A web tool for the choice of daylight scale model materials

Magali Bodart[1], Rodrigue de Peñaranda[1], Arnaud Deneyer[2], Gilles Flamant[2]

[1]Architecture et Climat, Université Catholique de Louvain, Louvain-la-Neuve, Belgium
[2]Belgian Building Research Institute, Limelette, Belgium

ABSTRACT: This paper presents a web tool that has been developed in order to help architects or lighting designers to choose materials for the building of daylight scale models. Those scale models are built in order to qualify or quantify, under real or artificial skies, the daylight penetration and distribution in buildings. The essential photometric and colorimetric parameters that influence the light reflection and transmission of building materials were identified and several methods, for the qualitative and the quantitative evaluation of these parameters were studied. As a result of this study, the web tool proposes two input possibilities. The first one is the simplest: the user chooses the full size material in a database and the web tool immediately proposes a list of scale model materials. The second one is based on a complete input of the full size material characteristics: its colour that can be measured or identified by a colour code (RAL, NCS, …) and its reflexion mode and its homogeneity that are then qualitatively described. In this second case, again, the tool proposes a list of selected scale model materials and the user can then choose a material in that list in accordance with the main objectives of his daylight study.
In addition, the web tool proposes, as illustration, RADIANCE simulation results like illuminance values, in a reference office room with walls made of the full size material, and animations showing the importance of wall lightness on inside daylight distribution.

Keywords: daylighting, scale models, photometry, colorimetry, material

1. INTRODUCTION

Scale models have been used for daylighting evaluation for more than ninety years [1]. Scale models can be illuminated under the real sky and sun or more commonly, for convenience and standardisation, under artificial skies [2]. When properly constructed, scale models portray the distribution of daylight within the model room almost exactly as in a full-size room. This is due to the low light wavelength values, compared with the size of the even smallest scale model. The physical behaviour of light is the same for a full-size room as for a scale model of all practical size [2].

Many books give advices or rules for building scale models[2-5]. It is obvious that reflection and transmission characteristics of opaque (walls) and transparent (windows) materials should be as close as possible to those of the full-size building. According to Cannon-Brookes, the correct simulation of photometric properties is one of the two core issues in scale modelling, together with the accuracy of dimensions [6]. Thanachareonkit et al. have identified as key factors the accuracy of scale model geometrical dimensions as well as its internal surfaces reflectance, regarding the discrepancies between the scale model and the real room [7].

However, there is few information on the photometry parameters that should be studied : how to quantify or qualify them in order to determine which scale model material would fit the best with the full-size material.

In its first part, this paper introduces the parameters that should be studied and shows that this choice depends on the available measurement devices. The second part of this paper presents a new web tool that has been developed to help the designer in its material choice, for the building of the mock-up. A material database that has been created on the basis of spectrophotometer measurements is available through this web tool. The user can also propose his own material, on base of its colour and of other photometric parameters, in order to find the best scale model material.

2. THE PHOTOMETRIC AND COLORIMETRIC PARAMETERS

2.1 Selection of parameters

The objective of the work was to propose, for each full-size material, a scale model material that would have the nearest photometric and colorimetric characteristics to the full size material. This work is based on a multi-criteria analysis: several parameters are determined and the comparison is done according to the importance given by the user to each of these parameters and according to the objective of the study. For the determination of the illuminances, the colour of the elements is not the most important parameter. Other photometric parameters like the reflectance value, mode,… are more important. If the objective of the designer is the room appearance, the colour and the reflection mode would have more importance than, for example, the exact hemispherical reflectance.

The parameters used to compare the scale model material and the full-size material are:

- the colour and the lightness,
- the hemispherical reflectance and/or transmittance,
- the reflectance and/or transmittance mode,
- the visual aspect.

2.2 The material colour and lightness

The objective of the colour characterisation is mainly to quantify the exact colour difference between the full-size and the scaled material surface. It is thus important to evaluate the surface colours in a colour system that can express colour differences. For this reason, we have chosen the CIE L*a*b* colour system that is widely use for non-luminous objects such as paints and plastics [8]. In the L*a*b colour space, L* indicates the lightness and a* and b* are the chromaticity coordinates.

The colour difference ΔE* between two samples is defined by the following equation:

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (1)$$

Where ΔL*, Δa* and Δb* are the difference in L*, a* and b* values between the full scale material and the mock-up material colours. The perception of the colour difference ΔE* vary in function of the observed colour and the human eye. The human eye only distinguishes colour differences if ΔE* is higher than 1 to 3.

2.3 The hemispherical reflectance

The hemispherical reflectance of a surface is the ratio of the reflected radiant or luminous flux to the incident flux in the given conditions. The hemispherical reflectance is the sum of the specular reflectance and the diffuse reflectance.

The hemispherical reflectance corresponds to the Y tristimulus value defined by the CIE in 1931[8].

The Y is linked to the L* value by the formula (2) and can thus be directly deduced from the L*a*b* value of the material.

$$L^* = 116 \times \left(\frac{Y}{Y_n}\right)^{1/3} - 16 \qquad (2)$$

with Y_n = Y stimuli for the white colour object = 100, under the standard illuminant D65, at incidence angle of less than 10°.

In the web tool, the hemispherical reflectance is either measured by a spectrophotometer (for the material in the database) either calculated from the colour coordinates (when the user introduces his own material).

2.4 The hemispherical transmittance

The hemispherical transmittance of a surface is the ratio of the transmitted radiant or luminous flux to the incident flux in the given conditions. The hemispherical transmittance is the sum of the regular transmittance and the diffuse transmittance.

2.5 The reflectance mode

The third parameter that characterizes the light reflection on a material surface is its reflection mode. The two well-defined reflection modes are:

- perfectly diffusing reflection mode, also called Lambertian reflection, for which the radiation reflected by the surface is distributed angularly according to the Lambert's cosine law, proposed in 1760 [9],
- specular (or regular) reflection mode, for which the radiation is reflected in accordance with the laws of geometrical optics, without diffusion.

Light reflected or transmitted by objects is usually neither completely specular (or regular) nor completely diffuse but is intermediate between these two extremes [10]. These surfaces may be termed as "glossy" (significant specular reflection), "semi-matt" (low specular reflection) or "complex" (the light is randomly reflected and distributed).

The reflectance mode is directly linked to the bi-directional reflectance distribution function (BRDF) measured by goniophotometers, that gives the particular shape of the whole reflected light (peak specular and diffuse part) [10].

It is often the case that the angle of illumination of a goniophotometer is variable and if several samples are to be compared, some method must be devised for simplifying the information. A way of summarising the information from data for various angles of reflexion is to use de material dispersion angle concept proposed by Baker et al. [3]. The dispersion angle is the angle between the direction of maximum intensity (I_{max}) of transmitted or reflected light, and the direction of intensity with a value of $I_{max}/2$, when the intensity distribution curve is supposed to be symmetrical about the direction of I_{max} (see figure 1).

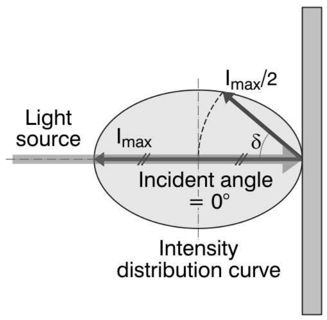

Figure 1 : Definition of the dispersion angle δ

The dispersion angle is thus easily deduced from BRDF functions and can be precisely measured with a spectrophotometer.

Figure 2 shows the proposition of material classification made by Baker *et al.* [3], according to the value of the dispersion angle.

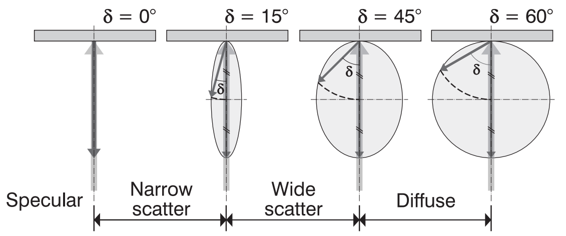

Figure 2 : Classification of a material according to its dispersion angle

2.6 The transmittance mode

As for the reflection mode, the shape of the light transmitted through a material has an impact on the view through this material.

The transmission dispersion angle has been measured for all the database materials and a classification similar to the classification used for reflexion is used.

2.7 The visual aspect

The visual aspect is a qualitative criterion that describes the surface homogeneity. For example, a uniform painted concrete wall is a homogenous surface. Non homogenous surfaces can be even (brick wall) or uneven (broken ashlars wall) (see figure 3).

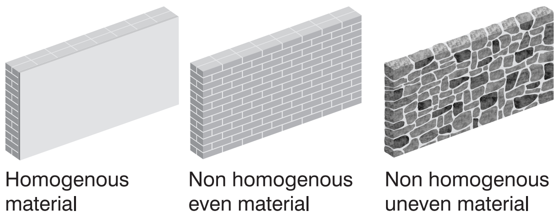

Figure 3 : Qualitative determination of the material visual aspect

3. IN-SITU CHARACTERISTIC'S MEASUREMENT

It is not always possible to have a sample of the full-size material and/or to measure it with a spectrophotometer. There are several solutions to determine the colorimetric and photometric characteristics of materials.

The first option is to use a portable colorimeter that measures the colour characteristics and the hemispherical reflectance. However, only the specialised laboratories have these kind of devices. Therefore, researchers have developed several methodologies for on-site material characterisation. Among them, one can find the method proposed by Fontoynont et al. [11] for the evaluation of hemispherical and specular reflectance of opaque materials by using an illuminance meter and a luminance meter.

This method can also be used to evaluate the hemispherical or normal transmittance of clear or translucent glazings.

The CIBSE guide [12] proposes two methods for the evaluation of material hemispherical reflectance. The first one is based on a luminance meter measurement coupled with an illuminance meter measurement. The second method proposes a sample card for the comparison between colour samples and on-site materials in order to determine the diffuse reflectance of these materials.

Those three methods were studied and tested on several internal walls and furniture. Their results were compared to colorimeter measurements and show that the results are crude. This can induce very large errors if these characteristics are used for the choice of scale model materials.

4. LABORATORY MEASUREMENT

The most accurate appliance for the measurement of photometric and colorimetric characteristics is a spectrophotometer. This appliance measures, for each wavelength, the light reflection or transmission, for several reflection or transmission angles.

Each laboratory has its own devices. For the measurements, we used the spectrophotometer of the Belgian Building Research Institute (BBRI).

The calculated characteristics from these measurements are:

- o the precise colour and lightness of the material,
- o the hemispherical reflectance or transmittance,
- o the specular reflectance or transmittance,
- o the dispersion angle.

Figure 4 illustrates the polar intensity diagram of the light reflected by a limestone, measured by the spectrophotometer, under an incidence angle of 15°.

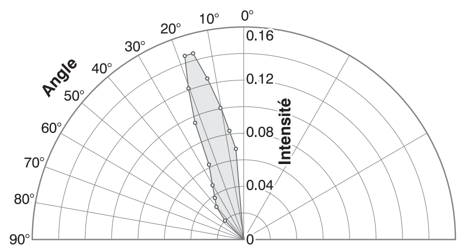

Figure 4 : Intensity diagram of light reflected by a limestone

5. QUALITATIVE DESCRIPTION OF THE MATERIAL SURFACE

When there is no dispose of a spectrophotometer, there is a need to characterise the reflection mode qualitatively. Therefore, we propose a correspondence between quantitative and qualitative values.

As shown on figure 2, three categories, linked to the dispersion angle, are proposed : narrow scatter, wide scatter and diffuse. As the narrow scatter comportment is observed for reflexion on smooth surfaces and the diffuse comportment is observed for reflexion on rough surfaces, we chose the classification shown on Table 1.

Table 1 : Correspondence between the qualitative and the quantitative reflexion characterisation.

Dispersion angle	(0°< δ≤15°)	(15°< δ≤45°)	(45°< δ≤60°)
Baker et al classification	Narrow scatter	Wide scatter	Diffuse
Qualitative classification of the surface	Smooth surface	Intermediate surface	Rough surface

Qualitative characterisation is given for each material included in the database. Dispersion angle values are given for most of the materials included in the database.

6. INDOOR SURFACE MATERIALS

6.1 Photometric characteristics

There is few information on photometric characteristics of internal building materials. Indoor surface photometric properties are often assumed to be diffuse, especially in most lighting simulation algorithms and programs. According to Baker et al., few finishes come close to being totally diffusing [3]. Most mat paints present some dispersion. There are only a small number of perfectly diffusing materials, among them: carpet, mineral fibre panels, porous or granular concrete, and grass.

Most surfaces materials which are employed in buildings come under the "wide scatter" heading. It is the case of mat paint, polyester fabrics, concrete and all mat surfaces.

Under the heading of narrow scatter, one can find satin paints, some types of veneered surfaces and some plastic coatings. The "specular and diffuse" materials are typically diffuse materials covered by a surface coating that induces the specular reflection component, as for example: lacquered, varnished or highly polished surfaces and some sorts of stratified surfaces.

6.2 Colour characteristics

The internal building materials have, in general, unsaturated colours.

6.3 Glazings

Practically, the scale model made to study the internal daylight should be scaled between 1/10 and 1/50. For technical reasons (costs + manufacturing), it is not possible to build a glazing that would have 0.6 mm or 0.12 mm width (in the case of a 6 mm glazing). A solution can be to take a 6 mm glazing having the same characteristics than the full-size glazing, if possible structurally in the mock-up.

Some authors advice to use unglazed models and to apply a corrective weighting factor. However, if the mean source of daylight enters the apertures at angle of incidence greater than about 60°, the glazing material must be included in the model to establish the proportion of daylight reflected of the glazing.

If the glazing is tinted, then a corresponding material should be used because the light colour would be influenced by the glazing [3].

As it is not possible to reproduce a glazing at scale, it is important to choose materials with the same transmission mode or colour as the full scale glazing. Several glazings and materials that could be used in scale models (plexiglass or glazings) were characterised by laboratory measurements and introduced in the database.

7. THE PHOTOMETRIC DATABASE AND THE WEBTOOL

The objective of the web tool is to provide architects with the scaled material that fits the best with the full size material. Moreover, this database gives also precise information on many indoor surface materials. This information is also useable for the characterisation of materials in (day)lighting simulation software's. At the moment, the database contains opaque and transparent material (glazing) but it is forecast to test translucent materials and fabrics (shading) materials.

The web tool is available at the following address: http://www-energie.arch.ucl.ac.be/materiaux/defaulte.asp

7.1 The webtool inputs

The objective, for the architect, is to find the best scale model material for representing the full scale material. He must thus characterise the full scale material. He has two possibilities.

The first possibility, which is the easiest, is to choose, in the database, the material he wants to scale. The tool gives then directly the colorimetric and photometric characteristics of the chosen material (see figure 6 and figure 7).

If the user is not satisfied with the materials proposed in the database, he can describe his own material.

Then, the inputs are :

1. The full scale material colour that can be described according to several colour systems (L*a*b*, H*L*C*,XYZ, Yxy, xyz) or the RAL code or the NCS code or, in the last resort, the screen RGB values.
2. The full scale material aspect that is described qualitatively by choosing among one of these adjectives: "rough", "intermediate", and "smooth", which are related to dispersion angle values according to table 1. The scale model material would be chosen, if possible, in the same category. This choice is subjective and will depend upon his personal appreciation. For that reason, it is preferable to work with materials included in the database.

For transparent or translucent materials, the transmittance and the reflectance, which are values given by manufacturer, are also needed.

7.2 The webtool outputs

Once inputs are given, the tools gives directly the best corresponding scale model materials according to the colour, the light reflectance (or transmittance), the lightness and the reflection (or transmission) mode (see figure 5).

The user receives also additional information :

- o the material colour according to the L*a*b*, the H*L*C*, the XYZ, the x,y,Y and the x,y,z colour systems;
- o the difference between the full scale material and the mock-up material in term of colour, lightness and reflectance (transmittance);
- o the RAL or NCS colour code that is the nearest to the full scale material colour;
- o the appearance of a reference room with walls made of the full scale materials, calculated with RADIANCE (see figure 5);
- o the illuminance curve obtained in this room, under overcast sky, calculated by RADIANCE;
- o And some picture animations showing the influence of wall lightness on light distribution in this reference room, by overcast sky.

Figure 5 : Visualisation of the daylight distribution in the room

8. FUTURE DEVELOPMENT

The database would stay in constant development by the addition of opaque materials, on base of the material introduced by the users; there is a record of the name of the material manually entered in the database.

In the future, we would characterise other glazings and, in particular, translucide (diffusing) materials. It is also planned to work on shading devices and daylight systems.

9. CONCLUSION

Precise and detailed laboratory measurements have been done for the creation of a web tool mainly intended to architects who want to realise daylight studies on scale models.

This web tool helps them to choose the best scale material to represent the full scale indoor surfaces in order to lower as soon as possible the measurement errors coming from the inaccuracy in the choice of mock-up material. In addition, the webtool calculates the correspondence between several colour systems and give useful colour information about the RAL and the NCS system. It can also be used in order to know the characteristics of several materials for the modelling in light simulation software.

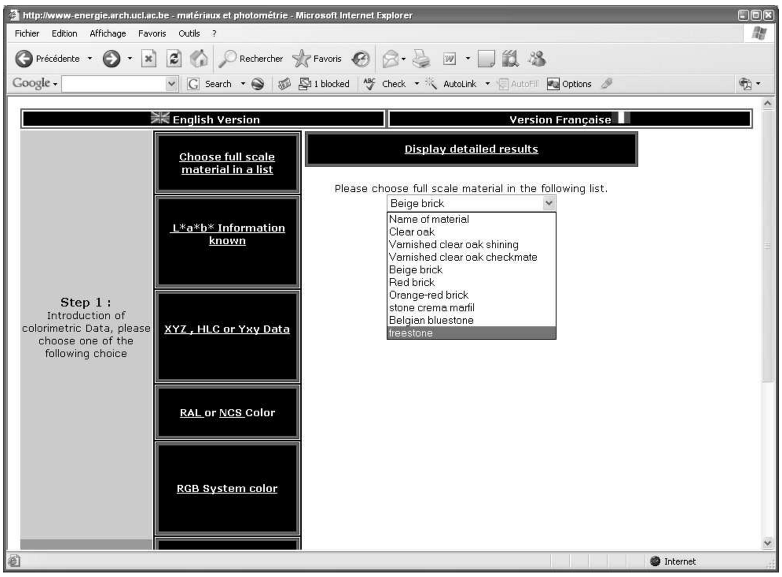

Figure 6 : Choice of the material in the database

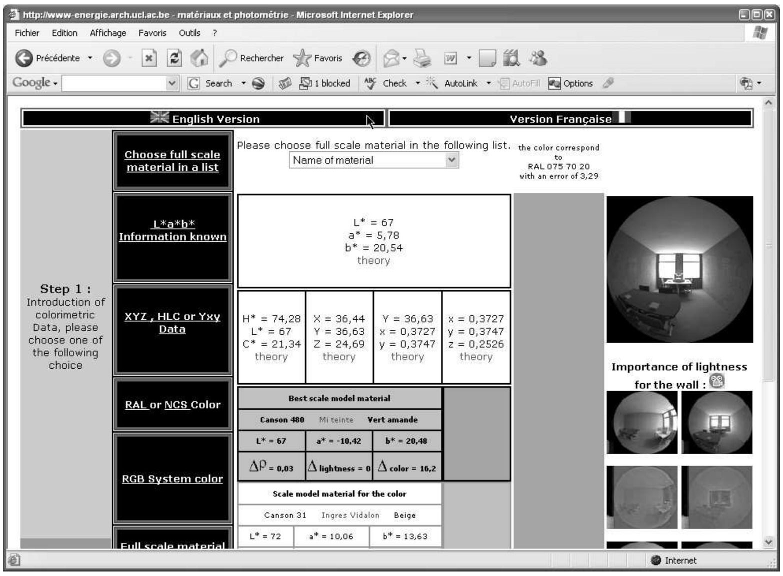

Figure 7 : Result obtained when choosing the full scale material in the database

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