Objective data from Radiance and subjective intentions from architects

Ljubica MUDRI[1]
lmudri@club-internet.fr

Jean-Dominique LENARD[2]
jdlenard@club-internet.fr

Marija CVETKOVIC[3]
cveleglg@bankerinter.net

ABSTRACT
This paper focuses on the existing links between intuitive and quantitative approaches for the study of luminous ambience.

In the early phases of the design of a building, architects generally have an intuitive and qualitative approach for the future luminous ambience (a calm and soft ambience, or to have a tension in the space, or a dynamic ambience, etc.). Once the building is finished, we can compare the measurements of luminance and chromaticities in the built space to the initial subjective intentions of the architect. This allows us to quantitatively qualify what is, for example, a dynamic ambience. The different studies we performed helped us define several qualitative expressions.

Once the building is achieved, it is too late to advise on possible modifications of the building morphology or of the way daylight is taken in order to make the resulting ambience closer to intentions. To bring the resulting ambience closer to intentions, we propose to use Radiance in the early stage of design. Radiance allows us to obtain “valid” images as far as daylighting is concerned along with quantitative data. Hence, we can interpret the distribution of luminance and show the correlation with intentions. Finally, during a discussion with the architect, we can find ways to improve the correlation between predicted results from simulations and intentions.

In this paper, we present 2 examples of this method applied on the luminous ambience of an already finished building and on a building in the design phase.

1. CONTEXT

Our purpose is to help the design of luminous ambience in daylighting by improving the correspondence between architectural intentions and the luminous ambience in the finished building.

Naturally, we use criteria for illuminance levels of work surface and for visual discomfort as defined in norms and recommendations and energy expenditures in interior spaces. We add here that a luminous ambience is the expression of architectural criteria defined by the architect on the basis of his/her subjective intentions. Discomfort criteria specify what is unwanted and architectural criteria define what is wanted. In this paper, we mainly focus on architectural criteria.

---

[1] Researcher/Lecturer at the Paris-Belleville School of Architecture, Paris & De Luminæ Lab, Consultancy in daylighting, Paris

[2] Computing, De Luminæ Lab, Paris

[3] Post-Graduate student, Department of Computer Science, Faculty of Electronic Engineering, Nis, Serbia and Montenegro.

The question of architectural aided design covers three main aspects: the precision and completeness of data, the problem of languages and a problem of speed of answer. [Mudri96]

On one hand, in architectural design, fundamental choices are taken during the sketch phase. Validations of these choices by architects also occur in this phase where they validate their architectural intentions. The architects' approach is rather intuitive, qualitative and descriptive and data in a sketch are imprecise and incomplete [Mudri96]. Moreover, architects need quick answers compatible with the speed of the design process.

On the other hand, validation of the technical qualities of buildings by experts with sophisticated classical techniques only occur in the detailed design phase. These validations are quantitative. Hence the languages used by architects and technical experts are different. In addition, the mathematical methods use precise and complete data which are only available *at the end* of the design and the necessary calculations are too long for architects during their design phase.

Previous studies [Lenard99] allowed us to find ways to build links between distribution of luminance and qualitative expressions. In that respect, we can interpret quantitative data issued from a study of daylighting in a space in order to compare them with architectural intentions, that is build an interpretation expressed in "architectural" terms.

These studies have been conducted for already finished buildings and showed that a qualitative interpretation of quantitative data can be quite meaningful.

Now, we move one step further and use a comparable method for buildings in design.

Naturally, as the building is still on paper, it is not possible to take measurements. Therefore, we use Radiance to "predict" future daylighting data. We then collect luminance and illuminance from Radiance images and analyse them in order to interpret these predicted data and compare them to architectural intentions.

Section 2 of this paper briefly presents the method we use and that has been defined for existing buildings. In section 3, we present an example of analysis on a finished building, the café in the National Superior Academy of Music and Dance of Paris by architect Christian de Portzamparc. In section 4, we show the adaptations of the method for buildings in design and present an example, the Wurth Foundation by architect Clément Vergely.

2. METHOD

The purpose of this method is to link quantitative data coming from a study of daylighting and qualitative data expressed by architects about the luminous ambience they build.

We define the luminous ambience as the way the luminous environment affects a subject. There are two main components: the objective luminous environment and the subjective response.

This method is based on a protocol of measurement that allows us to collect "valid" luminance and illuminance in an existing space. As this protocol is not the main scope of this paper, we invite the interested reader to refer to [Lenard99]. In parallel, we collect from the architect the qualitative expression he/she uses to define the luminous ambience in the building under study. Then we compare the quantitative and qualitative data to show existing links, drawbacks and ways for improvement.

We present briefly here the interpretation phase.

The distribution of luminance on glazed and opaque interior surfaces is interpreted on the basis of the following definitions:

We use the notion of contrast (C) as the ratio of luminance between two surfaces (L_0 and L_1) of an interior space, i.e. $C=L_0/L_1$. Contrast is widely used to analyse work ambience in scientific works about discomfort and glare or response to contrasts. Table 1 shows recommended contrast (luminance ratio) levels for workplaces [Hopkinson63, Euro92, Euro93]:

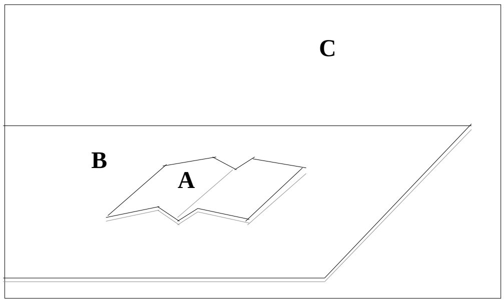


Fig. 1 Fields of vision

A: background of visual task;
B: environment – preferably rather uniform;
C: peripheral field – preferably rather uniform.

A:B	= 3:1
A:C	= 10:1
Light source: adjoining field	= 20:1
Interior in general	= 40:1

Table 1 Recommendations for necessary luminance ratios in the main field of vision

Most studies deal with workplaces. No ratios are currently defined for other types of spaces. In our work, we do not concentrate on workspaces. Moreover, to work with architectural intentions, one does not focus on a specific field of vision, for work, but on many fields of vision which cover the whole interior space. On the basis of the above ratios, from [AFE00] and our measurements [improved from Mudri02], we propose the following ratios. To take into account the lack of precision of the limits in the interpretation of these ratios, Fig. 2 presents a classification as fuzzy sets of the set of imperceptible contrasts for photopic vision in interior spaces (not valid for very low luminance levels).

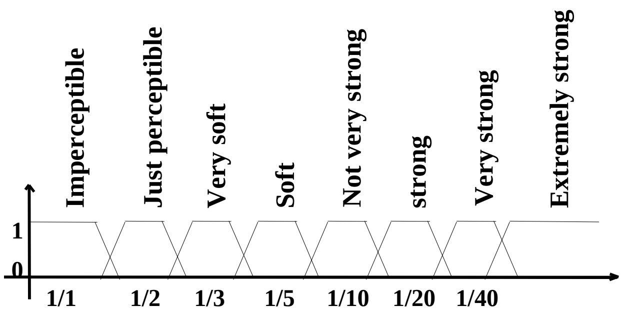
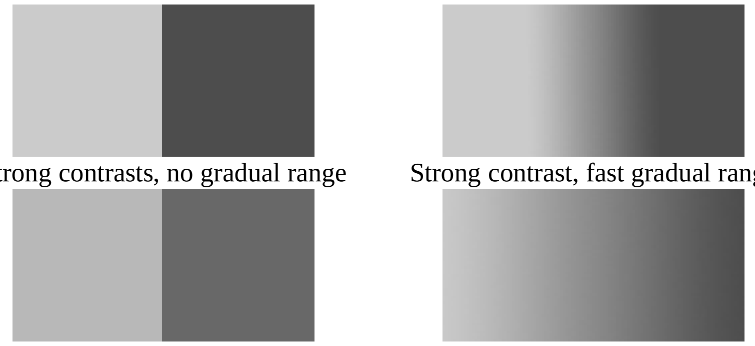


Fig. 2 First step to a link between qualitative/quantitative data

In this paper, we also use the expression "gradual range of luminance": 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 (very fuzzy), we speak of slow gradual range of luminance. On the contrary, if such limits are less fuzzy, we speak of fast gradual range of luminance.



Strong contrasts, no gradual range | Strong contrast, fast gradual range

Soft contrast, no gradual range | Soft contrast, slow gradual range

Fig 3. Contrasts and gradual range of luminance

When these contrasts and gradual ranges of luminance for the space under study, we interpret these results and show the correspondence with intentions. We call this phase analysis post-data (post-measurements or post-Radiance).

We now present:

- the method based on luminance measurements in the « Café-chapel » in a building of Christian de Portzamparc,
- the method based of Radiance simulations for the concept of the Wurth Foundation from architect Clément Vergely.

3. ON AN EXISTING BUILDING: "CAFÉ-CHAPEL"

In 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 the luminous ambience of the chapel, De Portzamparc 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."

3.1. 3.1. Measurements

Point	*Luminance*	*Point*	*Luminance*
n°	*cd/m²*	*n°*	*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

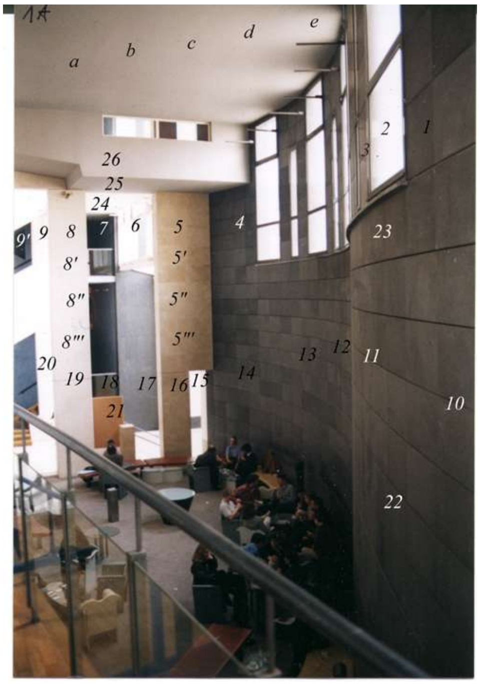


Fig. 4: The space of the chapel (café) : synthetic scheme of luminance

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 4. Point 6 is on the white frame of the window.

3.2. 3.2. Study of measurements

The café has been studied under two points of view and two different skies. Here, only point of view B for one sky is presented (as on figure 4), 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 belong 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.

4. ON A BUILDING IN DESIGN: WURTH FONDATION

4.1. 4.1. Modifications of the method - Our use of Radiance

As we use Radiance in the early phase of the design process, the whole building is not precisely defined. Some assumptions have to be made. Therefore, it is quite possible that an assumption leads to unwanted results and that a new hypothesis should be tested. This side-effect is of course quite interesting.

As we said, the question of duration is very important during the sketch phase. So we need to have rather quick renderings and this duration remains in our view an important obstacle. Therefore, we simplify the 3D model of the building without changing what influences daylighting and luminous ambience.

For the sake of speed, we also do not concentrate on rendering « perfect » images, ie highly-detailed images with a lot of complicated textures and detail objects (like door knobs, complicated furniture, etc.). Even if extremely realistic images can be obtained with Radiance, their rendering duration is too long, so it is useless for us in this phase. It would even be meaningless, as the building is not yet completely defined. On the contrary, we concentrate on obtaining images that contains the necessary quantitative information for us to study the space in a time that is compatible with the architect's expectations.

For the analysis, the amount of data and the flexibility is much increased with Radiance. We have luminance values for every point on the image. We can easily change the type of sky and get new values whereas waiting for a sky type to happen in reality can be quite long. There is no problem of outside light variability, therefore no problem of measurement duration. On the contrary, with measurements in a building, we have all the details of the space and the actual objects, it is therefore naturally "best" to use measurements when possible. Of course, for a building in design, this is not the case.

To analyse a luminous ambience from a Radiance image, we take into account each architectural object: opaque and glazed surfaces, pylons, beams, etc. and we analyse contrast and gradual ranges of luminance on each of these objects. We also study contrasts and gradual ranges which appear on limits between surfaces of objects, more precisely between the various surfaces in one object or between contiguous surfaces of different objects. For contrasts on limits, we compare luminance of small surfaces or of a small number of points that are contiguous on both sides of the limit. We also introduce the notion of movement: the increase of luminance levels within a gradual range may be translated in architectural language as the movement of light with starting and ending points.

4.2 Presentation of the project of Wurth Foundation

This project competes for the Wurth Foundation in Erstein, in the East of France. This building and the park should comply with the requirements of a vast space of exhibition for sculptures. The project is made of two volumes placed in the park like monoliths with very simple geometry. One of these volumes is the exhibition space.

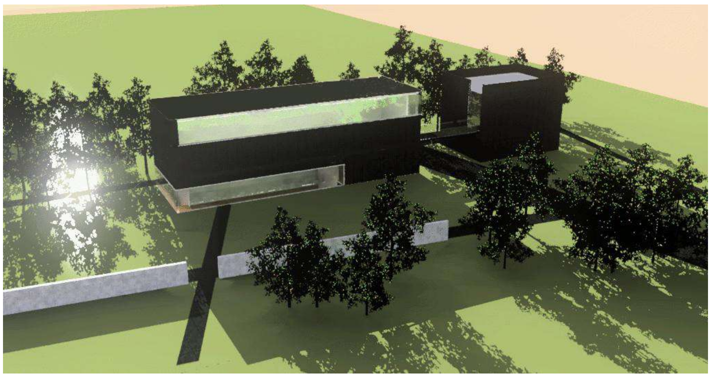


Fig. 5 Wurth Foundation, project, outside view, North facade

Architect's intentions

Architect Clément Vergely designed that the luminous ambience of the exhibition spaces should be calm, serene, where the presence of natural light should be felt but that is not violent, that the ambience is not yellowish but rather cold.
He also said that there should some sort of translucent blind to filter natural light.

Data and Hypothesis for simulations

Clément Vergely gave us the 3D model of the project. The exhibition space is made of two levels. Each level is a unique big volume. We mainly studied three fields of vision per level in order to "see" the whole interior envelope.

The glazing used is called "Diamant[4]". It is 5cm thick and a transmission factor of 0.91. Two glazed surfaces separated by 15cm have been designed, which allows for the placement of the translucent blinds. As the blinds are not defined in this design phase, we studied various transmission factors for the blinds. These are theoretical blinds defined as translucent materials in Radiance. When the desired characteristics of the blinds will be defined, we may look for it on the market.

The opaque surface are the wood floor which is designed in the project as very clear, a bit yellowish oak and all the walls and ceilings should be very clear, nearly white but not yellowish and rather cold. So we used the following material colour within Radiance (0.921569 0.948235 0.95).

We assumed three behaviours of the building using mobile blinds for different types of sky in order to stick to the architect's intentions, to protect the interior space from direct sunrays and to protect the view from too high sky luminance while keeping a maximum of daylighting. In that respect, we defined that blinds should have different transmission factors depending on the orientation of the glazed surface.

Here we present the luminous ambience in three skies, two overcast and one clear skies:

- A bright overcast sky characterised by a uniform sky with illuminance on the exterior horizontal plane of 30 000 lux (E_h=30000lux). In this sky, blinds with a transmission factor of 0.5 have been studied for all glazings except down floor, south window where the transmission factor will be at 0.8. This is because the trees (with persistent leaves) protect this glazing.
- A darker overcast sky characterised by a uniform sky with illuminance on the exterior horizontal plane of 10 000 lux (E_h=10000lux). In this sky, no blinds are used (blinds are supposed to be up).

[4] This glazing has been defined by Saint Gobain vitrage for the « Grande Pyramide du louvre ».

- A clear sky where we wanted a low position of the sun in front of the glazing. So we chose the 21st of December at noon. Translucent blinds with transmission factor of 0.2 are used for South and West glazing, no blind for the North side and West has no openings.

4.3. 4.3 Analysis

4.3.1. 4.3.1. Top floor

3 fields of vision have been studied: two of them with a front view towards the East wall, one with a view towards South and West (called axial view). One front and one axial view are presented below.

Fig. 6 Top floor, vision towards East wall, clear sky (front view)

Fig. 7 Top floor, towards South & West wall, clear sky (axial view)

Illuminance and luminance levels on the Top floor

For *overcast skies*, luminance levels range around: 1800 to 2000 cd/m² on both glazings (South and North) or overcast skies with E_h=30000 and E_h=10000. This yields a good equilibrium of the distribution of luminance on the glazings.

However, the distribution of luminous flux on opaque surfaces is different in these two cases. For overcast sky with E_h=10000, the opaque surfaces receive roughly twice (or 1.5) less flux. But North and South walls still have comparable level of luminance in the two overcast skies, what is well balanced (the North wall receive less because of the trees on the South side). This enhances the balance of the distribution of luminance on the whole interior space.

For the clear sky (noon, winter), levels of luminance are around 3000 to 4000 cd/m² on the South glazing and 600to 800 cd/m² on the North glazing. The distribution of luminance on the opaque surfaces shows levels that are between those of the two overcast skies. The North wall receive 25% more than the South one, so we cannot speak any more of equilibrium.

For all skies, illuminance levels are around 1000 to 1600 lux on the vertical opaque surface at the height of 170cm above floor level (to watch paintings) and from 400 to 900 on the floor (to watch sculptures).

Luminance ratios – top floor

For the *overcast sky E_h=30 000* :

Geometry

We see parallelepipeds and a triangle in perspective. With the front views, the vanishing point at the back is on an opaque wall in front (Fig. 6). With the view on axial view, the vanishing point is behind the edge (Fig. 7). The horizontality is quite visible on the whole interior space, on glazed and opaque surfaces. This horizontality is due to the distribution of luminance (see Fig. 8).

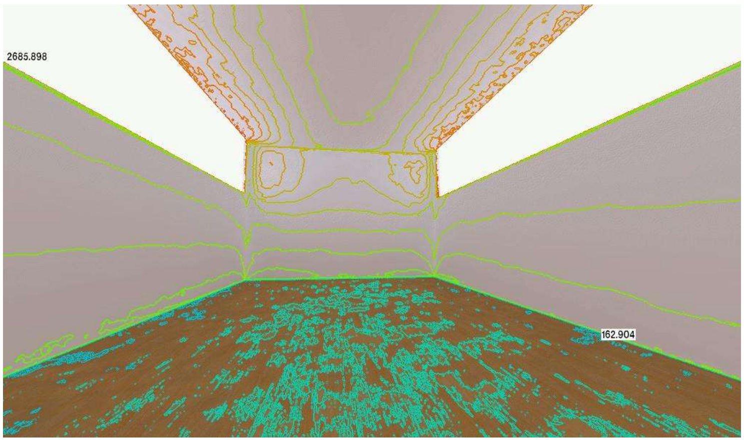


Fig. 8 False colour image of the top floor showing horizontality

We call horizontality the fact the comparable luminance levels follows the longitudinal axis on all surfaces (walls, floor and ceiling). In that respect, we will study possible symmetries for a vertical axis.

Contrasts of luminance:
Within surfaces: juste perceptible, below 1 to 2.
For limits between surfaces: just perceptible, below 1 to 2 with a maximum of 1 to 4, very soft.
Brightest surface: North glazing for front views, South glazing for axis view.
Darkest surface: Floor.
Maximum contrast: strong, 1 to 20, for points well apart in front views (1 to 24 for axis view).

Gradual Ranges of luminance:
Slow gradual ranges on all surfaces except for the limits between surfaces

Movement:
3 starting points and 3 ending points (Fig. 11)
Vertical symmetry along the vertical axis for starting points for front and axis views.
For ending points, symmetry in one front view and asymmetry for another front view and axis view.

For *overcast sky* E_h*=10 000*:
Geometry:
The horizontality is not as strong as with E_h=30 000

Luminance contrasts:
Within surfaces: just perceptible; below 1 to 2 mainly and strong 1 to 8 on the South glazing (trees on the sky).
For limits between surfaces: from very soft, below 1 to 3 to not very strong 1 to 10 (opaque vs. glazed surfaces).
Brightest surface: North and South glazings.
Darkest surface: Floor.
Maximum contrast: 1 to 32 for points rather well apart.

Gradual Ranges of luminance:

Slow gradual ranges on all surfaces except for South glazing which has no gradual range and except for limits between surfaces (in particular with different materials).

Movement:

Front views	Axis view
4 starting and 4 ending points	2 starting and 2 ending points
Symmetry for starting points	Symmetry for starting points
Symmetry for ending points	Asymmetry for ending points

For the *clear sky*:

Geometry:

The horizontality is also quite visible on the whole interior, on opaque and glazed surfaces.

Luminance contrasts:

Within surfaces: just visible, below 1 to 2 except on the ceiling which is soft around 1 to 4.5.

For limits between surfaces: from just visible to very soft around 1 to 2 with a maximum of 1 to 7.5 which is considered as a rather soft contrast.

Brightest surface: South glazing.

Darkest surface: Floor.

Maximum contrast: Strong, 1 to 43 for very separated points in front view (1 to 41 in axis view).

Gradual Ranges of luminance:

Slow gradual ranges on all surfaces except for limits between surfaces (in particular with different materials) and except for the shadows due to the trees which appear through the South opening which are in fast gradual range.

Movement:

Front views	Axis view
3 starting and 3 ending points	2 starting and 3 ending points
Asymmetry for starting points	Symmetry for starting points
Asymmetry for ending points	Symmetry for ending points

Luminance ratios for all skies

Fig. 9 Top floor, view towards East wall,
Overcast sky Eh=30 000 lux (with paintings and people)

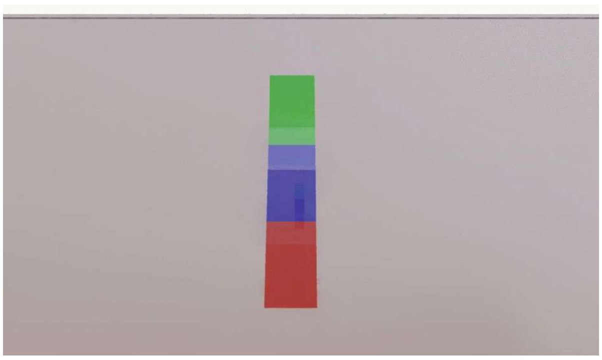


Fig. 10 Top floor, view towards South and West walls,
Overcast sky Eh=30 000 lux (with paintings and people)
XXX

For a point of view facing a painting at 2 meters, if a standard glazing is used to protect the paintings, then the reflection of the opaque and glazed surface at the back appear. Contrasts are around 1 to 3. This is very uncomfortable. However, if special glazing are used (with high diffuse reflections and specular transmission), these uncomfortable effects disappear completely as can be checked easily with Radiance.

Conclusion for the top floor:
For bright overcast sky (Eh=30000 lux), the levels of luminance on opaque and glazed surfaces are rather high. Very soft contrasts go along with slow gradual range of luminance. This describes well a *calm* ambience (slow gradual range), a *luminous* space (levels of luminance rather high) but with a *light which is not violent* (soft contrasts) as Clément Vergely specified it at the beginning of our work.

The fact that levels and distribution of luminance on South and North surfaces are very similar (500 to 600cd/m²) and that starting points are symmetrical and that ending points are nearly symmetrical add a quality of equilibrium which enhance the *calm* side.

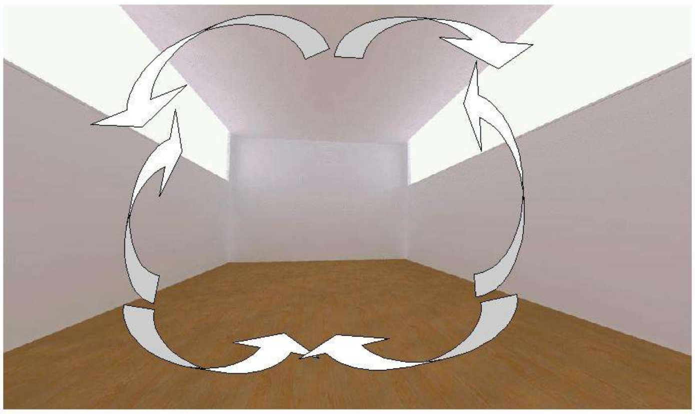


Fig. 11 Top floor as Fig. 8 with movements of light

The increase in luminance levels within gradual ranges can be translated in architectural language as the movement of light.

The light goes up from the sides of the floor on the vertical walls towards the glazings which are the ending points. It goes from the sides of the floor towards the middle. It sees to go from the ceiling to the glazings where it stops.

This movement of light is extremely simple and characterises the whole length of the space. It may give a feeling of *presence of natural light* as desired.

The space has no visual links with the outside. The view slips on the walls but cannot really escape outside. The view is therefore under the influence of soft luminous stimuli from the interior. This interiority and simplicity of the space enhances again the calmness of the ambience.

This ambience is favourable for the concentration on the exhibition as it excludes stimuli from the outside and minimises luminous stimuli from the interior and gives an actual presence of natural light which brings pleasantness.

Therefore, the results of the interpretation of data from Radiance correspond well to the intentions of the architect for the project.

We would like to add that: since this is a very long morphology with a strong horizontality, one may think that the calm of this ambience can lead towards uniformity. It is clear that the purpose here is to attract attention of the exhibition and not on the interior of the building. However, without betraying this idea, it is possible to decrease the risk of uniformity of the luminous ambience. For example, the insertion of a small zenithal opening could diminish the risk by stopping a bit this horizontality. This opening would not break the calm of this ambience because it would not bring additional exterior visual stimuli. It would also not change the facade. We recall this possibility only from our point of view of analysis of luminous ambience and without prejudging of all the criteria that only the architect masters.

The hypotheses on transmission factors for the blinds were correct for this sky.

For *dark uniform sky (Eh=10000 lux)*, levels of luminance are lower (than for Eh=30000lux), but we can say that the space is still luminous (around 300 to 400 cd/m² on North and South opaque surfaces). Contrasts of luminance are very soft and just perceptible along with slow gradual ranges of luminance on the majority of the interior surface. Contrasts are stronger on the surface of the South glazing with no gradual range (because of the contrast between the leaves and the sky). This is because no blind are set for this type of sky.

It gave a good presence of natural light and a good level of illuminance on the surfaces for exhibition. However, it let visible outside contrasts which are strong but not uncomfortable (below 1 to 20). The maximum contrast between opaque surfaces and this glazing is not strong (below 1 to 10).

Hence, the ambience is globally *calm* but this calm is interrupted by the animations on the South glazing and its relations with the contiguous space.

The equilibrium in the distribution of luminance between South and North surfaces appears (as in the previous sky) and starting and ending points are symmetrical (front views), which again underlines the *equilibrium* and the *calm* of the ambience.

To respect even more the architect with a calm and non violent light, it would be better to modify our hypothesis of no blind and to introduce blinds in this type of sky (with a very high transmission factor, around 80 to 90%). This would diminish contrasts and introduce gradual ranges of luminance on the glazing, avoid interior contrasts above soft and finally to recover interiority (by suppressing strong animations on the glazing).

On the contrary, if blinds are added, the risk of uniformity, which does not exist for the moment, may reappear.

In clear sky (noon, winter)
The levels of luminance are high (from 325 to 575cd/m² on the North and South opaque surfaces). Contrasts of luminance are just visible to soft along with slow gradual ranges of luminance except for the South glazing (fast gradual range). This describes well a *well-lit space*, a rather *calm ambience* with a *light that is not violent*.

The differences with the ambience of overcast sky (Eh=30000lux) are as follows: contrasts are soft and not very soft. There is a very fuzzy animation on the South glazing because of the tree leaves which are filtered by the blind (20% transmission). There is no more equilibrium in luminance on North and South surfaces: luminance levels are 5 times higher on the South glazed surface than on the North glazed surface. Luminance are higher (25%) on the North opaque surface than on the South one. There is asymmetry between starting points and between ending points. Horizontality is still present.

The space keeps its simplicity, its interiority and there is still a visible horizontality, which as in other skies, may lead to some uniformity.

We would like to add here a few remarks for all skies:

The illuminance levels are quite high (the ratio of glazed surface to the floor surface is 1/2.3 and F_{jmin} is 4.3% on the floor). There are no limit in the European norm [Euro04] for exhibition spaces. It corresponds to the luminous space that Clément Vergely wished to have.

For the colors upon which we have not focused, it can be observed that for dark overcast sky, the rather cold appearance is present. However, for bright overcast sky or clear sky the look may be a bit yellowish.

So, in the end, we can say that the lighting of this floor has a good *performance*. We did not detect *discomfort*, (except for South glazing in overcast sky with no blinds which is at the limit of discomfort, 1 to 20). We can say that *pleasantness* is present due to the presence of natural light. It corresponds well to the *intentions* of the architect, except for serenity which is a philosophical term which would require a more in-depth study. As the illuminance levels are high, it helps saving *energy* for artificial lighting and transmission factors of glazing and blinds could be decreased if it could imply some more energy savings for winter and summer thermal effects.

4.3.2. 4.3.2 Down floor

Fig. 12 Down floor, view towards the East wall, clear sky

Fig. 13 Down floor, view towards South and West walls, uniform sky (E_h=10000)

The details of the analysis of the down floor would be too long for this paper and would not bring new light on the explanation of our method.

The overall spirit of the ambience is similar to the one on the top floor. The South glazing is more covered by the tree leaves and the East side is more open (Fig. 13). It lighten the horizontality because the view can escape beyond the East wall. As the tree leaves are denser here, we have defined different blinds for the South side.

As a conclusion, we can again confirm the correspondences between the intentions of the architect and the images from Radiance for the down floor. The risk of uniformity is here less important because of the glazed surface on the East side.

5. CONCLUSION

We have described in this paper a method to aid architectural design of luminous ambience in daylighting in the early phases. It is based on the use of Radiance as a rendering tool to get images with quantitative data about luminance and illuminance.

We interpret the data from Radiance and compare them to the architect’s subjective intentions expressed in a descriptive manner. We showed that it is possible and useful to perform this analysis to aid design of luminous ambience.

The question of duration remains naturally the main difficulty to stay compatible with the speed of early design.

For the near future, we plan to develop a tool to help the analysis of Radiance images for architectural design (select parts of the images, calculate contrasts between limits or within surfaces, calculate distances, etc.).

6. THANKS

We would like to thank here Clément Vergely for his interest in luminous ambience studies, letting us use his project to present in this paper.
Our thanks also go to Greg Ward and the whole Radiance team for developing such interesting software for the analysis of luminous ambience and making it a Free Software.

7. REFERENCES

[Euro04] European Community (2004) Norm EN-12264 X 90-003.

[Mudri02] L. MUDRI, (2002), Luminous ambience, quantitative/qualitative data and subjective response, First International Workshop on Architectural and Urban Ambient Environment ; Nantes 6-8 février 2002

[AFE00] AFE (2000) *Eclairage intérieur des lieux de travail, Ed. Lux, Paris.*

[Mudri00] L. MUDRI, J.D. LENARD, (2000), Comfortable and/or pleasant ambience: conflicting issues?, PLEA2000 (Passive and Low-Energy Architecture), Cambridge, juillet 2000. *Cet article a obtenu le prix du meilleur article de son domaine.*

[Lenard99] J.D. LENARD, L. MUDRI, (1999), Measurements and qualification of ambiences in daylighting, In PLEA'99, Melbourne, septembre 1999.

[Ward98] G. L. WARD, R. SHAKESPEARE, (1998) *Rendering with Radiance*, Morgan Kaufmann Publishers.

[Mudri96] L. MUDRI, (1996) "Aide à la conception de l'éclairage naturel du bâtiment dans la phase d'esquisse architecturale et son impact sur l'énergétique", thèse de doctorat, centre d'énergétique de l'Ecole Nationale Supérieure des Mines de Paris, sous la direction du Pr. A. Dupagne.

[Euro93] European Commission. (1993) *Daylighting in architecture - a European reference book*, James & James, London

[Euro92] European Commission. (1992) *Energy conscious design*, Batsford Ltd, London

[DePortzamparc91] De Portzamparc, C., Ciriani, H., (1991) 'Cité de la musique, cité de la lumière', *L'architecture d'Aujourd'hui*, **274**:116

[Hopkinson63] Hopkinson, R.D., 1963, *Lighting*, Her Majesty's stationery service, Londres.