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ОЦЕНКА НА ОТРАЖАТЕЛНИТЕ ХАРАКТЕРИСТИКИ НА МАТЕРИАЛИ ЗА ФАСАДНИ ПОКРИТИЯ

Ива Петринска

Резюме: *За по-добро разбиране на характера на светлинното излъчване е необходимо да бъдат изследвани различни взаимодействия между светлина и материя. Тези взаимодействия могат да бъдат описани с помощта на спектрални и пространствени отражателни свойства на материята. В настоящата публикация е направено изследване на тези свойства за реални материали, използвани за покритие на сградни фасади. Светлинното излъчване е прието като известна величина (използван е светлинен източник с известен спектрален състав на излъчването). Оценена е промяната на отражателните свойства с промяна на посоката на наблюдение или геометрията на осветяване. Отражателните свойства са получени като са разгледани декоративни фасадни мазилки в ново състояние. За получаване на спектралните коефициенти на отражение е използван спектрофотометър, а за получаване на пространствените отражателни характеристики на материалите са използвани яркомер и радиометър. За описание на материалите в зависимост от взаимодействието им със светлината в дадена точка от повърхността им е изчислена двупосочна функция за разпределение на отражението (BRDF).*
Ключови думи: *отражателни свойства на реални повърхности, двупосочна функция за разпределение на отражението*

ESTIMATION OF THE REFLECTANCE PROPERTIES OF REAL MATERIALS USED FOR BUILDINGS' FACADES

Iva Petrinska

Abstract: *For better understanding of the behavior of light it is necessary to investigate the different interactions between light and the surface of the matter. These interactions can be described by means of spectral and directional reflectance properties of materials. Investigations of these properties for real surfaces, used for buildings' façades are made in the current paper. The incoming light is taken as a known quality (artificial light with known spectrum is used). The variation of the reflectance properties with the change of viewing direction or illumination geometry is estimated. The reflectance properties of the considered materials are obtained for new façade samples. For investigation of the spectral reflectance of the surfaces a spectrophotometer is used. Both luminancemeter and radiometer are used for estimation of the directional reflectance. For description of the appearance of the materials by their interaction with light at a surface point the Bidirectional Reflectance Distribution Functions (BRDFs) are calculated.*
Keywords: *reflectance properties of real surfaces, bidirectional reflectance distribution functions*

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1. INTRODUCTION

The reflectance of a given surface depends on the angles at which it is viewed and illuminated. For opaque materials most of the light emitted by the illuminating light source is reflected or absorbed. As a result an observer can only see the reflected part of the light from all visible surface regions as he views the illuminated surface. This dependence is usually described in terms of Bidirectional Reflectance Distribution Function (BDRF) [1]. The current paper presents investigation of the BDRF of typical façade materials. The degree to which light is reflected from a surface depends on the viewer and light source position, relative to the surface normal and tangent [2]. BDRF gives information on how light is reflected, so it must capture the view and light dependent nature of reflected light. BDRF is also wavelength dependent and also depends on the surface spatial orientation. The data obtained by experiments for the BDRF of different materials is useful for calculations and design of architectural and decorative lighting.

Very often the Bidirectional Reflectance Distribution Function (BRDF) is defined as the ratio of reflected radiance and irradiance [3]:

$$f_r(\lambda) = \frac{dLr(\theta i, \varphi i, \theta r, \varphi r)}{dEi(\theta i, \varphi i)},\ \text{sr-1} \quad (1)$$

where dLr is the differential reflected radiance, dEi is the differential incident irradiance, θr is the zenithal reflection angle, φr is the azimuth reflection angle, θi is the zenithal incident angle, φi is the azimuth incident angle.

BDRF is related to the Bidirectional reflectance factor (BRF) as follows:

$$R(\theta i, \varphi i, \theta r, \varphi r) = \pi . f_r\ (\theta i, \varphi i, \theta r, \varphi r) \quad (2)$$

The BRDF is a function of position, but in the current investigation this is not considered i.e. position-invariant BRDFs are obtained. The results obtained in the paper are presented in spherical coordinates, which means that every intensity vector is presented by its magnitude ρ and a pair of angles θ and φ which represent how angularly far the direction vector differs from two reference basis vectors. This representation is better for BRDFs, because a direction can be represented only by two parameters. Thus in spherical coordinates BRDFs are treated as wavelength dependent four dimensional functions. BRDFs are not bounded to the interval [0, 1], but may have values larger than 1. A classification of the BRDFs divides them into isotropic and anisotropic. The isotropic BRDFs are used for description of materials with reflectance properties invariant to rotation of the surface around its normal vector. Such BRDFs are common for relatively smooth surfaces. Anisotropic are the BRDFs that show reflectance properties that change with the rotation of the surface around its normal. Most of the real-world materials are anisotropic. Their BRDFs can be obtained either mathematically or in terms of experimental measurements. The current paper uses the latter for obtaining the reflectance properties of real façade materials. The measuring device used is specially constructed gonioreflectometer. The results that are obtained give the opportunity to use the reflectance data directly for lighting calculations and creating visual lighting effect, especially for the needs of decorative lighting.

For analytical description of BRDFs different methods can be used - numerical models, modelling of the surface geometry, combined with ray-tracing procedure or analytical models, fitted to measured data. The analytical methods can be theoretical - using a physical theory to build equation describing the BDRFs or empirical - that are mathematical models, developing the BRDFs on a vectorial base.

According to [4] all of the BRDFs, obtained by analytical models seem to underestimate the big values of the BRDFs and to overestimate the low values. Also these models were found to be unable to describe strong variations of BRDFs, so it is best if real data on the reflectance of a given surface can be experimentally obtained.

2. EXPERIMENTAL SETUP

The experimental data collected and presented in the current publication has been measured by means of a gonioreflectometer. Its constriction, as shown on fig.1 consists of the following elements: two vertical half-arcs, a horizontal circular rail ring and a horizontal sample holder. All the elements of the gonioreflectometer are painted in matt black paint. The vertical half arc mounted on the circular rail ring supports the light source and allows zenith movement of the latter and also azimuth rotation around the sample. The second vertical half-arc is stationary and is mounted on the inside of the circular rail ring and it supports the zenith movement of the spectroradiometer or the luminancemeter. In the middle of the horizontal arc, a rotating sample holder is mounted, which allows azimuth movement of the sample.

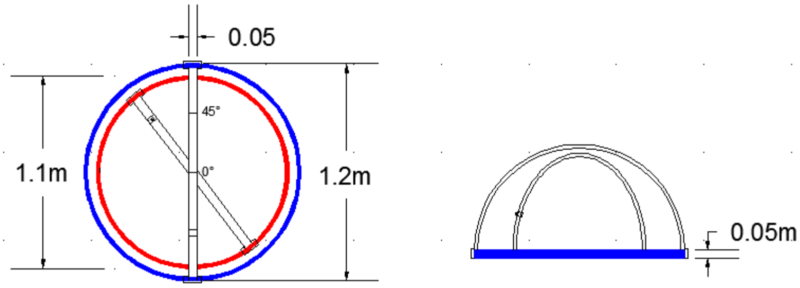


Fig.1. Gonioreflectometer for measurement of BRDF

A 25 W halogen incandescent lamp is used as a light source. In order to avoid illumination inhomogenities of the light spot, projected by the lamp, the incoming light intensity at different angles is measured for a net of measuring points with a calibrated luxmeter. For illumination from nadir, the special distribution of the light intensity is very homogenous, while from other different angles - 60º, 40º, the area closer to the light source is brighter than the area on the opposite side of the sample. If the center of the detector of the luminancemeter or radioreflectometer is always aimed and coincide with the center of the light spot, produced by the light source, the error from inhomogeneity will be negligible. This illumination inhomogeneity has to be estimated, because the light source considered doesn't emit parallel light rays. The source and viewing zenith angles change from 0 to 180 degrees. The relative azimuth between source and sensor also range from 0 to 180 degrees.

In concern of the application of the collected data, only the visible spectrum is considered in the current investigation. The results, given apply for wavelength of 600 nm. There are several ways to present a BRDF – here it has been measured for observation zenith angle θr = 0,15,30,45,60,90 degrees, the zenith angle of the light source θi = 0,10,30,50,70,90,110,130,150,180 degrees. The azimuth angles of the sample considered are φi = 0, 20, 40, 60, 90 degrees.

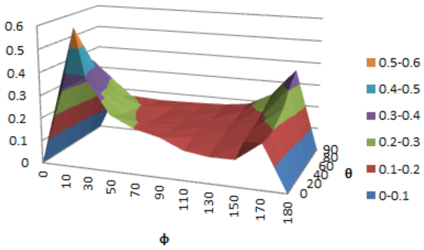
3. DESCRIPTION OF THE SAMPLES AND RESULTS

Typical for the samples, considered in the current paper, which are all with moderate roughness, is a constant diffuse component (and a specular peak for some of them). The samples are new in terms that they haven't been exposed to field conditions for extended periods of time. Two of the samples considered have been taken as representative and described in details. These are light blue mineral façade covering with color coordinates x = 0,2882±0,0005, y = 0,3090±0,0023 and brightness coefficient β = 0,357±0,012. The sample is with moderate roughness and is expected to show almost diffuse reflective characteristics. The second sample is dark grey polymer coating with scratched structure, grain size of 1.5 mm with added pearl effect and it consists particles with specular reflectance. Both samples are produced by "Saint-Gobain Construction Products Bulgaria - Weber division". BRDFs of the samples considered are calculated from the ratio of the reflected luminance (radiance) and the incident illuminance (irradiance) [2]. The accuracy of the measured data was determined to be up to 15% according to [5]. Before the measurement has been conducted, a calibration of the experimental setup has been carried out, taking into account the geometrical stability of the apparatus, the stability, homogeneity and conical illumination of the light source, consistency and repeatability of measurements [6].


a)

b)

Fig.2. Representative samples for BRDF measurement a) light blue surface with moderate roughness and b) grey surface with specular particles and moderate roughness



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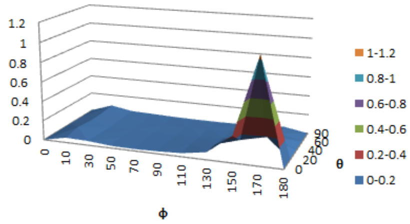
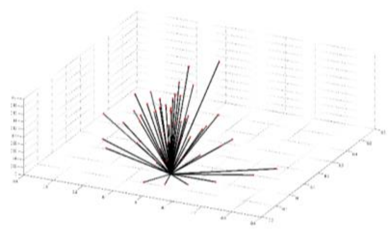


b)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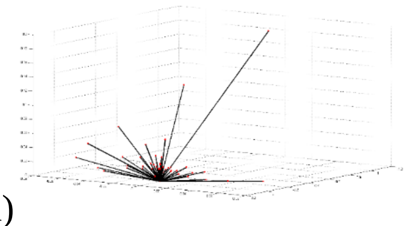

b)

Fig.3. BRDF and indicatrices of reflection of a) light blue surface with moderate roughness and b) grey surface with specular particles and moderate roughness for position of the detector at 15°

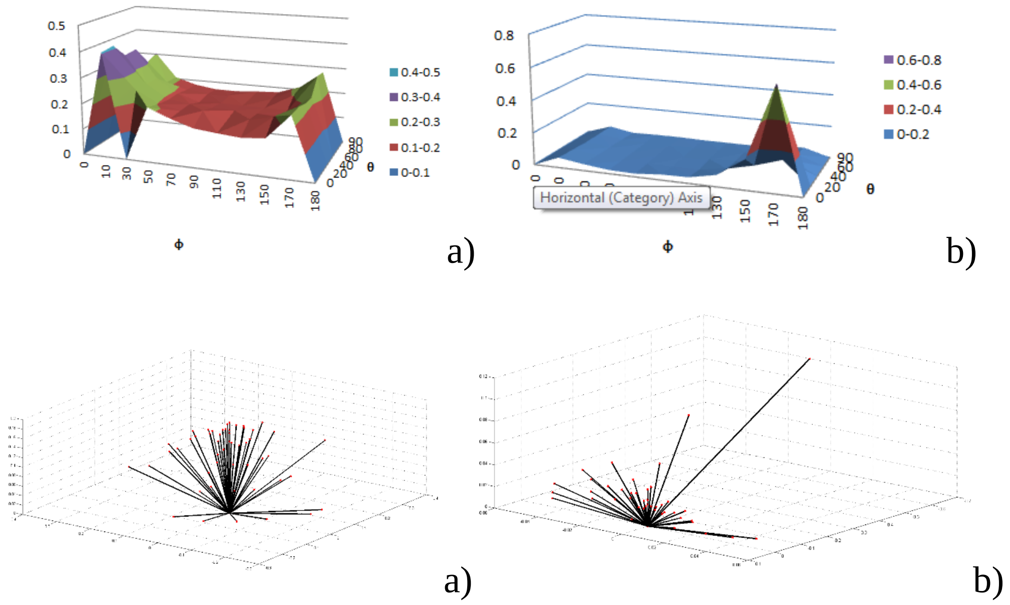


Fig.4. BRDF indicatrices of reflection of a) light blue surface with moderate roughness and b) grey surface with specular particles and moderate roughness for position of the detector at 30°

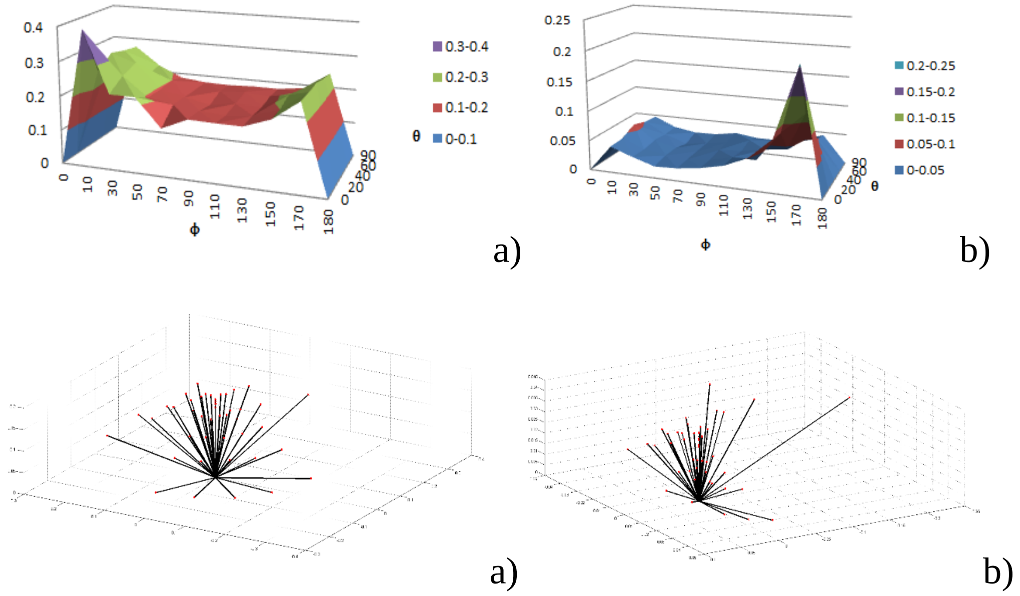
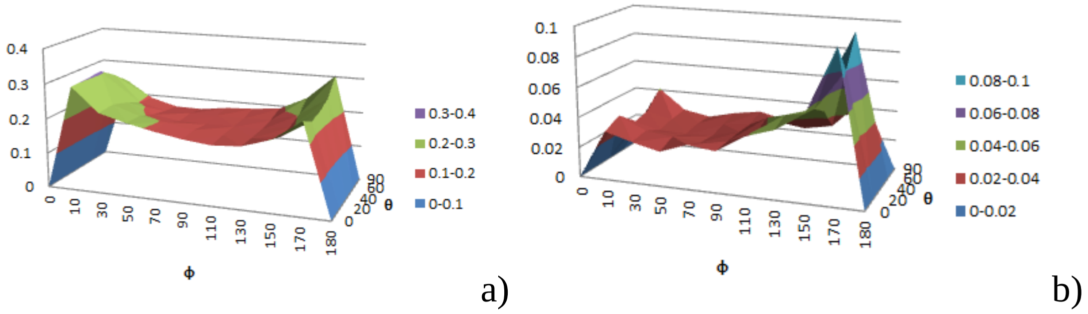
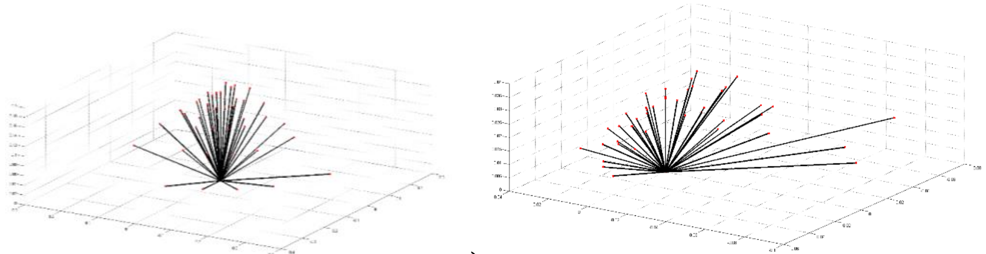


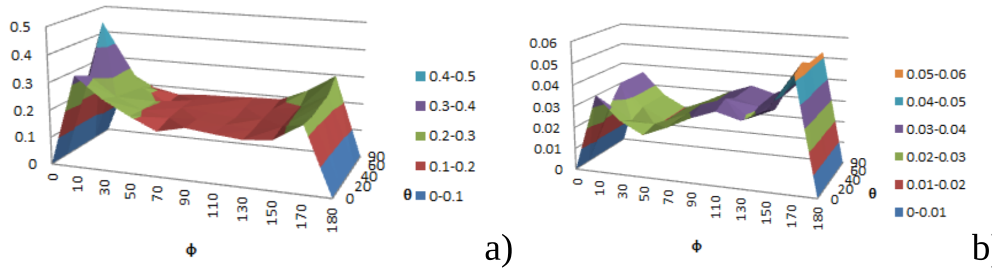
Fig.5. BRDF indicatrices of reflection of a) light blue surface with moderate roughness and b) grey surface with specular particles and moderate roughness for position of the detector at 45°



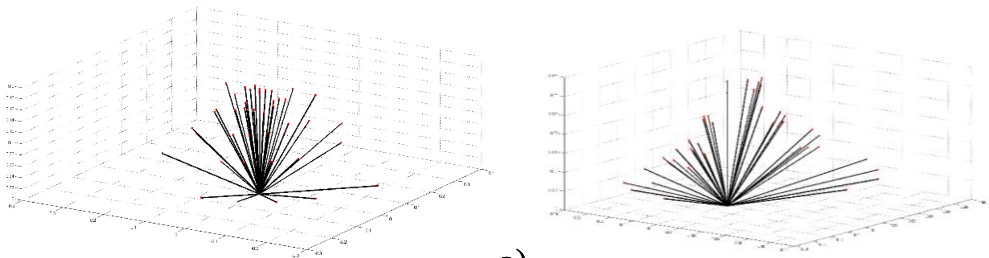


a) b)

Fig.6. BRDF indicatrices of reflection of a) light blue surface with moderate roughness and b) grey surface with specular particles and moderate roughness for position of the detector at 60°

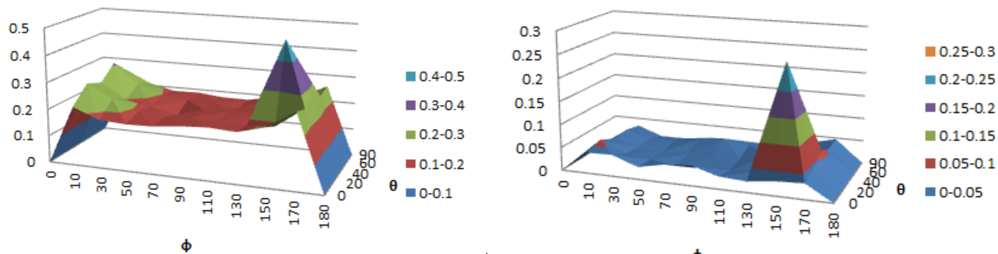


a) b)

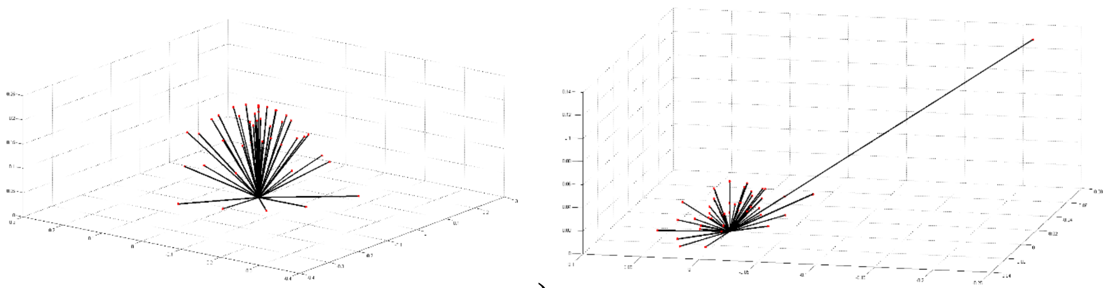


a) b)

Fig.7. BRDF indicatrices of reflection of a) light blue surface with moderate roughness and b) grey surface with specular particles and moderate roughness for position of the detector at 75°



a) b)



a) b)

Fig.8. BRDF indicatrices of reflection of a) light blue surface with moderate roughness and b) grey surface with specular particles and moderate roughness for position of the detector at 90°

4. CONCLUSIONS

The angular distribution of the reflection from common façade materials has been measured and shown in the current paper. As it was expected the first sample of light blue façade covering has almost diffuse reflection, while the second one have irregular specular peaks, due to the particles with specular reflection, included in it. The patterns of the reflection characteristics of both samples show that the smaller the illumination angle is, the more specular the reflection is, depending on the azimuth position of the light source. The results obtained are representative and can be used directly for architectural lighting simulations.

More complicated study has to be considered, including not only visible, but also light form the infrared and ultraviolet part of the spectrum. Also a verification of the measurement can be done by means of a CCD camera.

5. ACNOWLEDGMENTS

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