Integration of daylight quality in the design studio: from research to practice

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ABSTRACT: This paper presents the teaching method used in the lighting section of a design studio on Physical Ambiences (French term for Indoor Climate) at Laval University's School of Architecture. The teaching method comprised studies of daylight strategies in great architectural projects, readings, development of a lighting scenario according to basic biological needs and light transitions, quantitative analyses based on simple performance indicators, scale of shadows and contrast pattern analysis. These analyses were achieved using a variety of tools: physical models, manual calculations and graphical methods, spreadsheet programs, computer simulations, etc. The paper presents the teaching method as well as examples of projects achieved during the studio. The success of the studio demonstrates that it is possible to teach considerably advanced lighting concepts in a relatively short time (2 months). The results are powerful and informative data sets and images that feed the design process and enhance the architectural qualities of the project.

Keywords: daylight, teaching, quality indicators, design studio, physical models, computer simulations, Radiance, Ecotect

1. INTRODUCTION

The use of daylight in buildings is widely accepted as one of the important strategies to reduce overall energy use. Apart from its numerous positive health and psychological effects [1], daylight is a free, renewable natural resource and a high efficacy light source [2]. Daylight also provides a continuous spectrum of light, which enhances visual performance. People will tolerate much lower illuminance levels of daylight than artificial light, particularly in diminishing daylight conditions at the end of the day [3].

Despite its numerous advantages over artificial lighting, daylight is not always the preferred lighting solution because it is often associated with glare (direct, reflected) and overheating problems. Moreover, the intrinsic dynamic nature of daylight makes it a less reliable light source in the mind of engineers interested in meeting specific design targets (lux values). Architects often find it too complicated to consider at an early design stage and are often too poorly trained to be able to work strategically with daylight.

In order to promote the use of daylight in buildings, a two-month in depth lighting training was offered at Laval University's School of Architecture as part of a professional Master's studio on Physical Ambiences. This design studio includes three main themes: lighting, thermal comfort (heating, cooling, ventilation) and acoustics. The course consists of 9 studio hour/week supplemented by 3 hour/week lectures and tutorials. The whole course lasted 15 weeks from January to May 2006.

Prior to commencing, the 28 students who participated in the studio had successfully completed a three-year Bachelor degree of Architecture (B. Sc. Arch.). They had some basic knowledge of photometry (units, basic calculations), the human visual perception system (glare, contrast, adaptation), basic concepts in the use of daylight in buildings (e.g. daylight factor) and some knowledge about artificial lighting.

2. A METHOD TO TEACH DAYLIGHTING

2.1 General organisation of the course

The 3 hour/week theoretical course on daylighting included five lectures on the following themes:

- Daylight in great architectural projects
- Design strategies: building a light scenario
- Validation based on simple quality indicators
- Tools for analysis 1: physical models, graphical methods, manual calculations, spreadsheets
- Tools for analysis 2: computer simulations

2.1.1 Daylight in great architectural projects

In order to initiate the work and discussion, the students were first asked to choose a project amongst the list in Table 1. They had to study the project, present sketches of it and explain the daylight strategy used. A list of readings was also suggested to supplement the process.

2.1.2 Design strategies: building a light scenario

According to Lam [4], there is a sound, viable approach to the design of the luminous environment - a qualitative approach with universal validity because it is derived from fundamental human needs for visual information which are an inalienable part of man's biological nature. These fundamental needs for environmental information are described in Table 2.

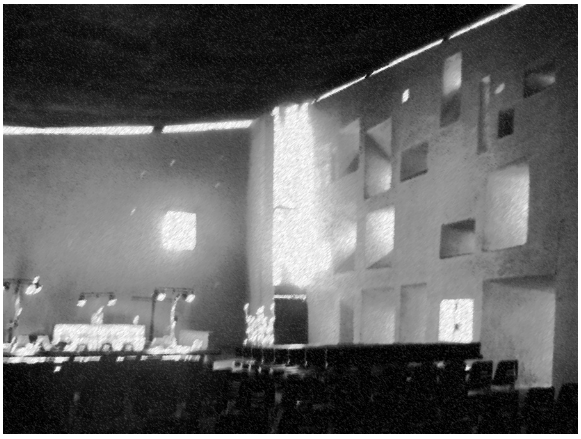


Figure 1: The need for enclosure in Notre Dame du haut Chapel, Ronchamp, France, by Le Corbusier (photo by Roxanne Pagé).

In the studio, the students were encouraged to describe and characterize each room of the building's program in terms of the response to Lam's eight biological needs. A special emphasis was put on the main entrance hall, which was a core, distributing area in the building's program. The students were asked to build a large scale (1:50) physical model of this hall and develop its architecture while considering:

- daylight transitions and adaptation from exterior to interior (as in Alvar Aalto's library projects)
- daylight used for orientation in the entrance hall (as in Erickson's Museum of Anthropology).

Table 1: List of architects and architectural projects studied as precedents.

A. Erickson	Museum of Anthropology, BC, Canada
Alvar Aalto	Mt. Angel Library, Oregon, USA
	Rovaniemi Library, Rovaniemi, Finland
	Seinäjoki Library, Finland
	North Jutland Art Museum, Denmark
	Vuoksenniska Church, Imatra, Finland
	Municipal Library, Seinäjoki, Finland
	Lahti Church, Lahti, Finland
A. Predock	Performing Arts Center, Tempe, USA
Le Corbusier	Notre Dame du haut Chapel, Ronchamp, France
	Sainte Marie de La Tourette Monastery, Éveux-sur-l'Arbresle, France
Louis Kahn	Kimball Art Museum, Fort Worth,Texas
	Library of P. Exeter Academy, USA
Jörn Utzon	Bagsvaerd Church, Copenhagen, Dk
Steven Holl	D.E. Shaw Company, New-York, USA
R. Pietilä R. Paatelainen	
	Kaleva Church, Tampere, Finland
F. L. Wright	Taliesin residence, Phoenix, Arizona
Tadao Ando	Chapel on Mount Rokko, Kobe, Japan
	Church of light, Ibaraki, Osaka, Japan

These two last features were emphasized in the hall because it is a dynamic area characterized by movements through space, changes in orientation and decisions on possible other pathways. The discussions on daylight in the hall were helpful in developing the light scenario for the whole project.

Table 2: The eight most important biological needs for environmental information according to Lam [4].

LOCATION with regard to water, heat, food, sunlight, escape routes, destination, etc.
TIME and environmental conditions which relate to our innate biological clocks
WEATHER as it relates to the need for clothing and heating or cooling, the need for shelter, opportunities to bask in the beneficial rays of sun, etc.
ENCLOSURE or the safety of the structure, the location and nature of environmental controls, protection from colds, heat, rain, etc.
NATURE i.e. the presence of other living things, plants, animals and people.
TERRITORY in terms of its boundaries and the means available within a given environment for the personalization of space
RELAXATION/STIMULATION of the mind, body and senses
REFUGE as a shelter in time of perceived danger

Lam [4] maintains that in most spaces, lighting which provides well for biological needs simultaneously takes care of most activity needs. This paradigm was introduced as a starting point for the design. Some examples drawn from famous architectural projects were shown as illustrations of the eight basic needs. For example, Figure 1 shows a response for the need for enclosure (daylight line at the top of the walls which emphasizes the definition of enclosure) in Le Corbusier's famous Ronchamp Chapel. Figure 2 shows a response for the need for location (orientation, path) in Arthur Erickson's Museum of Anthropology.

Figure 2: The need for location (orientation: where to go) in the Museum of Anthropology, British Columbia, Canada, by Arthur Erickson (photo by Jen Saypa).

2.1.3 Validation based on simple quality indicators

Once the light scenario for the project was well established, a simplified method of analysis of the daylight conditions based on earlier research [5,6] by the author was introduced. The method consists of considering a series of quality indicators in order to better characterize light conditions. The indicators proposed are listed in Table 3. A general guideline for interpreting the data (presented in Table 3) was also proposed based on a literature review [5] and personal experience of the author in the laboratory. The students were also encouraged to use more exploratory methods of analysis like the scale of shadows by Frandsen [7] and contrast pattern analysis by Demers [8, 9].

The scale of shadows [7] is a systematic description of the relation between the light source and the object (a sphere). The scale has 10 subjectively evaluated equal intervals, showing the effect of the change from a parallel to a diffuse light source on light modelling of a sphere. Geometrically it is defined by the percentage of the (partially) shaded areas on the sphere (0 %, 10 %, 20 %, etc.) produced by a circular light source of which the maximum, corresponding sky factor is 0 %, 1 %, 4 %, etc. In parallel light, the shadows are so sharp and dense that objects almost lose their form. Even tiny pits on the object's surface are big enough to create harsh and disturbing shadows. In diffuse light, the lack of shadows translates into a lack of three-dimensional form. A sphere appears flat rather than spherical, and texture is missing.

The contrast pattern analysis by Demers [8, 9] is based on an analysis of images produced by computer manipulations (raster graphics) of photographs of the interior. The computer manipulations produce a simplified greyscale image with five zones of brightness: 100%, 75%, 50%, 25% and 0%. The patterns obtained convey the major patterns of light and shadow in space. The technique necessarily requires that all photographs be taken using the same aperture and speed on the camera. Thus, for each experiment, the picture frame has to remain identical to ensure proper comparison of the data. Other aspects of the lighting pattern, such as the gradation and the concentration, can complete the analysis when needed (see [8, 9] for further details).

2.1.4 Tools for analysis

A large number of tools to test, measure or predict daylight were introduced:

- physical models
- graphical methods
- spreadsheet calculations
- manual calculations
- computer simulations

The students were encouraged to use physical models under real or artificial sky. Real sky studies can be made under perfectly clear sky with a sundial [10] at the corresponding latitude in order to analyse the position and magnitude of direct sunlight patches. Real sky studies under overcast skies were also encouraged although a calibrated artificial overcast sky is available at the School of Architecture (Fig. 3).

Table 3: List of daylight quality indicators

Indicator	Value	Interpretation
Daylight Factor	see recommendations for the type of space in lighting standards	
	< 1%	too dark
	2 %	minimum acceptable
	> 5%	looks substantially daylit [11]
	> 10%	risk for overheating
Horizontal illuminance	see recommendations for the type of space in lighting standards	
	> 500 lx	too bright for computer work, stabilisation of visible performance curve [2]
	> 1000 lx	appropriate for circadian Cycle [3]
Absolute luminance	10^{-5} cd/m^2	threshold for visibility [12]
	< 30 cd/m^2	too dark for vertical walls
	> 500 cd/m^2	too bright for art. lights, center of visual field
	> 1000 cd/m^2	too bright for art. lights, in field of view
	> 2000 cd/m^2	too bright for art. lights
	> 5000 cd/m^2	unacceptably bright [12]
Luminance ratios	1:3	smooth transition between too surfaces
	1:10	limit of acceptability for transition between adjacent surfaces
	1:40	upper limit for acceptable contrast in space
	1:13	suitable ratio for visual interest in 40° band [13].
Vertical-to-horizontal illuminance	2-3	balanced 3D lighting [14]
Direct sunlight patches		Some necessary for stimulation and mood Avoid large patches causing glare

The instruments available for the physical model studies were two LI-210SA cosine corrected photocells linked to a LI-250 light meter. The photocells are characterised by an error factor of less than 5%. The diameter of the photocells is 2,38 mm, which is suitable for the study of scale models at 1:50. A hand-made luminance meter was built using a mat black cylinder mounted on the photocell as shown in Figure 4. The ratios of cylinder depth (d) to radius opening (r) were determined using the following equation (described in [12]):

$$d = 5.6 * r \quad (1)$$

The hand made luminance meter was mounted with a small laser beam in order to facilitate pointing on various surfaces within the model.

Figure 3: Artificial sky (overcast) at Laval University's School of Architecture, Québec, Canada, used for physical model studies.

Some graphical methods (BRS Daylight Factor Protractor, Graphic Daylight Design Method - GDDM, dot charts, see [13]) were also presented together with an Excel-based spreadsheet program called Lum Calcul [15], which allows to predict the daylight factor based on the input of geometrical and reflectance values for simple rooms. Some manual calculations were ultimately introduced: the lumen and daylight factor methods.

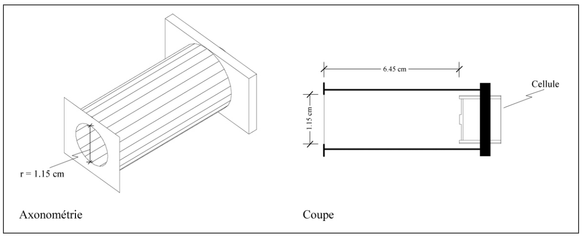


Figure 4: Black mat cylinder fitted to the photocells for the luminance studies (by François Cantin).

Finally, one whole course was devoted to showing the interface and giving a tutorial for the program Ecotect. The link to Radiance via the Ecotect interface was also explained and a small introduction to Radiance was presented. The students were left free to choose the tool which best satisfied their needs in terms of information and with which they felt more comfortable to work with. The students were asked to carry out their analysis considering a minimum of sky conditions and times as described in Table 4.

Table 4: Minimum sky conditions and times to include in the analysis of daylight conditions

Sky	Period	Times
Overcast	not relevant	
Clear (sunny)	Summer solstice	9, 12, 15 hrs
	Winter solstice	9, 12, 15 hrs
	Equinox	9, 12, 15 hrs

2.2 Design Studio Project

The students applied the lessons learned from the theoretical course in their design studio project or used the design studio project as a case study for analysis in the theoretical course. The studio project was a 3350 m^2 service pavilion located on the Baie de Beauport, near Quebec City. The building's interior program is described in Table 5.

The site was a relatively flat open area on the border of Saint-Lawrence river with a magnificent view of île d'Orléans to the North East and Quebec City to the South.

Table 5: Spatial program for the service pavilion

Room	Area (m^2)	Proximity
Hall	200	Ext. meeting area
Multipurpose room	700	Hall
Multimedia room	500	Hall
Kitchen	100	
Bistro	75	
Shop (rent)	100	
Pool	600 (350 pool)	
Dress room	150	
Storage	100	
First Aid	20	
Administration	100	
Capitainerie		
Mechanical	300	
WC	100	
Circulation	300	

3. RESULTS: EXAMPLES OF PROJECTS

A large number of projects and papers were presented. This section only shows a few examples.

3.1 Scale of shadows

Jody Lee Potvin-Jones carried out a study using Ecotect and Radiance and integrated a series of spheres in the space. The space studied was a hall to the multipurpose room. The hall was an elongated room with windows on the South and North ends. The student wanted to verify the necessity to add a light well above the central space of the hall. As shown in Figure 5, the light well significantly contributes to the illumination of the central part, especially the floor and part of the back wall above the stairs. The presence of the spheres enhances the appearance of 3D light in space and is quite helpful to visualize and characterize daylight quality.

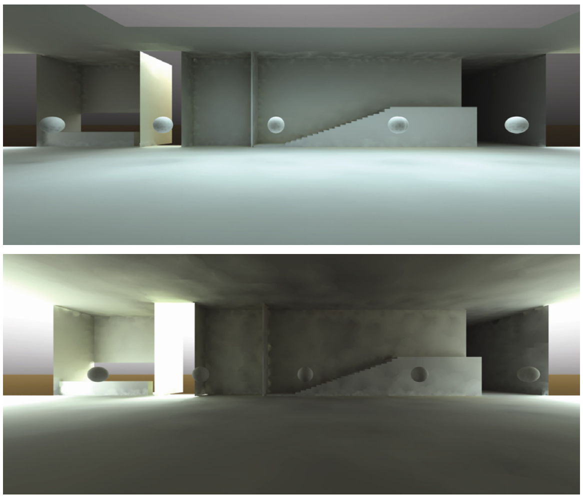
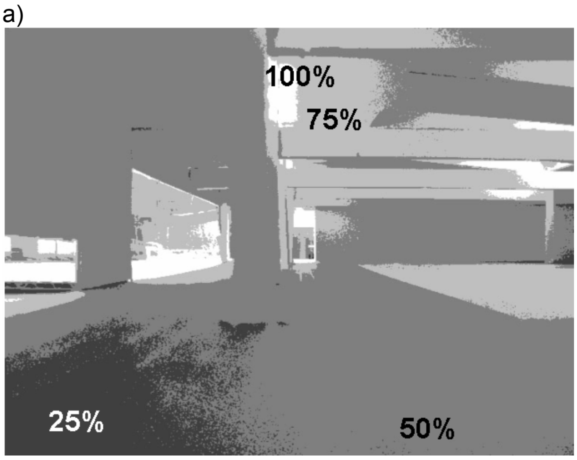


Figure 5: Radiance renderings of the hall with (top) and without (bottom) light well using the scale of shadows (by Jody Lee Potvin-Jones).

a)



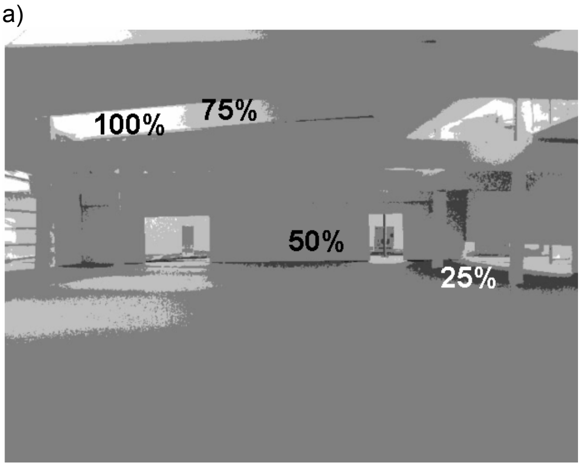
b)

Figure 6: a) Interior photograph of the swimming pool, view A from entrance, in physical model under artificial overcast sky and b) contrast pattern analysis (by Paule Bourdon).

3.2 Contrast pattern analysis

Paule Bourdon applied Demers [8, 9] contrast pattern analysis method for the swimming pool room. Some of the results for an overcast sky (photographed in the artificial sky) are presented in figures 6-7. The frequency distribution of grey levels obtained for both views are presented in Figure 8.

a)



b)

Figure 7: a) Interior photograph of the swimming pool, view B towards entrance, in physical model under artificial overcast sky and b) contrast pattern analysis (by Paule Bourdon).

The student drew the following conclusions from her analysis:

View A: from the entrance (Figure 6)

- Light is reflected in the space in a relatively balanced way (except for the entrance region, which shows a small darker patch of 25% grey, Fig. 6b).
- About half of the view has an intermediate (50% grey) intensity in luminance.
- The superior portion of the space is more daylit as shown by the dominance of lighter grey (75-100%) patterns around that region.
- Daylight is concentrated around the openings and generally emphasizes the structure, thus responding to the need for definition of enclosure.
- The exit is perfectly daylit, which contributes to orientation and way finding in the space.

View B: towards the entrance (Figure 7)

- An intermediate luminance level (50% grey) dominates the scene. This is confirmed in the frequency analysis diagram (Figure 8). This more uniform luminance distribution makes the scene look duller.

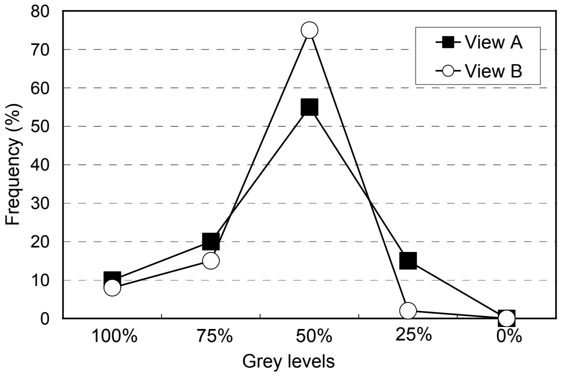


Figure 8: Frequency distribution of grey levels for views A and B (by Paule Bourdon).

4. DISCUSSION AND CONCLUSIONS

This paper presented a flexible method for teaching daylighting concepts and integrating them in the design studio. The method comprises studies of daylight strategies in renown architectural projects, readings, development of a lighting scenario according to basic biological needs and light transitions, quantitative analyses based on simple performance indicators, scale of shadows and contrast pattern analysis. These analyses were achieved using a variety of tools: physical models, manual and graphical calculations, spreadsheet programs, computer simulations, etc.

The paper presented some examples from student projects using the scale of shadow and contrast pattern analysis. The scale of shadows [7] was developed using white, perfectly diffusing spheres. However, most objects appearing in an architectural space are not white and diffuse. For example, a human face has lower reflectance, a colour component and is often a little specular. Specularity has some importance for creating highlights on the shape that illustrate the direction of strong direct light. Moreover, the optical qualities of a sphere surface are very important. The luminance and/or colour contrast between the sphere and the background decides if the sphere is visible at all. The concept of scale of shadows could be extended in the future to include specular objects, and objects of different reflectance and colour.

The success of the studio demonstrates that it is possible to teach considerably advanced lighting concepts in a relatively short time (2 months). The results are powerful and informative data sets and images that feed the design process and enhance the architectural qualities of the project.

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