. Heating Cooling Lighting: Design Methods for Architects. New York: John Wiley & Sons Inc.

Lam, William M.C. 1986. Sunlight as a Formgiver for Architecture. New York: Van Nostrand Reinhold.

______________ . 1986. Perception & Lighting. New York: Van Nostrand Reinhold.

Lechner, Norbert. 1991. Heating, Cooling, Lighting. New York: John Wiley & Sons.

Littlefair, P. J. 1991. Site Layout for daylight and Sunlight: A Guide to Good Practice. Garston: B.R.E. Publications.

Minnesota, University of. 1979. Earth Sheltered Housing Design. New York: Van Nostrand Reinhold.

Moore, Fuller . 1983. Daylighting: Six Aalto Libraries. The American Institute of Architects Journal. (June): pgs. 59-69

___________ . 1991. Concepts and Practice of Architectural Daylighting. New York: Van Nostrand Reinhold.

Pastier, John . A Milestone Takes Shape in California." American Instution of Architects Journal (January): pgs. 58-60

Robbins, Claude L.. 1986. Daylighting: Design & Analysis. New York: Van Nostrand Reinhold.

Schmertz Mildred F. 1987. Underneath A Garden. Architectural Record. (September): pgs. 112-121

Sterling, Raymond. 1981. Earth Sheltered Community Design. New York: Van Nostrand Reinhold.

Terman, Max R.. 1985. Earth Sheltered Housing. New York: Van Nostrand Reinhold.

Villecco, Marguerrite - Selkowitz, Steve - Griffith, J. W. 1979. Strategies of Daylight Design. The American Institute of Architects Journal (September): pgs. 68-92

Visher, Jacqueline C. 1987. The Psychology of Daylighting. The American Institute of Architects Journal. (June): pgs. 109-111

Wade, Herb. 1983. Building Underground. Emmaus: Rodale Press.

Wells, Malcolm. 1990. Notes from the Underground. New York: Van NostrandReinhold.

Wilson, Forrest. 1987. Daylight and the Human Eye. The American Institute of Architects Journal. (June): Pg. 112

APPENDIX A

GLOSSARY

Ambient lighting: Lighting throughout an area that produces general illumination, or light to see by.

Angle of Incidence: Angle at which light rays strike a surface, measured between the ray and a line perpendicular to the surface.

Atrium: An interior, covered open area in the center of the building.

Azimuth: The horizontal angular distance between the vertical plane containing a point in the sky and true north

Aperture - The rough opening in the structure of a building that admits daylight.

Baffle: A single opaque or translucent element used to shield a source from direct view at curtain angles, also used to absorb unwanted light.

Beam Daylighting: the intentional use of the direct component of sunlight to illuminate a building interior

Brightness: The subjective perception of luminance.

Candela: Luminous intensity, one candela is one lumen per steradiam.

Clear Sky (U.S. Weather Bureau): A sky that has less than 30% cloud cover.

Clerestory - That part of the building rising clear of the roofs or other parts of the building whose walls contain windows for lighting the interior

Cloudy Sky (U.S. Weather Bureau): A sky having between 30 to 70 percent cloud cover.

Color: The characteristics o light by which a human observer may distinguish between two structure-free patches of light of the same size and shape.

Contrast: The relationship between the luminance of an object and its immediate background. Mathematically, the difference between the luminance's divided by the luminance of the background:

Cut-and cover/ Earth sheltered space - Buildings that are placed into the soil near the surface and are designed to support the soil.

Daylight: Sunlight or light from the sky.

Daylight Factor: A relative measure of the daylight illuminance at an interior point or plane expressed as the ratio of the illuminance on the given plane to the simultaneous exterior illuminance on a horizontal plane from the whole unobstructed sky. Direct sunlight is excluded from both interior and exterior values of illuminance. The daylight factor comprises three components: the sky component, the externally reflected component, and the internally reflected component.

Direct Glare: Glare resulting from high luminance or insufficiently shielded light sources in the field of view.

Disability Glare: Glare resulting in reduced visual performance and visibility.

Discomfort Glare: Glare producing discomfort, interfering with the perception of visual information but not necessarily interfering with visual performance visibility.

Effective Aperture: A measure of the light transmitting ability of a fenestration system. Effective aperture is the product of window-to-wall ratio and visible transmittance. Typical values for windows range between 0.10 to 0.70.

Fenestration: Any opening or arrangement of openings for the admission of daylight. Normally filled with a glazing material and may include devices in the vicinity of the opening that affect light distribution.

Fin: A vertical building projection that is usually next to a window and is used for shading or light distribution.

Fixture: Lighting hardware, not including the lamp, used with electric light sources.

Flux: The time rate of flow of light.

Footcandle: The IP unit of illuminance that equals one lumen per square foot: produced on a surface all points of which are at a given distance from a directionally uniform point source of one candela.

Footlambert: A unit of illuminance equal to 0.3183010 candela per square foot:; the non-SI unit of measure of luminance.

Glare: The sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eye is adapted to cause annoyance, discomfort, or loss in visual performance and visibility.

Ground Light: Visible radiation from the sun and sky reflected by surfaces below the plane of the horizon.

High Intensity Discharge Lamp: Lamps in which light is produced by passing electric current through a gas, ionizing the gas, and permitting a current to flow between two electrodes.

Illuminance: The density of the luminous flux incident on a surface, expressed in units of footcandles or lux.

Illumination: The act of illuminating or state of being illuminated or quantity of light per unit of surface area.

Latitude: The angular distance north or south of the equator, Measured in degrees of arc.

Lamp: A generic term for a manufactured source of electric light.

Light- Radiant energy that is capable of exciting the retina and producing a visual sensation. The visible portion of the electromagnetic spectrum extends from about 380 to 780nm.

Light Court: An uncovered, interior open area in the center of a building.

Light Shelf:: A horizontal shelf positioned (usually above eye level) to reflect daylight onto the ceiling and to shield direct glare from the sky.

Louver: A series of baffles used to shield a light source from view at a certain angles or to absorb unwanted light.

Lumen: The SI unit of Luminous flux. The luminous flux emitted within a unit solid angle by a point source having a uniform luminous intensity of one candela.

Luminaire: A complete lighting unit consisting of one or more lamps and parts needed to distribute light, to position and protect the lamp, and to control and power the lamp.

Luminance: The physical measure of brightness, luminous intensity per unit projected area of any surface, as measured from a specific direction.

Lux: The SI unit of illuminance equal to one lumen per square meter.

Mined Space: Mined space is excavated through limited points of access from the surface either through vertical shafts or horizontal tunnels. Excavated in self supported rock or soil and is restricted to suitable geological conditions.

Monitor: A raised section of a roof that has vertical or near vertical glazed apertures, for the purpose of daylighting building interiors.

Nanometer: The unit of measure of wavelength equal to 10^{-9} meter.

Orientation: The relation of a building with respect to compass directions.

Reflectance: The ratio of reflected flux to incident flux.

Reflected Glare: Glare resulting from light reflection from high luminances from objects or surfaces in the field of view.

Reflection: The process by which incident flux leaves a surface or medium on the incident side of that surface or medium.

Sawtooth: A roof aperture system in which the glazing is placed on the short, usually vertical, surface of a series of roof serrations.

Sensor: A photocell device that tells a controller about daylight availability.

Shade: A screen made of opaque or translucent material to prevent a light from being directly visible at normal angles of view.

Sidelighting: The use of daylight aperture on the walls of building to provide daylight.

Skylight: A horizontal glazing roof aperture for the admission of daylight.

Toplighting: Daylighting apertures in the roof of a building that provide light from above.

Veiling Reflection: Regular reflections superimposed upon diffused reflections from an object that partially or totally obscures the details to be seen by reducing the contrast.

Visibility: The quality or state of being perceivable by the eye.

Visual Acuity: The measure of the ability to distinguish fine detail.

Visual Angle: The angle subtended by an object or detail at the point of observation, usually measured in minutes of arc.

Visual Field: The locus of objects or points in space that can be perceived when the head and eyes are kept fixed, the field may be monocular or binocular.

Visual Perception: The interpretation of impressions transmitted from the retina to the brain in terms of information about a physical world displayed before the eye.

Sources for glossary: daylighting Design & Analysis, 1986, Concept & Practice of Architectural Daylighting 1991, 1986, Perception & Lighting, 1986, Sunlight as a formgiver for Architecture. 1986, and Superlite 2.0.

APPENDIX B

TYPICAL REFLECTANCE FACTORS

Material	Reflectance (%)
Aluminum, polished	70-80
Asphalt	10
Brick (light buff)	48
Brick (dark buff)	40
Concrete	30-50
Cement	27
Glass	
(Clear or tinted)	7
(Reflective)	20-40
Grass	
(Dark green)	10
(Dry)	35
Mirror (Glass)	85-90
Paint	
(White)	70-90
(Black)	4
Procelain enamel	
(White)	60-90
Snow	60-75
Stone	5-50
Vegatation (average)	25
Wood	5-40

Typical Reflectance factor table Source Heating Cooling & Lighting , 1991, pg. 314.

APPENDIX C

DESCRIPTION OF A HYPOTHETICAL COMMUNITY LIBRARY/REGIONAL MUSEUM/LIBRARY / REGIONAL HISTORY MUSEUM

Project Summary and General Description

The Northern Nevada Community Library/ Regional History Museum will consist of approximately 112,000 square feet of exhibit and support spaces that are common to this type of facility. This facility will provide focal point for the newly developed community nestled into the foothills of northwest Reno.

The summary description of spaces, program requirements, and goals provided in this program document are consistent with the scope of the design project. This summary is based on similar facilities in the Las Vegas and Phoenix areas.

Goals

1. To create a facility that is both educational and entertaining to residents and visitors of the area.
2. To create a focal point, a hub of activity for this newly developed area.
3. To provide the area with a design that reflects the region and site.

4. To provide visitors an opportunity to gain knowledge and learn about the areas historical significant

Geographical Setting

The proposed site for The Northern Nevada Community Library / Regional historical Museum is located in a newly developed community in northwest Reno. The site, with its 180 degree view of Reno and Sparks and being nestled into the foothills northwest of Reno provides the opportunity to develop a focal point for the subdivision. The terrain is characteristic of the desert region and slopes toward the southeast with some areas to the south exceeding 20 percent. The site, which is zoned for commercial developments, is accessible from the east on Avenda Del Landa Lane.

Climate

Classified as a high desert region, the climate of the area provide pleasant summers and harsh winters. The Temperature extremes range from 17 F to 110F and has the average of three to five inches of rain fall annually. The area has relatively low humidity ranging from 30 percent or less and has 66 percent probability of sunshine annually. Due to this percentage, it will be important to recognize that protection against solar radiation is essential throughout the summer months but in contrast, during the winter months lower temperatures make solar radiation highly desirable.

Geological Consideration and Soil

Rugged mountains and small desert plants dominate the landscape. Soils are generally shallow, friable, and are very susceptible to wind and water erosion. The site is located on land under the jurisdiction of Washoe County. It will be assumed the surface and subsurface condition will allow for easy excavation and earth moving. It will be also assumed that the baring capacity of the soil is capable of supporting this type of structure.

Site Issues

For the purpose of designing a library / museum Facility, the designer has designated a site that is presently undeveloped and is under the jurisdiction of Washoe County. The existing roadway will be assumed of adequate size to support this type of facility and will not need to be modified.

Views

180 degree picturesque views of the Reno-Sparks skyline can be seen to the southeast of the site. The majestic Mount. Rose can be seen across the valley to the south of the site. To the west and north, new subdivisions are being developed with rugged hills of the Sierra Mountain Range as a backdrop.

Adjacent Developments / Buildings

The site is located in an area that is presently being developed. The site is surrounded on the north, south, and west sides by new housing tracks that are presently

being built. The subdivision is mater planed for 4.5 units per acre and will be assumed of adequate size to support this type of facility. Further south a commercial center including schools, shopping centers, banks, and restaurants is being developed to support this growing area. To the east of the site lies North McCarren boulevard, a four lane artery that will serve as the main vehicular link to community.

Circulation

Both pedestrian and vehicular circulation will be developed to limit interaction and promote safety. Existing road system which includes North McCarren Boulevard and Avenda De Landa drive will be able to handle traffic generated from this type of facility. It is anticipated that the primary approach to this facility by pedestrian and vehicular circulation will be from Avenda De Landa Way, which runs along the northern property line.

Parking

Parking for this facility will be provided on site with special consideration given to sun protection for pedestrian as well as for vehicles. For this project the demand generation ratio of 2.6 Spaces / 1000 square Feet x usable square footage will be used and assuming a square footage of 100,000 this facility requires 260 parking spaces. The parking will be broken down into the ratio of 30% (78 spaces) being considered short term parking and 70% (182 spaces) considered long term parking

Special Considerations

Security System. A building-wide security plan and provisions for surveillance of critical areas will be designed to appropriately meet the library / museum needs.

Daylighting System Care will be taken to insure the most appropriate daylighting strategies will be implemented into this facility in order to provide a healthy and satisfactory experience for users of the facility as well as to protect the contents with in the facility against damage. The following strategies were chosen based on a careful analysis of each case study. They are:

- Sidelighting
- Toplighting

Sidelighting strategies in conjunction with sunken courtyards will be used to provide visual links to the exterior. The placement of these sunken courtyards will provide the facility with a unique building image Lightselves will be used to shade south facing glass while adding to the overall exterior aesthetics. Interior spaces throughout the facility will be provided with windows facing towards exterior courtyard to provide the user with a visual connection with the exterior environment. Deciduous plants will provide seasonably controlled daylight penetration along exterior glazing. High ceilings will be proposed in areas adjacent to exterior glazing to allow natural light to penetrate deep into the facility. High ceiling heights will also provide the feeling of spaciousness thought the interior spaces.

Toplighting in the form of skylights will also provide the facility with a distinct building image while allowing natural daylight to enter the facility. The use of

toplighting strategies to delineate circulation patterns to encourage movement with in the facility will be proposed.

Both of these strategies will be implemented to provide the facility of this type and size with adequate natural daylighting. Steps will be taken to minimize against the harmful effect of solar gain and glare associated with these types of daylighting strategies.

Space Allocation Summary

1.00	Entrance	7,700 Square Feet
1.01	Greeting Zone (Outdoor)	2,000 sf
1.02	Entrance Lobby	2,500 sf
1.03	Circulation/Public Service	700 sf
1.04	Public Restrooms	1,750 sf
1.05	Custodial Closet	100 sf
1.06	Elevators/Elevator Equip. Rm.	450 sf
2.00	Library Services	55,850 Square Feet
2.01	Periodicals Department	5,000 sf
2.02	Periodical Department Office	180 sf
2.03	Staff Work Rm./Office	180 sf
2.04	Fine Arts Department	1,800 sf
2.05	Fine Arts Department Office	180 sf
2.06	Adult Fiction Department	9,600 sf
2.07	Adult Library Public Service/Reading Service	500 sf
2.08	Adult Non-Fiction Department	10,000 sf
2.09	Copy Center	200 sf
2.10	Young People's Library	9,600 sf
2.11	Young People's Library Office	180 sf
2.12	Young People's Library Staff Work Rm.	180 sf
2.13	Story Rm.	700 sf
2.14	Children's Restroom	250 sf
2.15	Toddler Rm.	180 sf
2.16	Service Rm./Office	1,000 sf
2.17	Literacy Program Rm.	200 sf
2.18	Micro Computer Center	750 sf
2.19	Sort Rm.	2,500 sf
2.20	Quiet Study Rms. (2 @ 200, 1 @ 600)	1,000 sf
2.21	School Lunch Picnic Area	300 sf

2.22 Reference Department........5,400 sf
2.23 Reference Department Office........180 sf
2.24 Staff Work Rm./Office........180 sf
2.25 Typing Rms. (6 @ 30)........150 sf
2.26 Info. Track Rm. ....400 sf
2.27 Conference Rm........1,000 sf
2.28 Private Study Rms. ....760 sf
2.29 Offices........1,000 sf
2.30 Maintenance Rm. ....400 sf
2.31 Storage Rms. (2 @ 500)........1,000 sf
2.32 Audio/Visual Department........700 sf

<u>3.00 Exhibits</u>........<u>18,100 Square Feet</u>
3.01 Exhibit Hall........15,000 sf
3.02 Temporary Exhibit Hall........3,000 sf
3.03 Custodial Closets........100 sf

<u>4.00 Museum Gift Shop</u>........<u>2,600 Square Feet</u>
4.01 Gift shop Area........2,000 sf
4.02 Storage Rm. ....600 sf

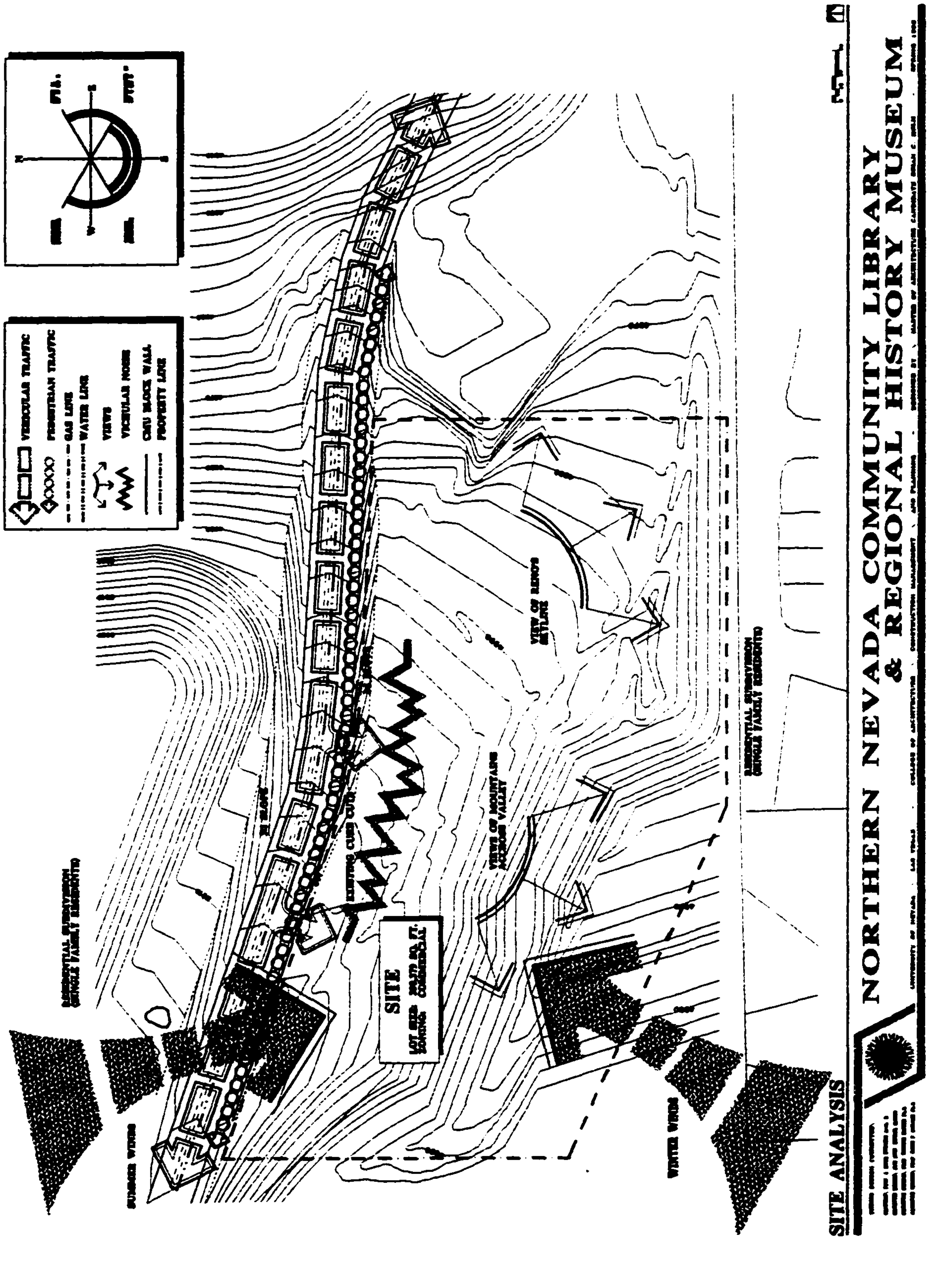
<u>5.00 Food Service</u>........<u>2,550 Square Feet</u>
5.01 Food Service Restaurant........700 sf
5.02 Food Service Kitchen........600 sf
5.03 Food Service Storage........400 sf
5.04 Catering Kitchen........600 sf
5.05 Custodial Closet........100 sf
5.06 Food Service Restrooms........150 sf

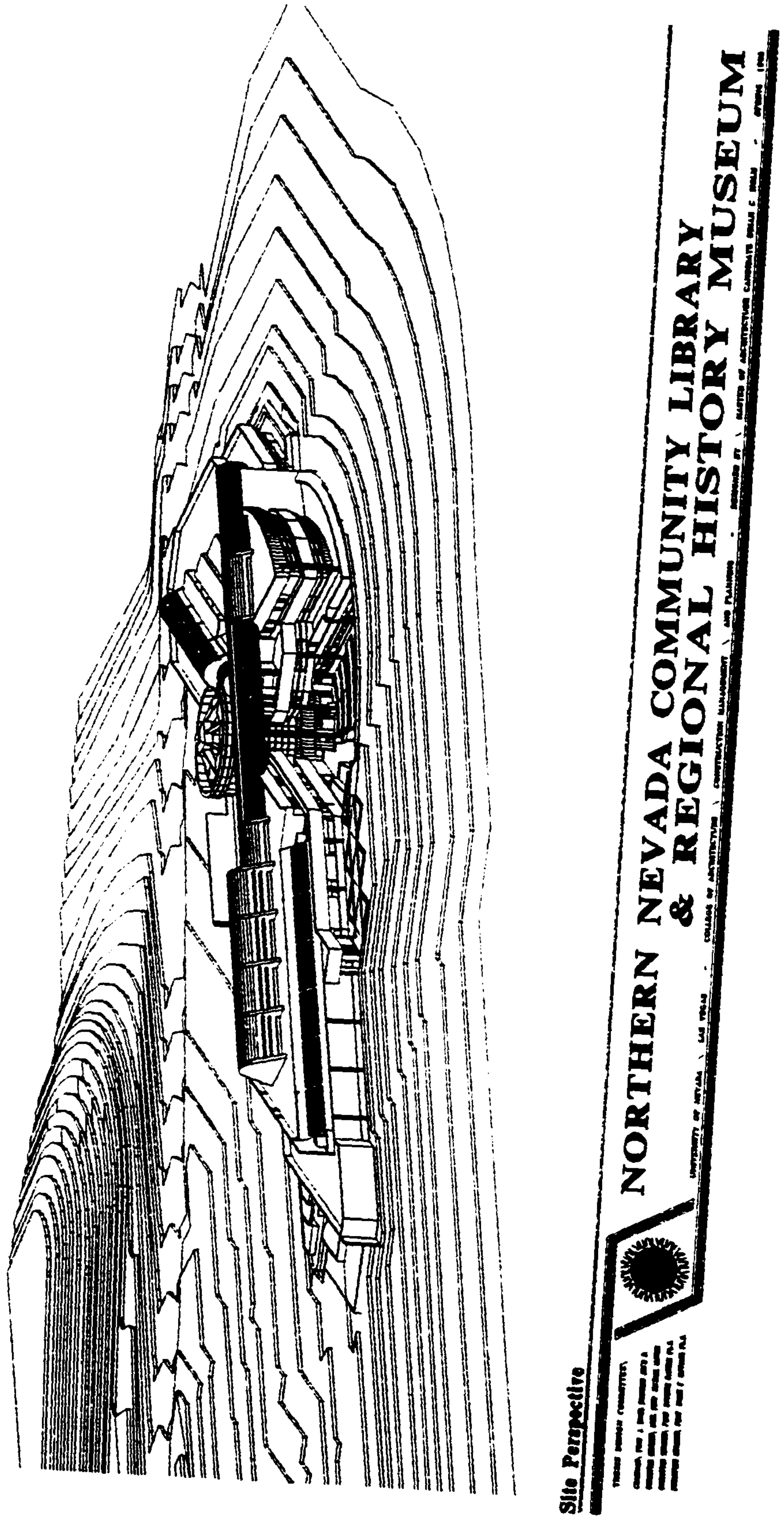
<u>6.00 Exhibit Support</u>........<u>6,050 Square Feet</u>
6.01 Carpentry Shop........1,000 sf
6.02 Machine Shop........275 sf
6.03 Audio Visual/Electronic Maint. Shop........200 sf
6.04 Audio Visual/Electronic Storage........200 sf
6.05 Exhibit Staging Area........1,000 sf
6.06 Exhibit Support Storage........3,000 sf
6.07 Exhibit Support Restrooms........275 sf
6.08 Custodial Closet........100 sf

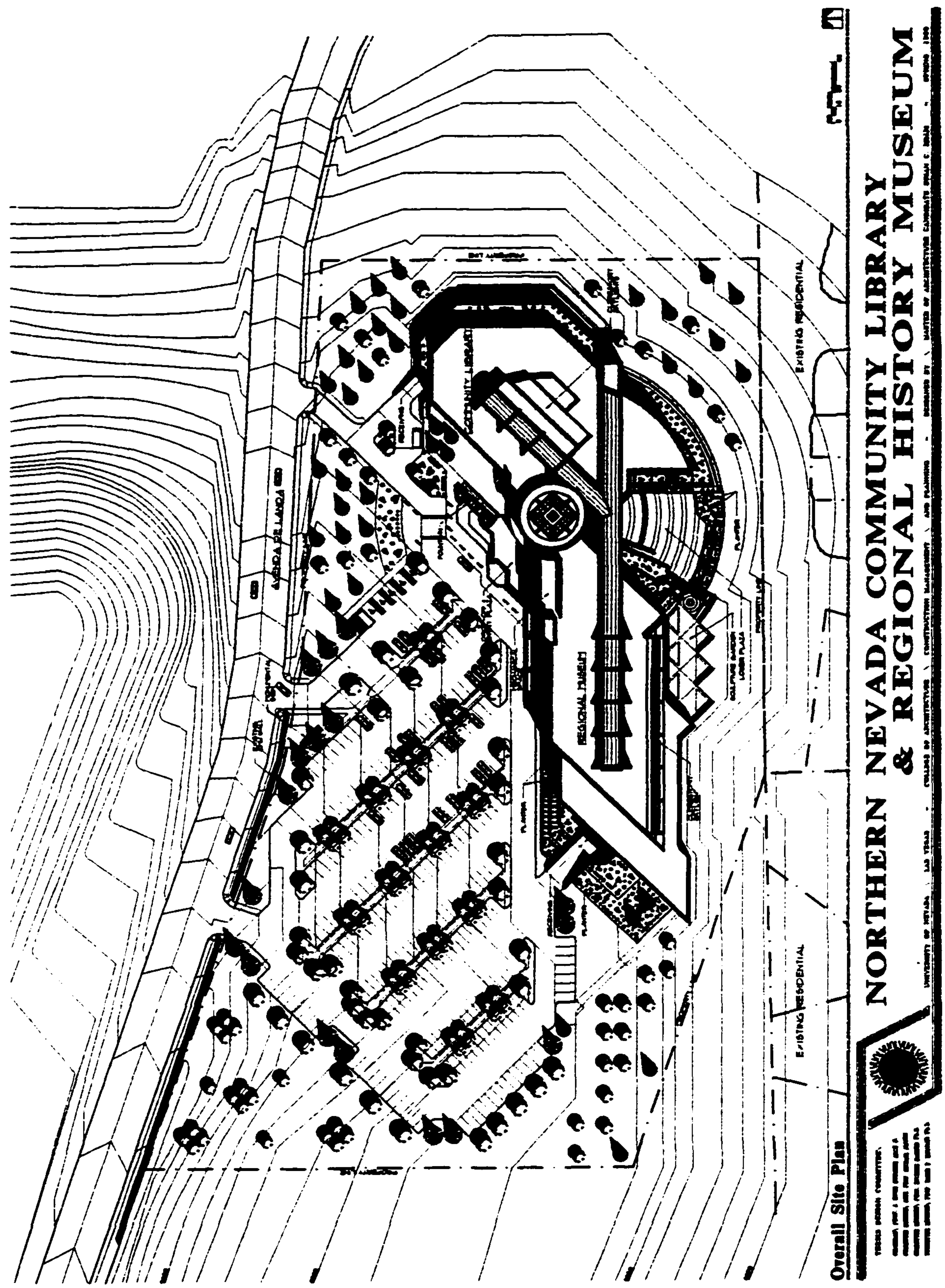
<u>7.00 Collections</u>........<u>350 Square Feet</u>
7.01 Collections Storage........300 sf
7.02 Collections Vault........50 sf

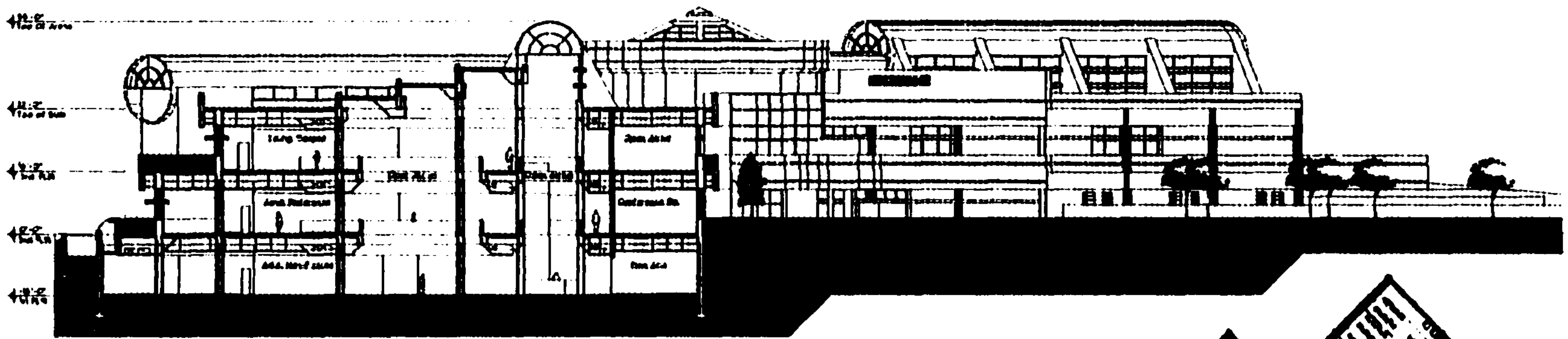
8.00	Operations	4,775 Square Feet
8.01	Receiving	1,000 sf
8.02	Freight Elevator	275 sf
8.03	Exhibit/Storage Corridor	2,400 sf
8.04	Building Maintenance Shop	400 sf
8.05	Maintenance Supervisor Office	100 sf
8.06	Maintenance Supply Storage	500 sf
8.07	Grounds Maintenance Storage	100 sf
9.00	Administration	6,038 Square Feet
9.01	Executive Director	250 sf
9.02	Director's Workroom	100 sf
9.03	Administrative Assistant	150 sf
9.04	Storage	100 sf
9.05	Board Rm.	600 sf
9.06	Board Rm. Storage	200 sf
9.07	Director of Development	150 sf
9.08	Development Office	600 sf
9.09	Director of Finance/Account.	150 sf
9.10	Finance Department Office	800 sf
9.12	Finance Department Storage	288 sf
9.13	Director of Operations	150 sf
9.14	Assistant to Oper./Exhibits	100 sf
9.15	Director of Exhibits	150 sf
9.16	Director of Marketing/Public Relations	150 sf
9.17	Marketing/Public Relations Office	800 sf
9.18	Public Relations Storage	100 sf
9.19	Department Head Receptionist Area	150 sf
9.20	Copy/Mail Rm.	200 sf
9.21	Office Supply Rm.	100 sf
9.22	Secured Administration Storage	50 sf
9.23	Staff Restrooms	150 sf
9.24	Staff Lounge	200 sf
9.25	Custodial Closet	50 sf
9.26	Cash Control Rm.	100 sf
9.27	Security Office	200 sf
10.00	Mechanical Rm..	4,000 Square Feet
10.01	Mechanical Rm.	4,000 sf

Assignable Square Footage	108.013
Gross Square Footage (Assignable x 1.25)	135,016

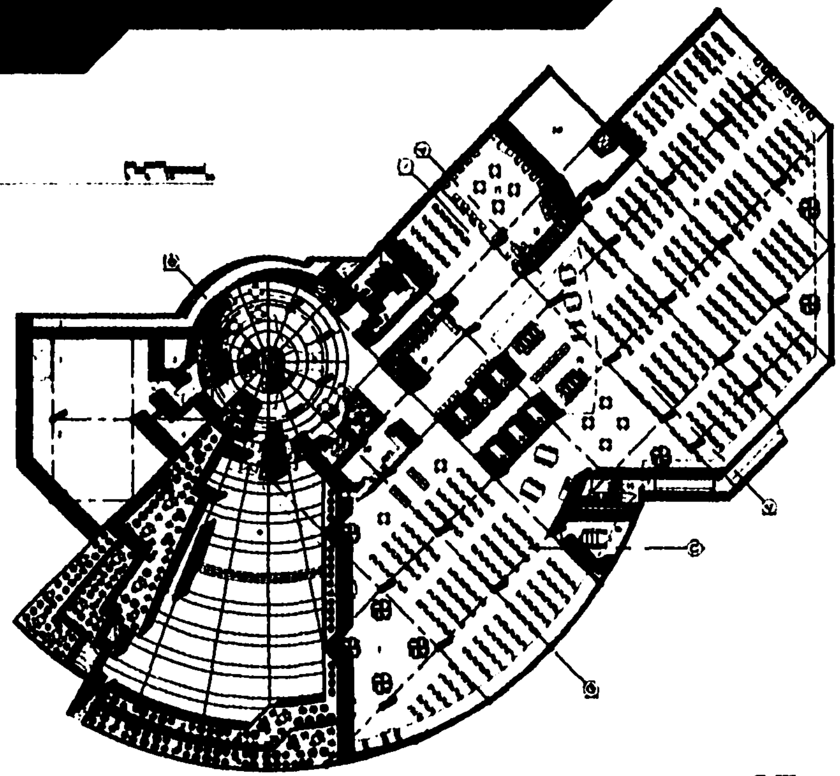

SITE ANALYSIS
NORTHERN NEVADA COMMUNITY LIBRARY
& REGIONAL HISTORY MUSEUM
SITE
VEHICULAR TRAFFIC
PEDESTRIAN TRAFFIC
GAS LINE
WATER LINE
VIEWS
VEHICULAR NOISE
CMU BLOCK WALL
PROPERTY LINE
SUMMER WINDS
WINTER WINDS
VIEW OF RENO'S SKYLINE
VIEWS OF MOUNTAINS ACROSS VALLEY


NORTHERN NEVADA COMMUNITY LIBRARY
& REGIONAL HISTORY MUSEUM
Site Perspective


NORTHERN NEVADA COMMUNITY LIBRARY
& REGIONAL HISTORY MUSEUM
Overall Site Plan
COMMUNITY LIBRARY
REGIONAL MUSEUM
EXISTING RESIDENTIAL
EXISTING RESIDENTIAL

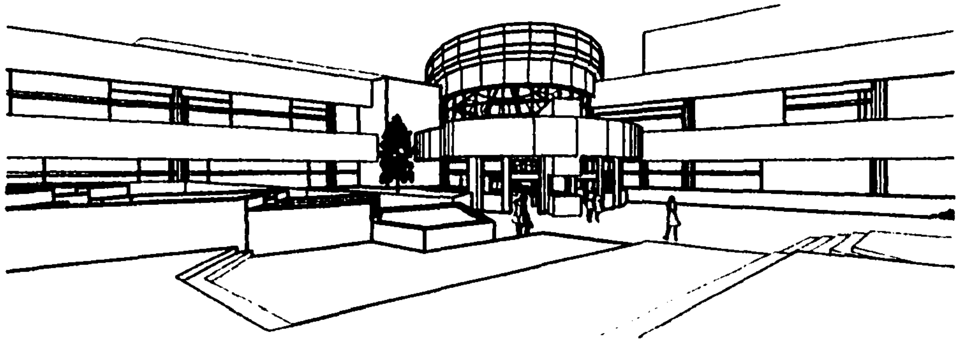


Section A-A Thru Libray

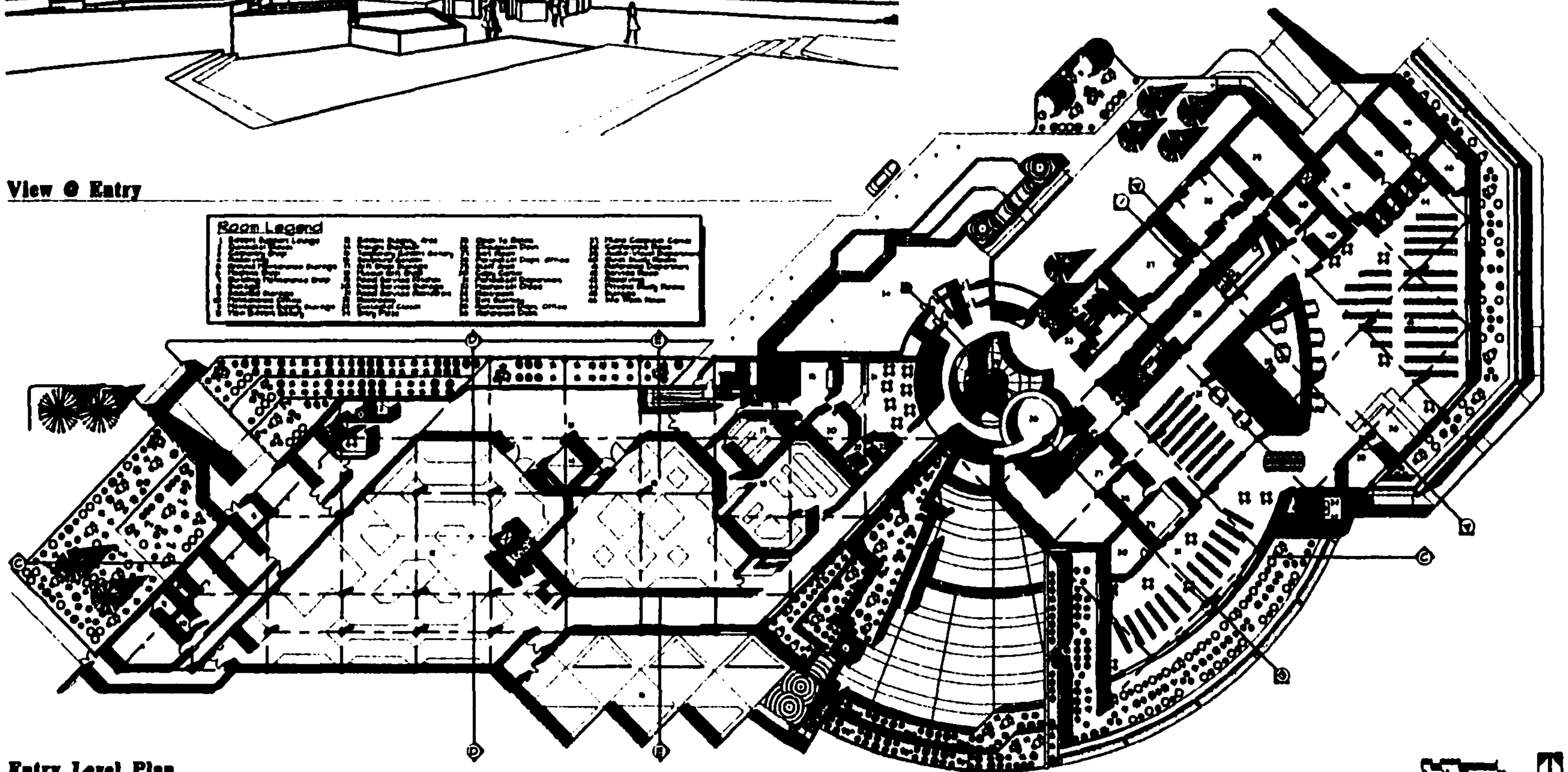


Lower Level Plan

NORTHERN NEVADA COMMUNITY LIBRARY & REGIONAL HISTORY MUSEUM

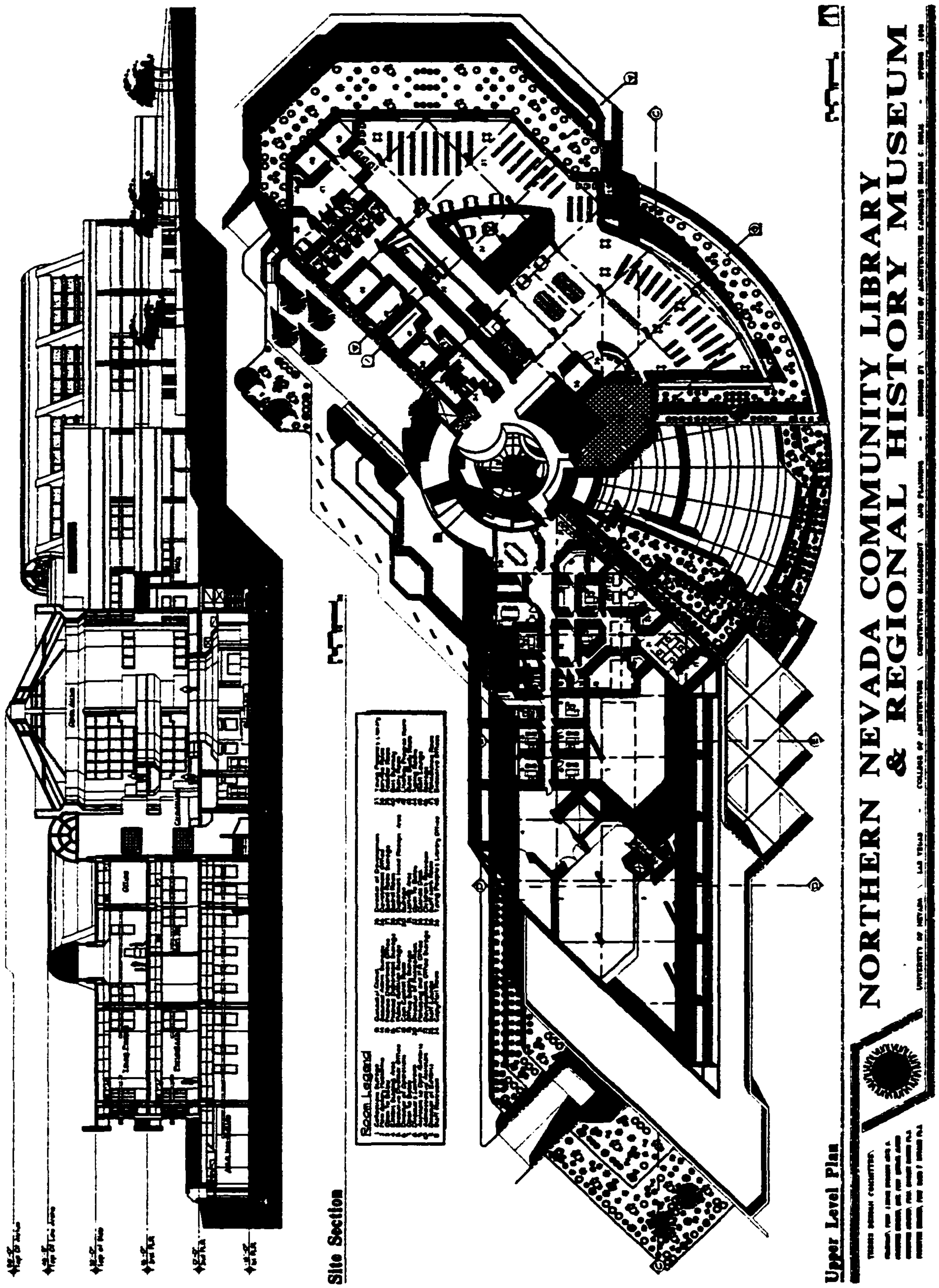


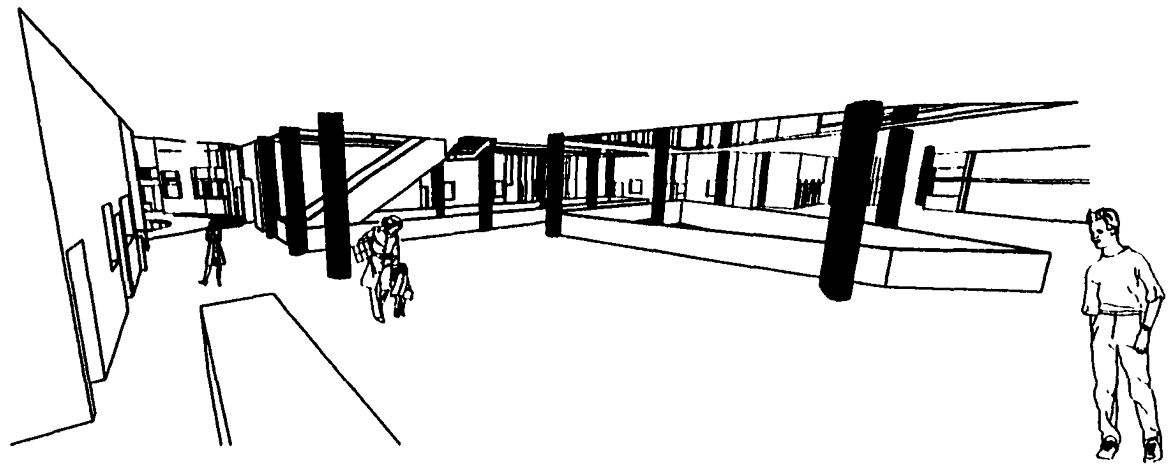
View @ Entry



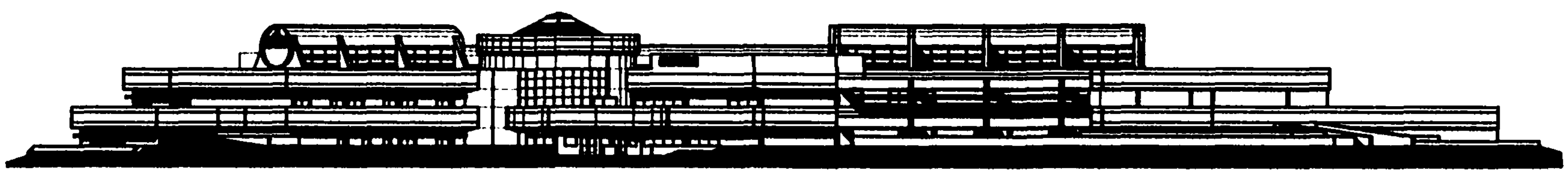
Entry Level Plan

NORTHERN NEVADA COMMUNITY LIBRARY & REGIONAL HISTORY MUSEUM


NORTHERN NEVADA COMMUNITY LIBRARY
& REGIONAL HISTORY MUSEUM
Upper Level Plan
Site Section
Room Legend

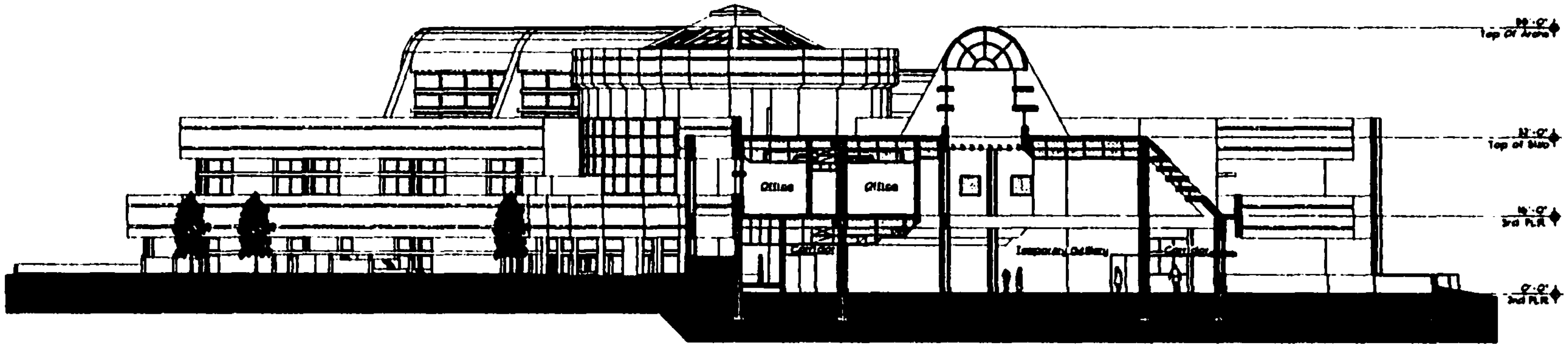


View @ Library

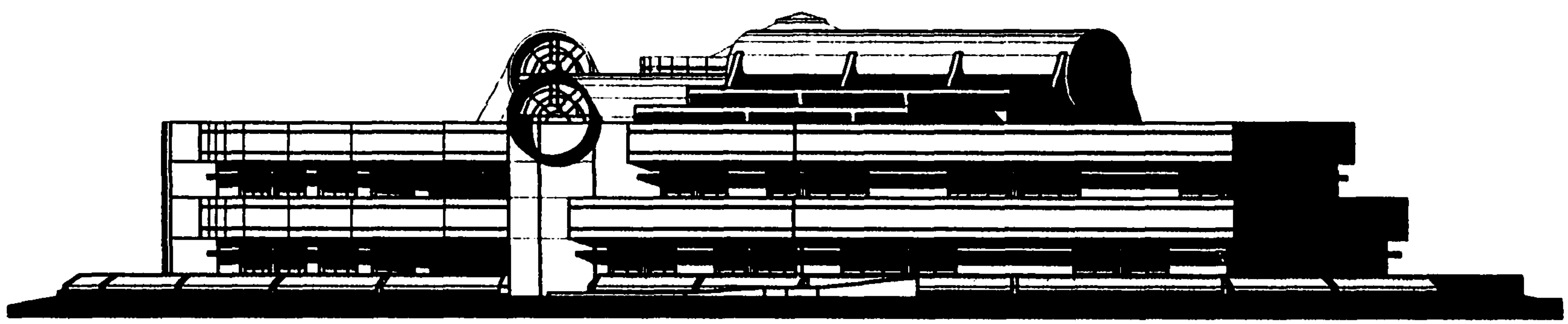


North Elevation

NORTHERN NEVADA COMMUNITY LIBRARY
& REGIONAL HISTORY MUSEUM

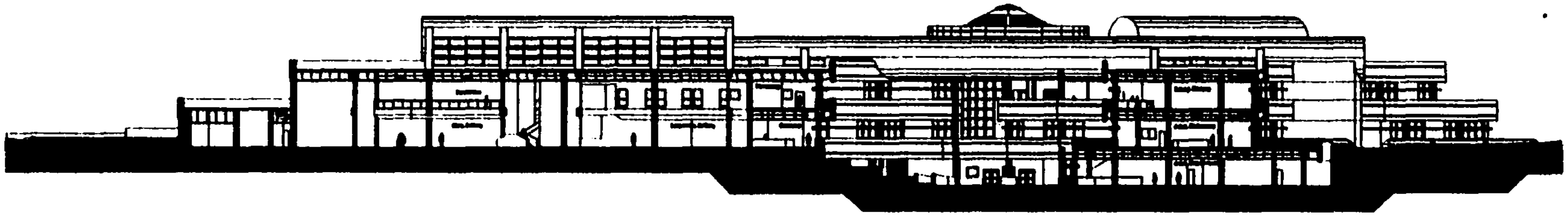


Section E-E Thru Temporary Gallery

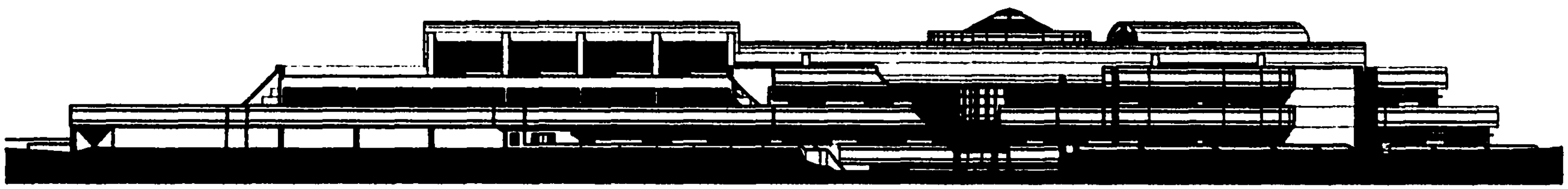


East Elevation

NORTHERN NEVADA COMMUNITY LIBRARY & REGIONAL HISTORY MUSEUM

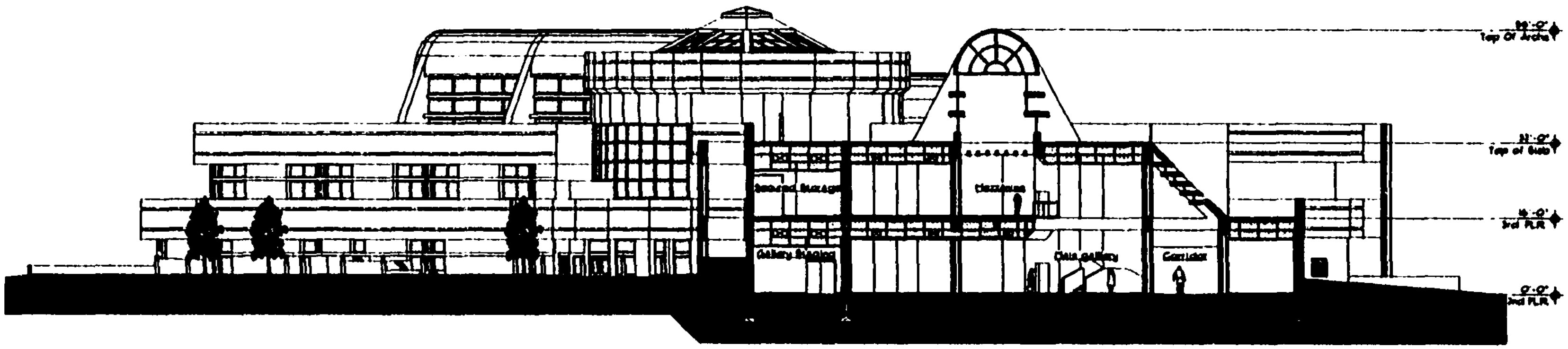


Cross Section

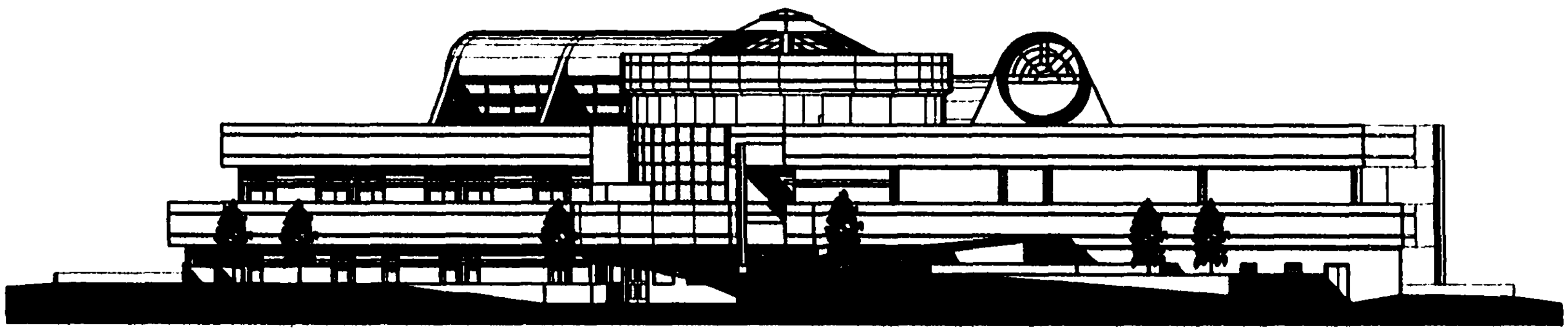


South Elevation

NORTHERN NEVADA COMMUNITY LIBRARY & REGIONAL HISTORY MUSEUM



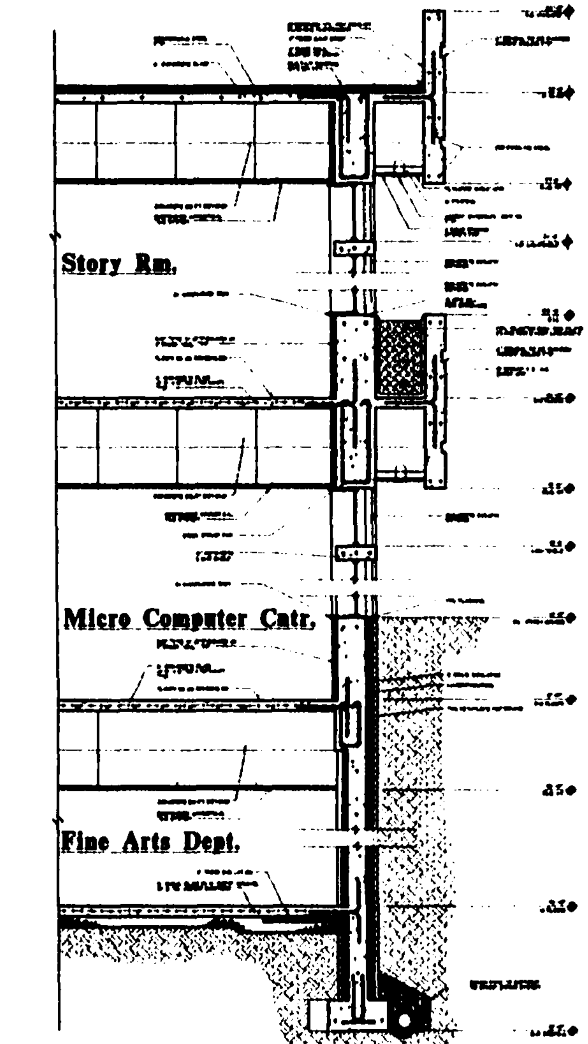
Section D-D Thru Main Gallery



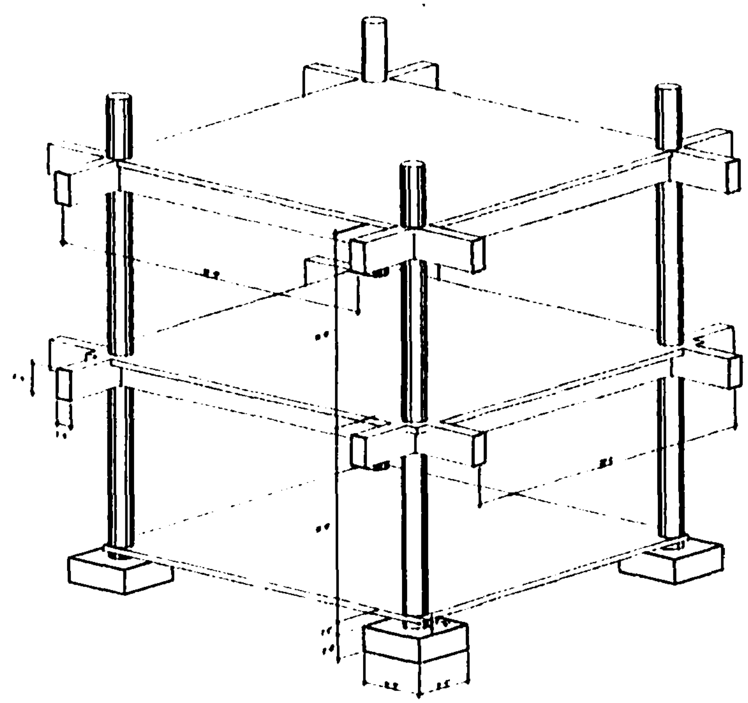
West Elevation

NORTHERN NEVADA COMMUNITY LIBRARY
& REGIONAL HISTORY MUSEUM

Wall Section



Structural Plan

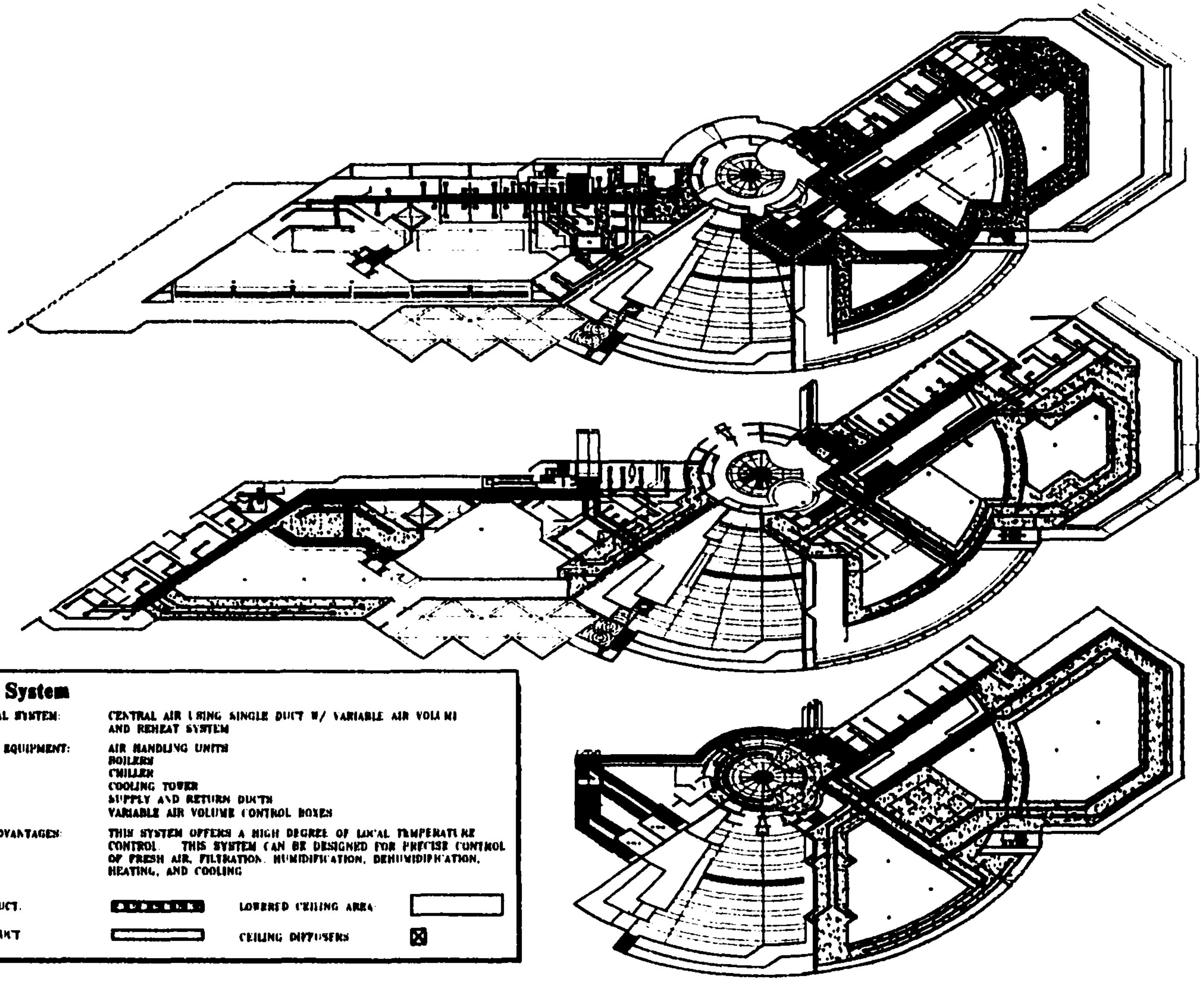


Structural System

STRUCTURAL SYSTEM	SITECAST CONCRETE TWO-WAY SLAB AND BEAM SYSTEM WAS USED FOR THIS PROJECT.
TYPE OF CONCRETE	4000 P.S.I COMPRESSIVE STRENGTH W/ ASTM. C33 HARDROCK AGGREGATE ALL REINFORCING STEEL SHALL CONFORM TO ASTM - 90
TYPICAL BAY	32'-0" SPAN MOST AREAS 42'-0" SPAN IN MAIN GALLERY
BEAM SIZE	18" WIDTH 2'-6" DEPTH
COLUMN SIZE	24" DIAMETER CONCRETE COLUMN TYPICAL THROUGHOUT

NORTHERN NEVADA COMMUNITY LIBRARY & REGIONAL HISTORY MUSEUM

UNIVERSITY OF NEVADA LAS VEGAS - COLLEGE OF ARCHITECTURE, CONSTRUCTION MANAGEMENT AND PLANNING - DESIGNED BY: MASTER OF ARCHITECTURE CANDIDATE



Mechanical System

MECHANICAL SYSTEM:	CENTRAL AIR USING SINGLE DUCT W/ VARIABLE AIR VOLUME AND REHEAT SYSTEM
STANDARD EQUIPMENT:	AIR HANDLING UNITS BOILERS CHILLER COOLING TOWER SUPPLY AND RETURN DUCTS VARIABLE AIR VOLUME CONTROL BOXES
SYSTEM ADVANTAGES:	THIS SYSTEM OFFERS A HIGH DEGREE OF LOCAL TEMPERATURE CONTROL. THIS SYSTEM CAN BE DESIGNED FOR PRECISE CONTROL OF FRESH AIR, FILTRATION, HUMIDIFICATION, DEHUMIDIFICATION, HEATING, AND COOLING

SUPPLY DUCT.	[legend symbol]	LOWERED CEILING AREA	[legend symbol]
RETURN DUCT	[legend symbol]	CEILING DIFFUSERS	⊠

Mechanical Plans

THESIS DESIGN COMMITTEE,

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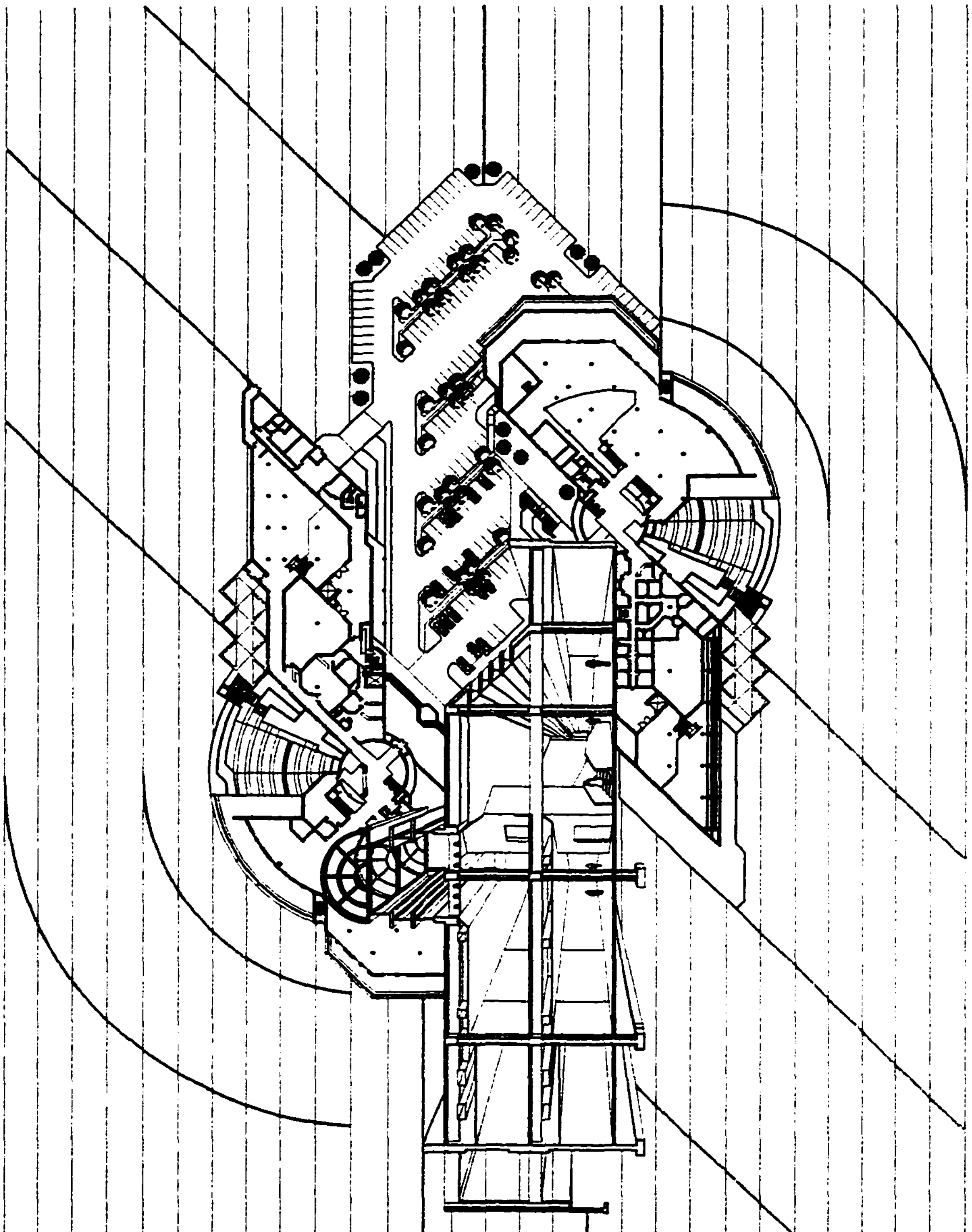

APPENDIX D

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Brian C. Holm

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University of Nevada, Las Vegas

Thesis Title: Use of the Case Study Method to Provide Initial Design Strategies for Daylighting as a Primary Design Determinant in Earth Integrated Structures

Thesis Examination Committee:
Chairperson, Professor J. Hugh Burgess Arch. D.
Committee Member: Asst. Professor Michael Alcorn
Committee Member: Professor Zouhier Hashem Ph.D.
Graduate Faculty Representative: Professor Samir F. Moujaes Ph.D.

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