MEASUREMENTS AND QUALIFICATION OF LUMINOUS AMBIENCES IN DAYLIGHTING

The case of the National Superior Academy of Music and Dance of Paris

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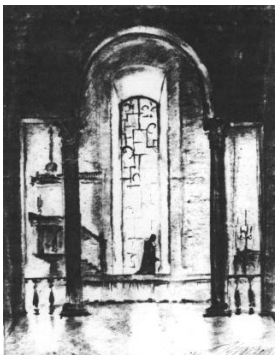
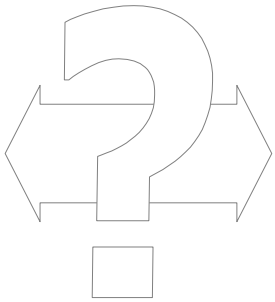
ABSTRACT This paper is centered on the relationship between intuitive and quantitative approaches for the understanding of luminous ambience in order to formalize criteria for the classification of luminous ambiences. We measured luminance and illuminance levels on glazed and opaque surfaces in interior spaces and built a synthetic scheme of these levels. We then analyzed and compared these measures and their interpretation to impressions felt by several subjects in the spaces, or to intentions expressed by the architect during the design of the project when available. This comparison has proved itself very meaningful and shows that many relations between the intuitive approach and quantitative measured data may be established. The second part of the work deals with the definition of criteria to classify ambiences. They allowed us to prepare a computer tool, based on neural nets which will be used to help architects store and browse through a large number of images.

1 Introduction

This work is part of a line of research on the integration of luminous ambience in the design of sustainable and low-energy architecture. We focus in our work on educational buildings (schools, libraries) because of the importance of luminous ambience for the functions of these buildings. We present here the case of the National Superior Academy of Music and Dance of Paris. We chose this building for the qualities of its integration in the luminous environment. This paper is centered on the relationship between intuitive and quantitative approaches for the understanding of luminous ambience in daylighting.



A Aalto, sketch of a church



Illuminance at point M in the interior space through a window

$$E_M = L \int_{\theta_1}^{\theta_2} \int_{\varphi_1}^{\varphi_2} \sin\theta . \cos\theta . d\theta d\varphi$$

$$\frac{L(\zeta,\alpha)}{L_z} = \frac{f(\gamma).\Phi(\zeta)}{f(Z_0).\Phi(0)}$$

Radiation theory formulas

Fig.1 Illustration of what we mean by intuitive and scientific approaches for luminous ambience

The scientific approach is, in our opinion, far too tedious to be used directly by architects. It is very difficult for them to apply the formulas of radiation theory in the early phase of the design of luminous ambience. In the sketch phase, architects proceed, indeed, in an intuitive

manner regarding the repartition of luminous flux and the future subjective response to the luminous ambience. On the contrary, the scientific approach is used as a basis (as far as architects are concerned) for the development of computer-aided design (CAD) tools specialized in natural and artificial lighting which perform evaluation of ambiences during the project. It is also used to design devices for window protection, to redirect luminous radiation during its propagation in interior spaces, etc.

In addition, it should be pointed out that the evaluation of luminous ambiences in daylighting by a sophisticated computer tool requires a well-defined morphology for the architectural projects and that this evaluation is still rare and rather expensive and only accessible to large public projects. Therefore, in the early phase of architectural design, architects cannot use the capabilities and tools of the scientific approach (apart from a few simple experts' rules) and generally only proceed in an intuitive way.

2 Objective

The purpose of this work is to provide links between qualitative-intuitive and quantitative-scientific approaches in the specific field of luminous ambience in daylighting. In the long term, it will be a basis to help and enrich architects' intuitions regarding luminous ambiences and to prepare criteria for the classification of luminous ambiences.

3 Method

We have chosen several buildings of particular interest for luminous ambience. We measured luminance and illuminance levels on glazed and opaque surfaces in interior spaces and built a synthetic scheme of these levels. The analysis and interpretation of measures were compared for each building to subjective expressions given by several people (generally students and professors) or by the architects who designed the projects. We present here the case of the National Superior Academy of Music and Dance of Paris for which the architect's point of view has been published (De Portzamparc, 1991).

For this work, we had to do the following:
1- define a protocol of measurements to ensure the validity of results;
2- interpret the measures according to previously published scientific works;
3- express an intuitive response that is representative despite its subjectivity.

3.1 Protocol of measurements

The levels and repartitions of illuminance and the spectral composition of natural light vary from one time to another in the exterior environment and, therefor, in interior spaces too. In order to obtain reliable, significant and comparable data, we had to define the proper moments for measurements and several complementary information. We have used the following information in addition to the measures of luminance. Because of the changes in some of these data, several measurements may be necessary. The measurements of the complementary information were, of course, taken just before the measurements of luminance. These complementary data were as follows:

- Geographic location of the site.
- Date and exact time: It is used to calculate the height and azimuth of the sun and to compute data for the luminous climate for the site under study.
- Type of sky (clear sky, intermediate clear, intermediate mean, intermediate overcast, overcast) (European Commission, 1993). The type of sky is important to ensure the quality of measures. It is necessary to measure each interior spaces for at least two types of sky, clear and overcast. For the clear sky, if the opening may receive direct light from the sun, there are several significant moments in a day (five for a south orientation, three for west and east orientations, two for north-west and north-east and one for north). Under different orientations, measures would naturally show different repartitions

of luminance in interior spaces. On the contrary, a uniform overcast sky yields the same repartition of luminance for any time and orientation, only the level may change (clearer or darker). Hence, we have taken only one set of measurements for overcast skies. For an intermediate mean sky, it is necessary to measure for visible and for hidden sky.

- Exterior horizontal illuminance level in a clear prospect (on the site) at measurement time. If impossible to measure, an interior vertical illuminance level in front of windows is used.
- The point of view on the plan of the building (pictures and measures are to be taken from the same point of view, indicated on the plan).
- Luminance measurements on glazed and opaque surfaces and indication of measured points later indicated on the pictures that are taken at the time and from the point of measurements. Luminance measurements should not take more than 15 minutes for non-overcast skies for one interior space (the sun travels approximately 5 degrees in 15 minutes). The main reason is that exterior light changes and, if measurements are not taken within these 15 minutes, measures would not be comparable. Measurements were performed using illuminance meter Minolta T-1 et luminance meter Minolta LS-110.

3.2 Interpretation of measures according to previously published scientific works

We use for the interpretation the notion of contrast (C) which we define as the ratio of luminance between two surfaces (L_0 and L_1) of an interior spaces, i.e. $C=L_0/L_1$. In the majority of scientific works concerning discomfort (and glare as extreme discomfort) or subjective response to contrasts, the notion of contrast is used to study the quality of a work ambience. Table 1 shows contrast levels for workplaces recommended by the European Commission:

Table 1 Luminance contrasts recommended by the European Commission for workplaces

Space under study	$L_0 : L_1$
Background of visual task : close environment	*3 : 1*
Background of visual task : peripheral environment	*10 : 1*
Maximum contrast for two surfaces (for example between a light source and adjoining fields)	*20 : 1*
Maximum contrast for two non contiguous surfaces (the interior in general)	*40 : 1*

Source: (European Commission, 1992)

Other places or situations may lead to other ratios. Unfortunately, contrast studies are rare in situations other than workplaces. Therefore, we use ratios given for workplaces. We consider them as references even if they were set for a particular function of space. Figure 2 shows a ranking of contrasts. As limits are not precisely defined, we present them as fuzzy sets.

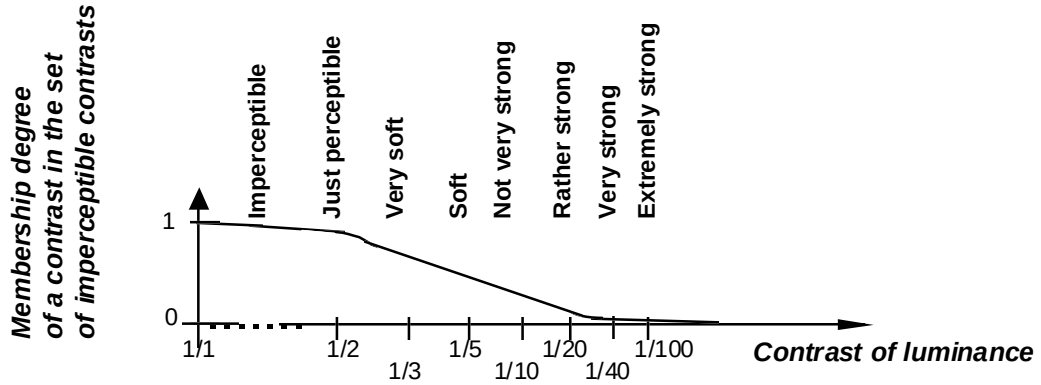


Fig. 2 Contrasts presented as the fuzzy sets of the set of imperceptible contrasts (Mudri, 1996)

For a given surface, if luminance levels increase or decrease continuously for contiguous points, we can speak of a gradual range of luminance. In our work, if luminance levels decrease or increase so that limits between clear and dark cannot be precisely defined, we speak of soft gradual range of luminance. On the contrary, if such limits are clearly defined, we speak of strong or very strong gradual range of luminance. (Mudri, 1999)

3.3 Expression of an intuitive representative response despite its subjectivity

In the case of the National Superior Academy of Music and Dance of Paris, the subjective intentions of the architect Christian de Portzamparc have been published (De Portzamparc, 1991). We have chosen a space called "chapel" because of its peculiar ambience. It is not a classroom. It is a complex space for spontaneous work and coffee-breaks, not quite closed, but sheltered, with a spiritual side like in a temple but also where any event is possible. Henceforth, we shall refer to this place as the café. Considering luminous ambience of the chapel, he stated that: "Some students prefer a padded, soft and dark ambience […] the more exuberant are in front of the light, in the café which is noisier."

4 Results

Point n°	*Luminance cd/m²*	*Point n°*	*Luminance cd/m²*
1	15	*13*	9
2	531	*14*	5
3	39	*15*	222
4	4	*16*	17
5	25	*17*	21
5'	22	*18*	11
5''	21	*19*	54
5'''	20	*20*	176
6	444	*21*	23
7	4	*22*	8
8	66	*23*	11
8'	62	*24*	153
8''	60	*25*	37
8'''	58	*26*	44
9	131	*a*	34
9'	5	*b*	60
10	11	*c*	96
11	13	*d*	125
12	9	*e*	165

Table 2 Points measured

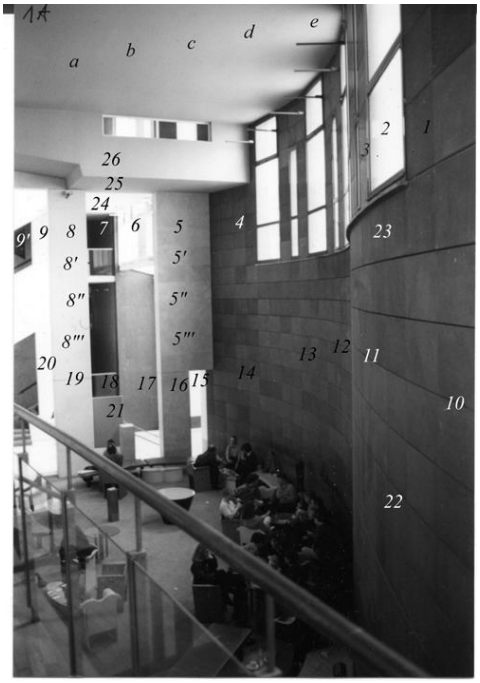


Fig.3 The space of the chapel (the café) : synthetic scheme of luminance

Conditions for measurements:
Intermediate overcast sky (hidden sun);10th October 1998, 4 p.m.; Point B is where the above picture was taken. The vertical interior illuminance is 400lux measured at point B oriented towards the glazed surface. Points shown in table 2 are indicated on figure 3. Point 6 is on the white frame of the window.

The café has been studied under two points of view and two different skies. In this paper, only point of view B for one sky is presented (as on figure 3), yielding the following results:

1- Right-hand side surface, black marble, covered, against the light, the back of the café

- Maximum contrast on the opaque surface 3:1 (points 10 to 14 and 22, 23). The contrasts which are just perceptible and spread over a large surface lead to very soft gradual range of contrast on this surface. Luminance levels are rather low.
- Maximum contrast with the glazed surface 50:1 (points 1, 2, 3 and 23). It is a strong contrast. However, the whole line of high luminance of the glazed surfaces are aligned at a great height and the luminous flux from these openings does not reach students in the café but stays higher. It reaches the opposite interior surface which reflect it. Students are psychologically protected from this flux. The flux and the contrast belongs to the gangway which is higher. This flux delimits the height of the café.

2- Opposite surface, made of different opaque surfaces

- Surfaces close to the café have contrast around 2:1 (points 5, 5', 5'', 5''' and 16 and points 8, 8', 8'', 8''' and19). Gradual ranges are barely visible and very soft.

- On the contrary the global image of the opposite surface which is entirely opaque (delimited by points 26, 5, 16, 28 and 9') is very variable with contrasts up to 35:1. On the whole, one cannot speak of gradual range. Luminance levels also vary from rather low to rather high (point 6 reaches 444cd/m² whereas point 7 is at 4cd/m²).

3- The illuminance at table height in the café at the limit of the clear space is 100lux. This illuminance is rather low. Let us say rather dark (considering that a work surface, to read for example, should reach 400 to 500lux). It can be noticed that illuminance on the tables of the café is much lower.

From these data we build a first relationship between the intuitive approach and the quantitative measured data. Christian de Portzamparc said it well: Some students […] are in front of the light". It does not mean that they receive the direct light on the face. Indeed, no portion of the sky (or exterior reflections) is visible from the café. However, there is an opposition between low contrast, soft gradual range of luminance and rather dark illuminance on one side (at the back) and, on the other side, strong contrast, no gradual range and much higher levels of illuminance at the exterior limit of the café. This opposition is very specific to this space. Students are sheltered in a rather dark and soft space. They feel protected, and they can see a luminous flux as an exterior limit, but it does not reach them. Hence, the measurements performed in the café on the right-hand side surface (dark) and on the opposite surface (part close to the interior of the café) have low levels of luminance, soft gradual range of luminance and rather low illuminance levels. On the contrary, the noisier side, as named by Christian de Portzamparc, is very well illustrated by the measurements when we consider the whole composite opposite surface with rather strong and varied contrasts, no gradual range of luminance and changing levels of illuminance with large surfaces having high illuminance levels. The opposition between calm and noisy is very characteristic for this space and very well shown on the measures.

We have then determined 6 logical zones on the surfaces of the café. Each zone contains 5 points of measurements. In table 3, the points belonging to a zone and the corresponding luminance are in the left-hand side of the table (points are in brackets: point 11 has 13 cd/m²). These data are identical to those of table 2, but per zone. On the right-hand side of the table, each zone is ranked with respect to intervals presented on figure 2. It is worth noticing that the above-mentioned opposition clearly appears on the table: Contrasts per zones are either just perceptible, very soft or extremely strong.

	Initial data					***Classes***								
	cd/m²	cd/m²	cd/m²	cd/m²	cd/m²	Contrasts								D.
zone	(point)	(point)	(point)	(point)	(point)	Im	jp	vso	so	nvst	rst	vst	est	
1	13 (11)	9 (12)	9 (13)	5 (14)	11 (10)			+						+
2	15 (1)	531 (2)	39 (3)	4 (4)	11 (23)								+	
3	25 (5)	22 (5')	21(5")	20 (5"')	17 (16)		+							+
4	66 (8)	62 (8')	60 (8")	58 (8"')	54 (19)		+							+
5	4 (7)	444 (6)	23 (21)	66 (15)	131 (9)								+	
6	34 (a)	60 (b)	96 (c)	125 (d)	165 (e)				+					+

Table 3 Points measured and grouped first in zones then in classes

Classes: *im, jp, vso, so, nvst, rst, vst, and est,* correspond to classes on figure 2, D. is for gradual range of luminance.

5 Classification using neural nets

Some classes are predefined, others may be determined by the architects using the system, some may be proposed by the system itself. A first level of predefined classes is of simple type: building time… A second type is made of qualitative expressions defined in this work (see table 3). A higher level may be obtained by comparing all the zones of the space: considering table 3, classes "tense" and "relaxed" may be presented as in table 4.

Zone subset X(i)	Initial data									*Classes*
	c o n t r a s t s								Gradual range	
	im	jp	vso	so	nvst	rst	vst	est		
X_1 (1, 3, 4, 6)		++	+	+					+	Relaxed
X_2 (2, 5)								++		Tense

Table 4 A higher level of classification from zone 1 to 6 as in table 3

Then it may be stated that: if a space has tense and relaxed zones, then there is an opposition (as far as luminous ambience is concerned).

Data as in table 3 (about 15 tables) have been used to calibrate neural nets. Neural nets have been capable of learning what contrast and gradual range of luminance are. They were then able to classify new pictures in the defined classes. As it is, to simplify the calibration of the neural nets, a gradual range class has been predefined, but without specifying strong or soft, this particular question has been raised by the neural nets during the learning phase.

6 Conclusion

In this work, we have defined a protocol of luminance measurements for interior spaces for the overall interior surfaces and not only for working spots. This protocol (necessary because of the variability of natural light) helps to define extreme situations. It allows us to have comparable data and to rebuild intermediate cases if necessary.

We have recorded and compared measures and qualitative (subjective) expressions for several spaces. This comparison was our basis to build definitions, founded on measured data, for qualitative expressions on luminous ambiences. It can also be used to enrich the language on luminous ambience and be of great help on the classification of luminous ambiences. We use this comparative approach in teaching, in our school of architecture.

We built a method to help structuring luminous ambiences in natural lighting and develop a first implementation in neural nets. The results are quite promising for further work on auto-adapting neural nets in order to allow architects to integrate their own images (reference images) and to easily browse among very large sets of images using the proposed auto-adapting structure with predefined and personal keywords.

We would like to deeply thank Christian de Portzamparc and the National Superior Academy of Music and Dance for letting us work on this luminous ambience of exceptional quality.
We thank also Michel Perraudeau, CSTB, Nantes and Jean-Luc Ploix, Netral, Paris for their help and support throughout this work.

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