Interpretation models and their applications for luminous ambience

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ABSTRACT: Quantitative information from measurements or simulations of interior luminous ambiences yields a large quantity of data. These data may be very useful to analyse the performance and comfort of a luminous ambience in design or rehabilitation and promote a controlled use of daylighting instead of artificial light. However it is necessary to interpret these data with terms accessible to architects.
The purpose of our work was both theoretical and applied: we improved data collection and interpretation methods of quantitative data on luminous ambience. We then applied these methods to design a modified luminous ambience in an existing space.
We had the opportunity to work in the cafeteria of the "Galeries du Grand Palais" in Paris.
We improved the measurement method for luminance and chromaticities on the interior opaque and glazed envelope of spaces in natural and mixed lighting (both natural and artificial). We interpreted these measures (a large number of quantitative data) in qualitative terms. On the basis on these analyses, we followed the inverse path: we expressed the concepts for modified luminous ambiences, then built these ambiences. We could verify with measurements the correspondences between our qualitative intentions and measured quantitative data.
This work gave interesting insights for the definition of criteria for the analysis of luminous ambience.

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INTRODUCTION

In mixed lighting, users switch on electric light in spaces for two main reasons: To have more light and to have a more pleasant ambience. In that respect, a better design of luminous ambience in daylighting is an important factor to reduce artificial light consumption. On one hand, for the quantity of light, one may delay the use of artificial light during the day. On the other hand, let's not forget that electric light is used not only to have more, but often to create a more pleasant ambience. Hence, being able to control the design of luminous ambience allows creating ambience in daylighting that are more efficient, more comfortable and pleasant, what leads to a reduction in electric light usage as complement.

We define the luminous ambience as the way the luminous environment influences a subject. This definition covers the notion of luminous environment with all its characteristics (energy for example) and the subjective response. In the design of luminous ambience, architects' approach is essentially qualitative. They express intentions and compare them with the results once the building is finished. On the other side, many quantitative pieces of information may be collected on a luminous ambience, even during the design. However, these data cannot be used directly by the architect. It is necessary to interpret them in terms that are closer and more comparable to those used in architectural intentions. In this work, we focus on these interpretation models of quantitative data. In this field, our purpose is to contribute to the resolution of the problems of criteria and language for the design of luminous ambience within the phases of architectural design. We aim at building a scientific basis to improve the understanding and design of luminous ambience that are comfortable, pleasant and economical by better using natural light.

To reach this goal, we collected qualitative and quantitative data on an existing space. We used interpretation models to express these collected quantitative data in descriptive, synthetic and significant terms for architects and we compared them to the intuitive and qualitative expressions we collected. This allowed us to gradually build links between measured quantitative data and qualitative expressions. On the basis of these results, we built a new luminous ambience in the same space using the converse approach: we expressed intentions in qualitative terms (for example, a less hard ambience). We deduced hypotheses in technical terms (for example, decrease very strong contrasts of luminance). Using these technical data, we designed the concept and built the new luminous ambience (for example, put filters). Then, we reapplied our approach (take measurements and use interpretation models) to validate that the concept of the new ambience reflects the expressed intentions.

With this method, we develop models to interpret and characterise qualitative expressions using quantitative data. These characterisations may then be used by architects during the design to benefit from the quantitative data available to validate the realisation of their qualitative intentions.

We present here the main points of this work: the method to collect data, the interpretation method and their application on the case of the cafeteria of the "Galeries du Grand Palais" museum in Paris.

2. Data collection

Collecting data on luminous ambience is not an easy task and one must be very careful to make sure data are valid. We have been working on a protocol to collect measured data in situ. We measured luminance and illuminance levels and chromaticity (x and y) on glazed and opaque interior surfaces in a given field of vision in mixed lighting (i.e. natural and artificial at the same time), using a luminance-chromameter and a lux-chromameter. To ensure that we collected valid data, we use and improve measurement protocol defined in [1].

Because of the variability of natural light in time, we had to precisely define 2 aspects in this protocol: the placement of the measuring devices and the calibration of measured data. We placed our lux-chromameter on a vertical glazed surface to measure the variability of the luminous flux entering from the outside of the space. We placed our luminance-chromameter at the "user" point of view to measure points in the interior field of vision under study. For every interior point measured, we simultaneously measured the vertical illuminance on the window and the chromatic coordinates. These measurements allowed us to calibrate interior data (luminance and chromaticity) according to a unique outside measure (illuminance and chromaticity). For the outside reference measure, we chose the one that most often appears. Hence, we obtained interior luminance and chromatic coordinates for several points as if the measurements were taken at the same time.
Measurement protocol [1] was improved by tackling the case of mixed lighting and the colour of light: It is clear that the above calibration should only be performed on the part of the luminous flux that comes from the natural light which varies. Therefore, the fraction of the luminous flux due to natural light must be separated from the one due to artificial light. To do this, we measured, using the same protocol, the same points in artificial light only and deducted the measured values from the ones obtained in mixed lighting to get the natural light contribution. The calibration could then be performed only on the contribution from natural light. Then, we added this calibrated value to the part contributed by artificial light to obtain a global calibrated value for luminance and chromatic coordinates.

For every field of vision, we have between 100 and 200 points of measurements for luminance and chromatic coordinates (x and y). We present an example of luminance distribution on luminance diagrams (Fig. 3) for initial and modified ambiences.

3. Data Interpretation

Once the measurements are taken, we analysed them to determine contrasts, gradual ranges of luminance and the dominant colour. This approach is enriched from [1] and inspired by [2, 3]. We do not look for a mean luminance (or mean chromaticity) for the whole field of vision or any other mean value. We prefer to split the field of vision into smaller parts and to study the characteristics of each part and the relations between them. These parts are defined because of their homogeneity and coherence from architectural and lighting points of view (Fig. 3). We use the expression "islet of luminance" to describe a small surface with very close luminous characteristics for all its points. A contrast of luminance is the ratio of luminance between 2 islets. A gradual range of luminance is a characteristic of the frontier between islets (very fuzzy, rather fuzzy, etc.).
For each part, we defined the following characterisations:

- Maximal contrast (points giving this contrast): contiguous, close, rather distant or very distant).
- Contrasts between close islets of luminance: just perceptible, very soft, soft, not strong, etc. (fig 1).
- Contrasts: punctual or linear.
- Gradual ranges of luminance: slow, average, fast, without.
- Gradual ranges of luminance: unordered or ordered (increasing, decreasing, ordered variation)

For each part, we also calculate the dominant tints and their saturation to determine:

- the part of the spectrum (wavelength, cool or warm spectrum part) are the islets of luminance.
- if the groups of luminance are little or rather saturated for the dominant tint.

This allowed us to link the quantitative and qualitative data. A first step in this link is presented on figure 1 for luminance contrasts.

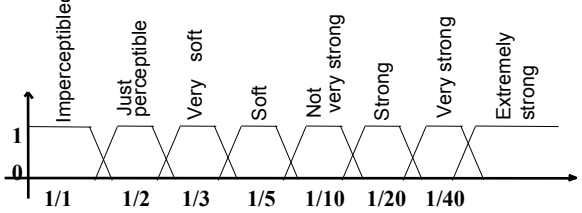

Figure 1: Classes/thresholds for luminance contrasts

To take into account the lack of precision of the limits, figure 3. presents a classification of the ratios as fuzzy sets [4]. These ratios are designed for diurnal vision and for an interior space.

These thresholds for luminance contrasts are directly linked to visual comfort thresholds in workspaces, as defined in [5, 6]. In short, these definitions show: a contrast under 1/3 is comfortable, is comfortable between 1/3 and 1/10, is rather comfortable between 1/10 and 1/20, little comfortable between 1/20 and 1/40, is considered as limit for discomfort but still bearable between 1/40 and 1/50. In this work, we are interested in rest spaces in order to bring more knowledge on contrasts thresholds within this type of spaces. We use contrast thresholds defined for workspaces as a starting point because we lack such thresholds for rest spaces and we hope to contribute to define them.

4. Application: the case of the cafeteria for the "Galeries of the Grand Palais" museum

We applied the above methods in two existing spaces. One is presented here: the cafeteria of the "Galeries of the Grand Palais" museum.

4.1. Description of the existing space

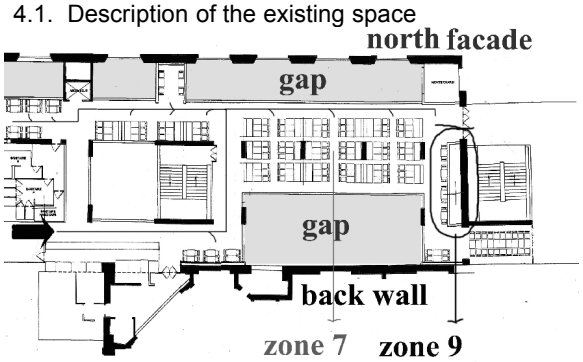

Figure 2. Cafeteria map

This cafeteria is made of 11 spatial zones. The natural light coming from the North facade is not sufficient. Artificial lighting is necessary as a complement throughout the day. All zones are lit via the same concept of artificial lighting with 3 types of luminaires: fluorescent tubes on the whole surface of the ceiling above the cafeteria and the gaps. Spotlights follows the tubes. Luminaires with a prismatic shape are placed on some peripheral zone walls and on the pylons separating zones. These 3 types of luminaires are identically distributed across the 11 zones, which, hence, have a very similar luminous ambience despite of being slightly different architecturally.
The light in the initial ambience is considered neutral. This was a desire in the initial concept in the sixties to have, for the rest space, a white light "because it is neutral". This concept is still the one used by the staff of the "Galeries du Grand Palais".

4.2. Initial luminous ambience and modifications

During our work, we were not allowed any piece of furniture and light intake. The changes of luminous ambience could only come from changes in the electric lighting. These changes were temporary (6 months) and made up for this research.

At the beginning of our work, we defined a first hypothesis: in a large public rest space (here around 200 seats), users have various dimensions of personality and may be in different moods after the visit of the museum. Hence, some may prefer to sit in a subdued light, others may prefer the full light. We decided to introduce the possibility to choose on the basis of the luminous ambience by creating different luminous zones. We worked on the modifications of 7 zones and we show in the following pages an example of modification for the luminous ambience of zone 9. A synthesis is given on the comparison (measurements and qualitative expressions) for the initial and modified ambience.

We collected from a group of students in architecture their subjective expressions in this zone 9. The results for the luminous ambience were:

- well lit, very clean, nearly surgical.
- ambience of a passageway, not a place where one would stay or stop.
- not animated ambience, but not calm, rather hard.
- For the modified ambience, we desired to:
- create an animated and intimate ambience to invite to stay and avoid this ambience of passage.
- create a soft ambience to avoid the impression of a hard ambience.

The pictures at the end of the paper show the two ambiences.

To realise our intentions in terms of ambience, we first make hypotheses:

- More animated: To introduce a more varied distribution of luminance, to introduce a tint.
- Softer: To decrease strong contrasts of luminance and to be careful not to introduce new strong contrasts, to introduce gradual ranges of luminance. Tinted spots should have very low brightness whatever the tint.
- More intimate: To create a rhythm in the distribution of luminance. Create smaller spaces within the zone using the new distribution of luminance and to avoid a unique ambience. As zone 9 is small, to avoid creating a tiresome ambience, all the small spaces should be identical.

To reach these objectives, the following *works have been performed in zone 9:*

- place tinted filters on the fluorescent tubes. The tints of the 2 filters is violet, more in the warm tones, with different saturation.
- place tinted filters on the prismatic luminaires. These luminaires are on the limits between two zones (9 and 8). Every luminaire receive two filters with two tints (filter tints on the fluo. tubes in each zone).
- elimination of the existing spotlights in the ceiling.
- place a new suspended luminaire above each of the 4 table and 3 spotlights of coloured light between the table. The spotlights are placed very high to produce luminous spots on the vertical wall contiguous to the tables and the ceiling.
- The choice of works was also dictated by the fact that the existing false ceiling was a hard constraint because its age and complexity makes any intervention difficult.

So, it was impossible to touch the false ceiling, to put anything on the walls, the tables or the ground. The only solution left was to slide thin pieces of steel between the slats of the ceiling to hook them on the concrete structure and to spread cables to hang low voltage luminaires to turn them in all directions.

4.3. Analysis of the results

We present for each part quantitative contrasts and thresholds. Through the analysis, we see how these notions are organised in the space of the cafeteria and produce a specific luminous ambience. Finally, we present briefly the interpretation of this analysis via high level qualitative expressions.

4.3.1 Part of the vertical walls

Comfort thresholds due to contrasts: The introduction of coloured filters on the prismatic luminaires greatly reduces the contrasts with the pillar (from 1/77 to 1/10). On the prismatic luminaires, contrasts change from very strong to not very strong (1/45 to 1/110). The initial maximum contrasts between the luminaire and the handrail changes from /218 to 1/19. All the other contrasts are now under 1/10.

Measurements analysis and comparison to the qualitative: Apart from the fact that contrasts (especially contiguous and close ones) are not as strong and are now comfortable or rather comfortable, other effects take place:

Walls are less uniform because of the new spots that animate them. The measures show that the left wall, which was monotonous across its surface, has now a rhythm. This is due to the luminous spots, even if some are little coloured. Spots appear at the limit between tables (which indicate the limit) and create just perceptible contrasts (1/2) with the background (points 16 and 87). Along with this contrast, there are also slow gradual ranges of luminance. The spots are of a light blue tone (point 16) and change for violet (point 84) at the limits (the tints of zone 9 and 8). Moreover, above each table, there is a triangular spotlight (very soft contrasts, a little over 1/2 for points 8 and 87). The top of this spot is the luminaire itself. This creates 4 small spaces, independent and a little lighter. As for the back wall, it is less uniform. Several new luminous spotlights give it a small peculiarity with a soft contrast from 1/4 to 1/8 (points 96 and 97, 54 and 58). The overall surface of the wall is still with soft gradual ranges of luminance, mostly unordered (ordered in the initial ambience).

To conclude, let us say that the 4 spaces created for a low luminance level distribution, a tint and soft contrasts are supposed to be felt as intimate and soft.

4.3.2. Part of the tables and chairs

Comfort thresholds due to contrasts: Seat backs contrast much less with tables (from 1/21 to 1/7.5). On the left wall, the new triangular luminous spotlight creates a stronger contrast (from 1/10 to 1/15) between the wall and the chair; it is not very strong. Other contrasts are smaller than 1/10.

Measurements analysis and comparison to the qualitative: This overall part is rather contrasted because of the alternation of dark surfaces (chairs) and brighter ones (tables). The rather high and not very comfortable luminance contrasts decrease and become comfortable. Measurements show that there is nearly no gradual range of luminance as in initial ambience. Colours change towards the red part of the spectra. More importantly, the relation with the contiguous wall has changed. In initial ambience, the wall was a uniform surface and the tables/chairs, which is contrasted, was just placed against this monolithic wall. In modified ambience, the contrasts between tables and chairs are lower but still exist (tables with still higher luminance, chairs with lower one). This rhythm (higher, lower) also appears on the contiguous wall: higher luminance above the table and lower luminance between tables (above the chairs). Shadows appear between the brighter spaces. This creates individual spaces separated from one another. Moreover, the overall part is darker. Luminance levels are twice lower on table surfaces. The ground is also darker which helps to merge it with the tables and chairs. As for colours, tables surfaces are warmer as they reflect the light coming from the fluorescent now coloured with warm tones.

To conclude, let us say that the ambience is more padded, more intimate but also more animated because of new chromaticity. One may say that this particular composition gives a feeling of intimacy.

4.3.3. Part of the tables and chairs

Comfort thresholds due to contrasts: The rather strong contrasts initially observed (1/16 to 1/13.5 between the plinth, point 27, and the luminous spots close to the ground, point 24 and 23) are lowered (respectively 1/10 and 1/1.8). On the contrary, on contrast is higher, it is the new maximal contrast, not very comfortable, which changes from 1/11 to 1/16 (between the plinth and the distant luminous spot ion point 38). All the other contrast are lower than 1/10.

Measurements analysis and comparison to the qualitative: Measurements show that contrasts decrease a bit between the 2 ambiences and are now a little softer, except punctual raises. Luminance levels are twice lower. Punctually, luminous spots, due to the new suspended luminaires appear. These spots correspond to the rhythm of the composition between bright spaces (tables) and darker ones (between chairs) and enhance this composition. On the whole, luminous spots are smaller and more numerous, more dissimilar. They are not in the same direction in their position and some bring a new tint.

Luminous contrasts between contiguous or close islets of luminance are always under 1/10 on the wooden floor. There are gradual ranges of luminance on the whole ground surface and they are a bit faster than in the initial ambience. As for colours, the ground reflect the luminous slats (2 fluorescent tubes) that now have the same tint, in the warm violet spectrum but with different saturations. This difference is visible on the reflection from the wooden floor. The two lines are not merged in one and that avoids the strong linearity which initially appeared.
To conclude, let us say that the user should now be less guided towards the back of the zone by a longitudinal lighting.

4.3.4. Part of the ceiling

Comfort thresholds due to contrasts: The extremely strong longitudinal contrasts due to the luminous slats and the contiguous ceiling have been lowered from 1/80 to 1/20 or 1/75 to 1/5. The elimination of the spotlights (point 82, etc.) changes extremely strong contrasts without gradual range of luminance (1/60) for imperceptible contrast. The reflection of the new spotlights (3 points) leads to rather strong contrasts with gradual range of luminance with the contiguous ceiling. These contrasts range from 1/20 to 1/30 (not very comfortable).

Measurements analysis and comparison to the qualitative: The modified ambience successes in reducing the uncomfortable contrasts which changes for not very comfortable and comfortable. The overall surface of the ceiling is darker (2 to 3 times lower

luminance levels for opaque parts but for luminous spotlights). However, the ceiling is animated by:

- the introduction of new luminous spotlights which bring rather soft contrasts (apart from 3 spots) and fast and random gradual ranges of luminance.
- coloured filters on the fluorescent tubes, which have same tint (reddish violet) with different saturations. This difference in saturation helps in diminishing the linearity of the initial ambience.
- stoppage of the neon lines at the connection between zone 9 and 10 (in 10, only one neon line continues with a slightly different tint than in 9).

To conclude let us say that these modifications strongly decrease the feeling of linearity. Hence this zone should less be felt as a passage. The strong decrease in extremely strong contrasts also lowers the hardness felt in the initial ambience.

4.4. Validation of the qualitative results

After these works and analysis, we organised several visits during the teachings in our school of architecture. With the students we discussed on the qualitative expression we could used for the ambience. This allowed us to confirm or infirm our hypotheses, to verify if the works done corresponded to our intentions, hence to validate the characterisations. This is not meant to be a statistical validation, but more a confirmation by a group of students.

We had defined several hypotheses during this work:

Hypothesis 0: To create a neutral ambience, a white light should be chosen (hypothesis from the designer of the cafeteria).

The initial ambience has not been considered as neutral but as hard. This comes for the existence of contrasts that are too strong between the white neon and the grey ceiling. When this contrast has been diminished, the hardness disappeared. We can say that the use of a white light is not sufficient. It is necessary to take great care of contrasts.

Hypothesis 1: In a large rest space, it is interesting to create several zones with different luminous ambiences to give a choice to the users.

This has been quite validated by all students who declared that these ambiences would have an impact on their choice of seat. An employee of the "Galeries du Grand Palais" said that if he came with friends he would go in zone 7, if he came alone he would go in zone 8 and if he came with his wife he would go in zone 9. To create different luminous ambiences also helped to break the monotony detected in the whole cafeteria. In a large public space, luminous ambience is a criterion for the choice of spaces by users.

Hypotheses 2: a varied distribution of luminance and a tint can lead to animation.

The group has recognised the ambience as more animated. Create contrasts with different shapes, rather than gradual ranges of luminance, helps to create objects of light which can animate too uniform walls. However, students found that this criterion is not sufficient and that these objects of light must enter an overall composition designed with all the other objects in the field of vision to avoid cacophony.

Hypotheses 3: To eliminate strong contrasts and to introduce gradual ranges of luminance lead to a soft ambience.

When contrasts are diminished towards rather soft or not strong contrasts and when gradual ranges are introduced, some students found the ambience soft, others found it calm. Hence, our hypothesis is not sufficient to differentiate them. During the discussions, we concluded that: if luminance contrasts are soft and not strong with no gradual range of luminance, the ambience is calm. If all the contrasts are with gradual ranges, then the ambience is soft. This hypotheses remains to be confirmed.

Hypotheses 4: To create, via the light, small spaces can lead to an intimate ambience.

The students easily validated the intimacy. In this case, luminance levels are less important. However, the shapes of the luminous spotlights which made a roof around the table and the rhythm between darker and brighter which isolated each table, created the intimacy we looked for.

The group of students found the initial ambience well lit and very clean. We could not keep these qualifications completely, as we wanted to create an intimate ambience, hence with darker zones. The group also mentioned other qualifications which were not in contradiction with the intentions.

Another objective of this work was to show that it is possible to create a more pleasant ambience while saving energy. This objective could not be reached since it was not possible to act upon the way natural light was taken, or upon the ground the ceiling, the vertical walls and the furniture. For example, it is clear that, to save energy, one should not use strong neon then cover them with filters to decrease the luminance. Due to the project situation, the constraint of a public institution and the fact that it was temporary, we did not have other solutions. Hence, the energy spent is greater in the modified ambience.

5. CONCLUSION

The work presented in this paper aimed at contributing to improve the links between qualitative and quantitative approaches on luminous ambience. In that respect, we worked on the quantitative characterisations of qualitative expressions. We presented the methods for data collection and interpretation and some characterisations.

We currently use these results in other projects and on the teachings in Paris-Belleville School of Architecture. We are developing a software for the analysis of luminous ambience on images. We also continue to build new characterisations.

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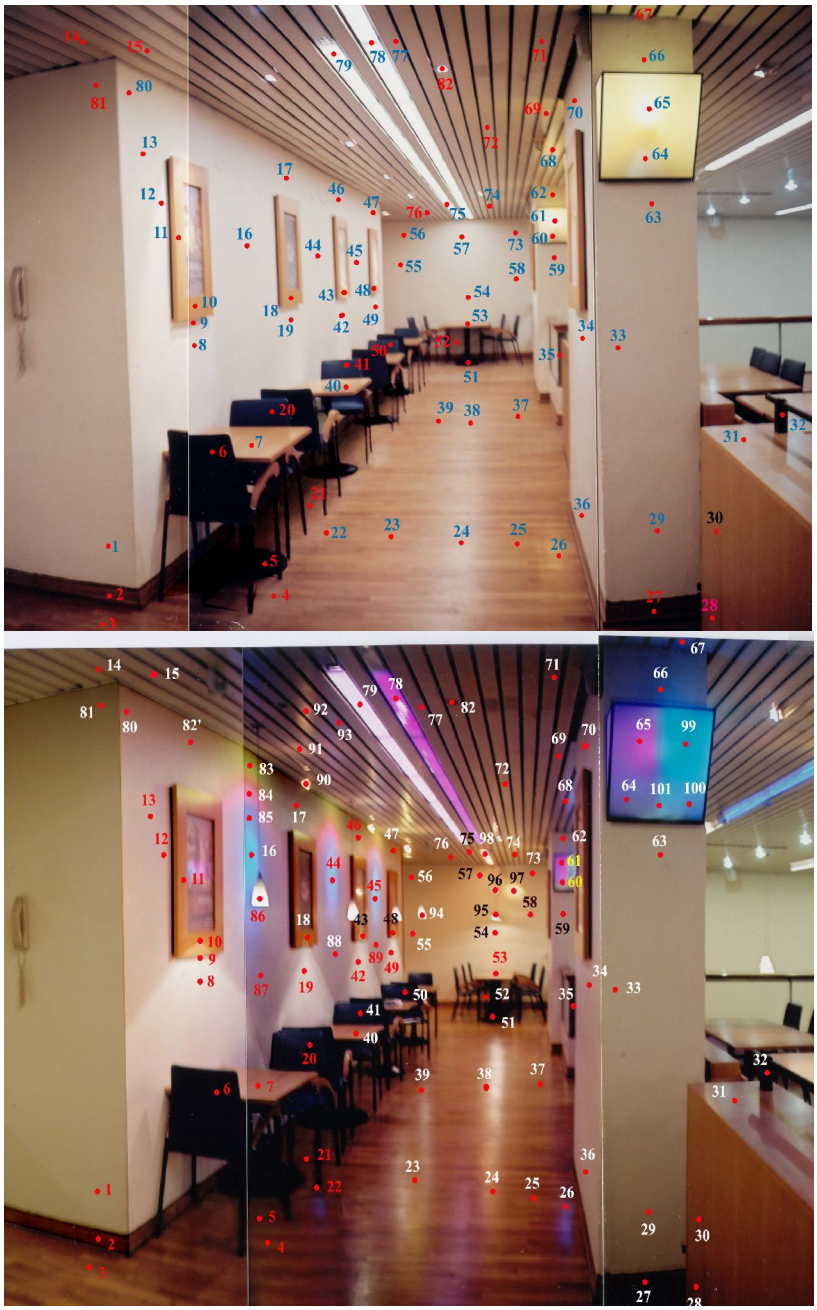

Initial Ambience

Fluorescent tubes with white plastic diffusing faceplate are placed longitudinally (from North facade to back wall). They are integrated into the false ceiling made of aluminium slats across the whole ceiling.

Prismatic luminaires on the pylons between zones at 2m high.

Light spots distributed across the ceiling, more densely above the gap.

Modified Ambience

New lightspots directed towards the left wall, creating low brightness and little coloured identical spots between the paintings.
New luminaires place above each table making a triangular shape above each table on the left wall.
Filter placed on the existing prismatic luminaires.
Filter placed on the existing neon tubes.
Spots underneath the cafeteria were switched off. The spots above the gaps were left as they were in the initial ambience

Figure 3. Field of vision in initial and modified ambience and detail of luminaires for the modified ambience

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