INTRODUCTION

The Mount Angel Abbey Library is located on the hilltop of Mount Angel and part of the Benedictine Monastery. It is one of two designs [1] by Finnish architect Alvar Aalto in the United States after the MIT dormitory [2] and in a series of five recently completed library designs in Finland [3]. Aalto visited the Monastery during the design phase and was attracted by the site's views of the Willamette Valley and the potential strengths in shaping sunlight to express interior spaces.

The central atrium with abundant natural light is one of the significant elements of Aalto's designs. Aalto adjusted the orientation of Mount Angel Abbey Library to get more sunlight and protect Douglas fir trees near the library after visiting the site [4]. The space arrangements of Aalto's libraries are enhanced by conscious and careful natural light application. He developed a number of lighting devices to diffuse daylight. The combination of conical skylights, roof monitor and clerestory windows enhance the spatial richness of Mount Angel Abbey Library.

Many of Aalto's lighting devices are designed to address the sun angel of Finland. Mount Angel Abbey Library adapts some significant lighting strategies [5] of Aalto's library designs in Finland. The efficiency and modification of these devices are the main issues of this paper.

The transitional space between entrance and main space, reception desk and interior corridors are well lit by conical skylights [6]. Conical skylights allow even distributed, reflected, shadowless light into indoor space. The depth of the conical skylight diverges light to numerous directions and reduces direct sunlight. The light brought in by conical skylights at the lobby and light borrowed from roof monitor balance the lighting quality and interior space. Visitors will be encouraged to appreciate the splendor and scale of the library.

Curved and sloped glass surface of roof monitor reflects and scatters the natural light [7]. The north facing skylight also strengthens the double ceiling space and tall columns [8] in the reading space [9]. The clerestory windows on the main floor provide diffused sunlight to study carrels along the wall.

METHODOLOGY

Boundary of Analysis

The library sits on the hillside with a prominent north facing elevation. The library is spread over three main floors and composed of books stacks, reading rooms, book archive, and administrative offices. For the purpose of this exercise only the main library space and the mezzanine were analyzed as they share a contiguous space and retain prominent Aalto daylight devices.

Reflectance Measurement

Cataloguing the reflectance of surfaces in the Mt Angel Abbey Library was instrumental in understanding the relationship between shaping daylight through architectural form and interior finish qualities of surfaces. The Known Sample Comparison Method [13] was used to measure diffused (nonspecular) reflectance.

$$Reflectance\ of\ unknown\ surface:$$

$$\frac{luminance\ of\ FL\ of\ sample}{luminance\ of\ FL\ of\ gray\ card}(.18)$$

Table 1: Reflectance Values

Surface Definition	Location	Color	Reflectance
Walls	Mezzanine	White	0.904
Carpet	Level 3	Brown	0.115
Column	Level 2	White	0.881
Reception	Level 3	Wood	0.400
Aalto Chair	Level 3	Brown	0.166
Aalto Stool	Level 3	Black	0.047
Aalto Table	Level 3	Black	0.023
Book Stack	Level 3	Gray	0.216

A Konica Minolta CS-100A-Luminance & Color Meter was used to measure the various surfaces and catalogued in (Table 1). The reflectance values were then transposed into the simulation material library to further enhance daylight analysis accuracy.

Aalto used highly reflective wall surfaces, dark floors, and mid-tone furniture surfaces to promote uniform daylight distribution and accentuate daylight movement throughout the library. The careful selection of surface material further supports spatial dynamics and ultimately reinforced rhythmic and behavioural movement throughout the library.

Illuminance Field Measurement

The intent of the field measurements was to corroborate generalities of spatial daylight distribution on Level 3. Field measurements were taken with an Extect EA30 Wide Range Light Meter and compared illuminance (lux) values to the simulation model using Radiance. Field measurement and computer simulation used the same date and approximate sky condition. In general, both sets of data were complementary with the exception of light values directly underneath conical lights.

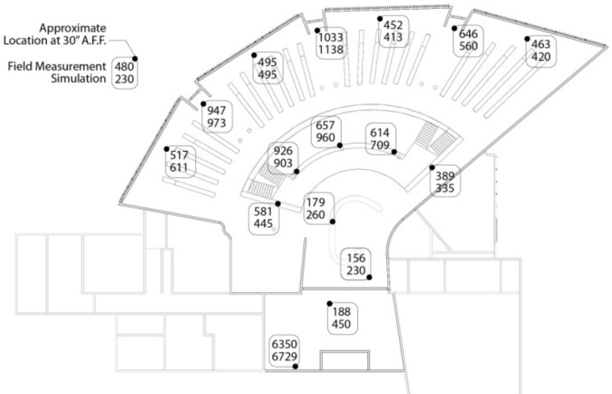


Figure 1: Field Measurement

The cause is unknown but there is some speculation that the glass type of the dome-like tops of the conical lights has a much lower visible light transmittance than simulated.

Computer Modelling and Daylight Simulation

A partial Construction Document set was provided by Professor Cartwright at the onset of the analysis. Drawing legibility was at times intangible thus promoting field measurements to verify location and dimensional accuracy of clearstory windows and windows not shown on plans or elevations. A digital model of the Library was constructed and imported into Ecotect Analysis overlaid with Desktop Radiance. Material reflectance was assigned based on field measurement (Fig 1). The simulation model situated Mt Angel Abbey at 45°Latitude, 122°N, and used Commission Internationale de L'Eclairage (CIE) as the standard design sky for the daylight simulation.

FINDINGS

Overview

A series of baseline analysis were simulated to evaluate daylight performance compared to daylight standards suggested by the Leadership in Energy and Environmental Design (LEED)[10], Collaborative for High Performance Schools (CHPS)[11], and the Illuminating Engineering Society (IES).

Baseline Performance A

Baseline A was simulated without book stacks and achieved 56% daylight compliance according to the CHPS standards and 46%-53% by LEED IEQ 8.1 standards. However, it should be noted that the analysis grid included the library proper: circulation, transition spaces, book stacks, in addition to regularly occupied areas from the perimeter inward.

Unfortunately, using pre-existing daylight standards are unable to address potential strengths of daylight qualities offered by Aalto's daylight devices; thus, resulting in low daylight performance values.

Table 2: Baseline Performance A

Criteria: Sunny Sky, Without Book Stacks			
	Mar21st Noon	Sep21st 9a.m.	Sep21st 3p.m.
CHPS (1)	56%		
CHPS (2)	Achieved		
LEED (3)		53%	46%

CHPS EQ1.1.1: Achieve an average horizontal daylight illumination > 250 LUX at 30-inch above the floor.
CHPS EQ1.1.1: Achieve daylight uniformity at the work plane not greater than 8:1
LEED IEQ 8.1: Achieve illuminance of levels of a minimum of 250L and a maximum of 500L in clear sky condition

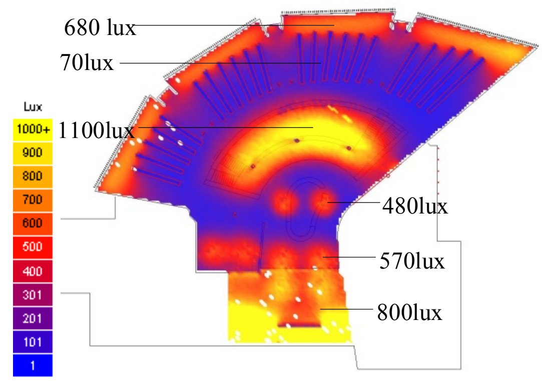


Figure 2: March 21st - Clear Sky Condition - Noon

Baseline Performance B

Baseline B incorporated book stacks to the simulation decreased the amount of illuminance falling between the 0-250lux from 43% to 58% during the March 21 analysis; thus, permanent furniture impacts daylight distribution and jeopardizes average horizontal illumination. Both LEED and CHPS daylight values decreased as a result of including book stacks in the evaluation.

Table 3: Baseline Performance B

Criteria: Sunny Sky, With Book Stacks			
	Mar 21st Noon	Sep 21st 9a.m.	Sep 21st 3p.m.
CHPS (1)	41%		
CHPS (2)	Achieved		
LEED (3)		37%	34%

CHPS EQ1.1.1: Achieve an average horizontal daylight illumination > 250 LUX at 30-inch above the floor.
CHPS EQ1.1.1: Achieve daylight uniformity at the work plane not greater than 8:1
LEED IEQ 8.1: Achieve illuminance of levels of a minimum of 250L and a maximum of 500L in clear sky condition

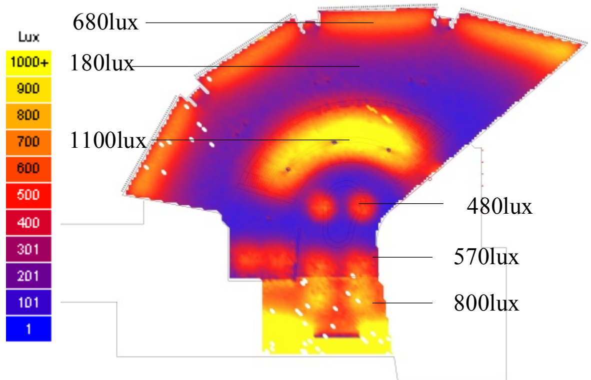


*Figure **3:** Clear Sky Condition - Noon - W/ Book Stacks*

Daylight Zone Factor

In reaction to the low level daylight results following CHPS and LEED criteria an alternative lighting method was chosen to capture lighting quantities based on occupancy task. The division of space resulted in four Light-Zones: Reading, Transition, Catalog, and Book Stacks[12]. Each Light-Zone applied the Illuminating Engineering Society (IES)[13] recommended maintained illuminance targets (lux) applying the horizontal (E_h) targets across multiple age groups. Each Lighting Zone is weighed against the floor area generating a floor area factor (A_f) that normalizes the additive values of all the zones. The result of the Daylight Zone Factor (DZF) raises the average horizontal daylight illumination from 41.6% established by CHPS criteria to 55% based on Daylight Zone Factor – a 13.4% increase in recommended illuminance.

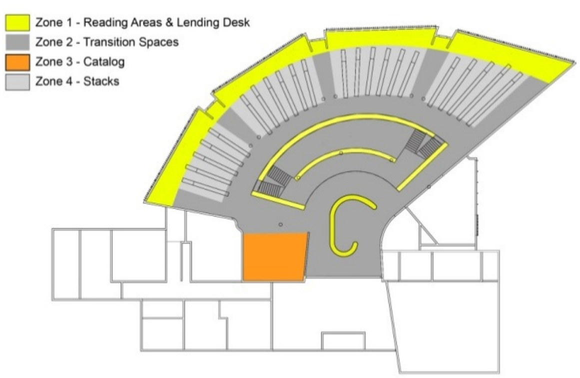


*Figure **4:** March 21st - Clear Sky Condition – Noon*

*Table **4:** Daylight Zone Factor*

Zone 1 - Reading & Lending Desk & Mezzanine

A	A_f				
		Age	<25	25-65	>65
		Target lux	250	500	1000
1955	0.19	Illuminance (%)	87	25	0

Zone 2 - Transition

A	A_f				
		Age	<25	25-65	>65
		Target lux	25	50	100
5045	0.48	Illuminance (%)	96	92	76

Zone 3 - Catalog

A	A_f				
		Age	<25	25-65	>65
		Target lux	150	300	600
560	0.05	Illuminance (%)	66	32	0

Zone 4 - Book Stack

A	A_f				
		Age	<25	25-65	>65
		Target lux	150	300	600
2983	0.28	Illuminance (%)	36.06	15	1.6

DZF: *Daylight Zone Factor* (%)
A: *Floor Area*
A_f: *Floor Area Factor*
E_h: *Horizontal Illumiance Targets*
$Z1$: *Lighting Zones*

Daylight Zone Factor Equation:

$$DZF = (Z1(A_f\ X\ E_h) + Z2(A_f\ X\ E_h) + Z3(A_f\ X\ E_h) + Z4(A_f\ X\ E_h))/100$$

$$DZF = (Z1(.19 * .25) + Z2(.48 * .92) + Z3(.05 * .32) + Z4(.28 * .15))/100 = 55\%$$

Conical Skylight Testing

Conical skylights are frequently applied in Mount Angel Abbey Library at transitional area, reception desk and interior corridors. The original conical skylights have cone angle of 6.2°. In this study, conical skylights are modified to test the optimum daylight quality. Conical skylights are modelled to have cone angles of 0°, 15° and 25° and placed on the ceiling of 20'x20'x18' testing chambers for daylight quality simulations.

The simulated false color images show that generally the larger the cone angles are the more daylight is admitted to the room. This is applicable to both Oregon and Helsinki climate zones. The maximum illuminance levels of all the testing chambers don't excess 500 lux. 500 lux is comfortable illuminance and will not cause glare. In this case, the conical skylights perform better if more light is brought in the space.

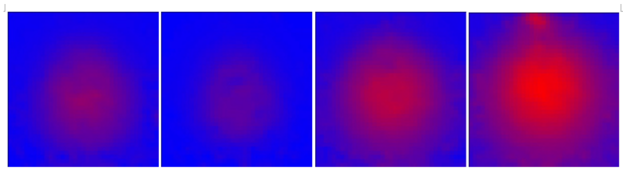


*Figure **5:** Spring Equinox, Oregon 44 Latitude*
From Left to Right: 6.2°, 0°, 15°, 25°

Conical skylights with bigger cone angle are able to bring more daylight indoor space. However undesirable direct sunlight may be brought into building space as well. Very bright spots which indicate direct sun beams are shown on both conical skylight testing results and baseline performance of existing building.

According to conical skylight testing results, direct sunlight appears on the floor of testing chamber for conical skylight with cone angel 6.2°, 15° and 25° on April 21st based on Oregon climate. The bigger the cone angles the more direct sunlight in the testing chambers. Direct sun beam has illuminance of more than 1000 lux. Based on recommended illuminance, it is like to be too brought for visual comfort. The darkest area in the testing chamber has illuminance of less than 100 lux. Direct sunlight leads to very contrasting illuminance in indoor space and has a large extent to cause glare issue. The original conical skylights design for Mount Angel Abbey Library permit average amount of daylight and average amount of direct sunlight compared to other testing chamber. In Oregon climate zone, it is feasible to conclude that the Mount Angel Abbey Library conical skylight design balances the amount of daylight and direct sunlight.

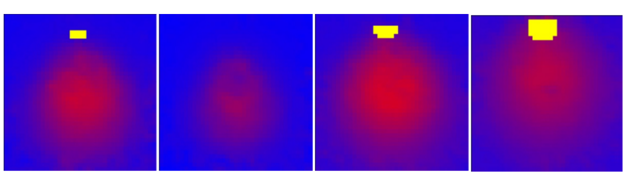


Figure 6: April 21st, Oregon 44 Latitude
From Left to Right: 6.2°, 0°, 15°, 25°

Most of Aalto's library design and conical skylight designs are for Helsinki sun angle and climate condition. Conical skylights are inherited from Helsinki library by Aalto to apply on American architectural designs. Therefore conical skylight chambers are tested in Helsinki climate zone in the study to compare the applicability of the design in Oregon and Helsinki.

The Radiance simulation results show that the amount of light permitted in testing chambers based on Helsinki climate is much less compared to that based on Oregon climate zone. The lighting condition and quality of chambers in Oregon is considered to be better compared to that in Helsinki. The illuminance of indoor space with conical skylight of 6.2° cone angle is about 300 lux and below. Almost half of floor area has insufficient daylight for normal library functions. There is insufficient evidence to specify that the conical skylights of Mount Angel Abbey Library are designed to address sun angle in Oregon. It is plausible to indicate that Aalto didn't copy a Helsinki Design directly.

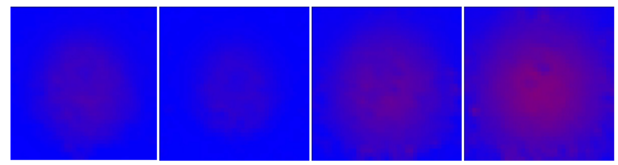


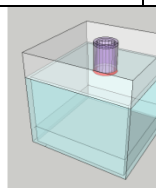
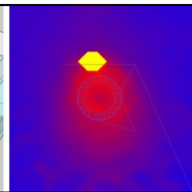
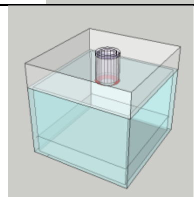
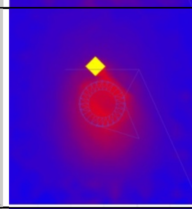
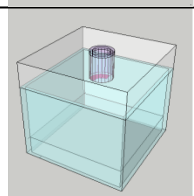
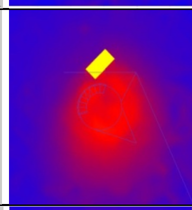
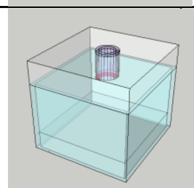
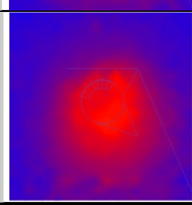
Figure 7: Spring Equinox, Helsinki 60.3 Latitude
From Left to Right: 6.2°, 0°, 15°, 25°

Conical Skylight Proposal

Conical skylights of Mount Angel Abbey Library are mostly applied in service areas. The amount of daylight brought in by conical skylights is generally sufficient for the functions of the spaces. The biggest limitation of current design is the direct sun beams permitted by skylights during summer time. The contrast between bright sunlight and relative dark area may be the potential resource for visual discomfort. The more updated researches on daylight quality analyse focus on not only quantity of light but also well-being of building occupants. Since library is a built environment mainly for reading purpose, lighting quality is essentially significant to architectural design.

The later part of this study intends to propose a solution to future improve the conical skylights of Mount Angel Abbey Library. The researchers propose to design a light reflector under the conical skylights to reflect and diffuse the direct sunlight during summer. The shape, the size and the location of the reflector is adjusted in order to obtain the optimum results. Simulation process which is similar to conical skylight testing is carried out to evaluate the light quality of the space after light reflector is added to the design. Eventually the following four designs are selected as potential solution to enhance the existing conical skylights.

Table 5: Conical Skylight Reflector Proposal and Simulation on April 21st

Light Reflector	Light Reflector Model	Radiance Simulation
Reflector 1 10"wide ring, curved upward		
Reflector 2 12" wide ring, curved downward		
Reflector 3 12" wide one third ring, curved downward		
Reflector 4 12" wide half ring, curved downward		

Light Reflector 1 has a 10" wide circular ring below the conical skylight to block the direct sunlight. Direct sunlight usually goes into the space near the lower edge of conical skylights. The ring is curve upwards to capture the dynamic of the whole conical lights. The ring shape light reflector will be able to block the direct sunlight near the edge and allow sunlight to come into the indoor space through the whole at the centre. The design is aesthetically pleasant and likely to be accepted by library users. However according the radiance simulation result, the design still misses some direct sun beams at noon. Due to the reduction of the lower opening the skylights, the amount of daylight obtained is reduced, too.

Based on Light Reflector 1, Light Reflector 2 intends to further minimize the direct sunlight and increase amount of diffused light in the space. The ring shape of Reflector 1 is remained. The width of the ring is widened up to 12" to block more direct sun beams. The ring is curved down to better address the angle of sunlight passing through the conical skylights. The simulated plan shows the direct sunlight on the floor is less compared to Reflector 1. However the amount of daylight on the floor is reduced, too. The area with illuminance 300 lux and above is smaller compared to that of Reflect 1. Reflector 2 is curved downward. It may be more visible to building occupants. The simple and clean appearance of original conical skylights may be compromised.

Reflector 3 is designed to address the reduced amount of diffused daylight for Reflector 2. The principle reason for light reduction by Reflector 2 is the enlarged surface area of the reflector. Direct sunlight only comes into the space during certain period of time and projects with certain angle. The light reflector is not necessary to be a full ring. Therefore Reflector 3 is a half ring of Reflector 2. Half the ring which is not likely to block much sunlight is cut away to permit more diffuse daylight. The simulated image indicates that the area which receives more sunlight greatly enlarged. The daylight quantity is almost the same compared to original conical skylights without reflectors. The constraint of the design is the increase amount of direct sunlight gained in the indoor space. And the half ring shape of reflector may be aesthetically challenging.

Reflector 4 is a design modified from Reflector 3. The surface of reflector is cut even more to maximize amount of diffused daylight. The direct sun beams problem is reduced by adjusting the position of the reflector. Reflector 4 is raised up and get into the conical skylights. By doing this, more sun beams can be obstructed by the reflector. The daylight quality simulated based on Reflector 4 is the best among all the designs. 70% to 80% of the floor area in testing chamber receives more than 300 lux daylight. The distribution of daylight is more even due to the larger opening area of the conical skylight. The glare is almost eliminated by the reflector. The raised reflector successfully minimizes the direct sunlight and creates visually more comfortable lighting condition. Reflector 4 shares the same aesthetic problem with Reflector 3. Locating reflector at higher position may lessen the visibility of the reflector to building users.

Shaping Light

Aalto takes possession of daylight and composes a series of light-zones that generates an undulating visual performance. Daylight drapes the lobby but quickly diminishes in intensity along with spatial compression leading to the circulation desk that retains a helm-like visual control over the main library. Conical skylights dabble the entry way but the visual queue is a waterfall of daylight emanating from the central roof monitor. Appropriately position, the roof monitor casts diffused daylight throughout the center of the library and across three levels of reading areas and transitional light-zones. Beyond the crown of daylight lies book stacks in a wake of light that is bounded by a softer cascade of daylight emanating from clerestory windows.

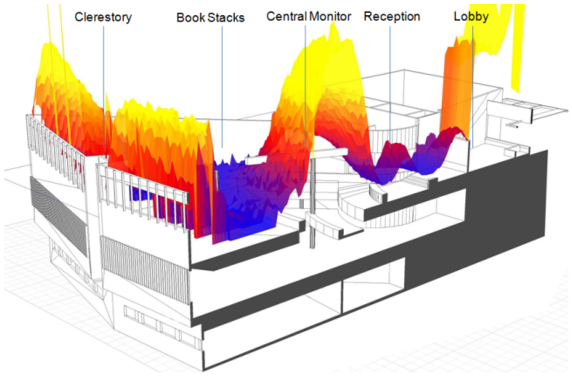


*Figure **8:** Illuminance Section - Roof and Daylight Monitors not shown*

Aalto's carving of light reinforces the ocular centric experience and strengthens a ritualistic pattern movement that resonates throughout much of his later work including the Municipal Library in Rovaneimi.

At Rovaneimi, Merete defines the library similarly as three light-zones: reception, reading niches, and transitional shadow-zones. The reception desk retains central oversight of the entire library and daylight accentuates central circulation and reading areas. There is a consistency in design custody between these two libraries that orchestrates "spatial pauses between light-zones"[12] and reinforces internal awareness while systematically divorcing from the surrounding environment by offering very few and sparse views to the outside.

CONCLUSION

The "Oregon Project" known to Aalto was a carefully orchestrated display of daylight that shaped space, rhythms of visual interaction, and fortified a ritual of library tasks and interactions. 40-years later, this paper benchmarked Aalto's daylight performance against modern daylight performance criteria to discover that current standards are unable to illustrate the strength of his daylight solutions. More important, was the delicate nature in which Aalto aligned specific tasks to specific daylight devices. The results of this study favours a Daylight Zone Factor that takes into account specific tasks and specific IES daylight recommendations to better asses Aalto's daylight solutions.

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