Introduction

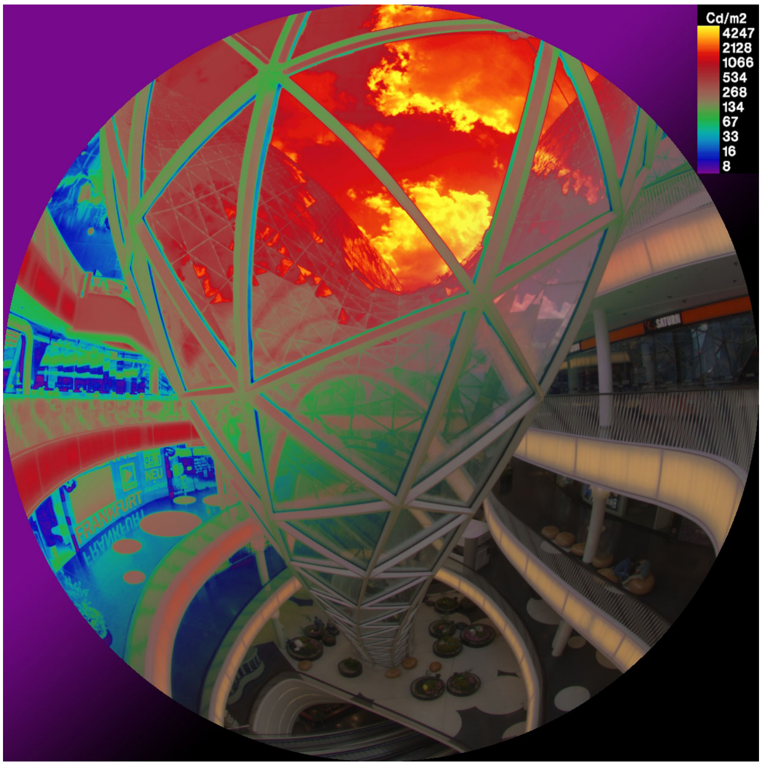

Figure 1: Photo realistic HDR image technique can provide use the luminous information about any environment immediately.

The purpose of lighting design can be divided into two main categories: Visibility and Appearance. [1] The visibility requirement that can be quantified mostly by measuring lux levels on the visual task planes and is the one which most of the lighting requirements are based on. However, in the field of professional lighting design, when analyzing the lighting conditions of a space, the quality of a lit space is much more important than the quantity of light applied. The problem is that it is not easy to judge the light quality of an interior or exterior space. Therefore, measurement is usually the only method that many lighting design experts use for the assessment of rooms or spaces; and then it is based on their knowledge and experience. They interpret the data and translate those numbers into quality terms.

The easiest, fastest and cheapest way of measuring is to measure the lux level with a lux meter. Most of the lighting standards use illuminance and not luminance when specifying their lighting requirements. However, since the luminance values are more directly related to what we see rather than illuminance values, luminance is more relevant when considering the visibility and, indirectly, the appearance of the space. Being view-independent and requiring a stable light condition are the two other obstacles that prevent the lighting profession from using luminance when analyzing a space. Furthermore, although it is possible to measure the luminance value of each point in a realistic

[1] Christopher Cuttle, p. 23

[2] Mehlika Inanici, 2005, p. 4

space using a luminance meter, such measurements take a long time and errors can arise due to measurement uncertainties. Therefore, in order to be able to use luminance as a primary measurement method, there is a need for a tool that can capture the luminance values of the whole scene at the same time. A photo realistic HDR photography technique is the answer.

High Dynamic Range (HDR) Images

Approximately a decade ago, more advanced digital imaging cameras were introduced to the market. Some effort has been made to develop software to create physically based HDR images. Due to the limitation of cameras to capture a large dynamic range of luminance in a realistic scene, we need to assemble a sequence of LDR (low dynamic range) photos taken by them to create a HDR (high dynamic range) image which includes the whole range with each pixel corresponding to a realistic luminance value. However, there is another way to produce HDR images: by using physically-based rendering tools such as Radiance, Dialux-evo, Relux-pro, etc. that are more relevant for virtual spaces.

Such an HDR image can be used later for the qualitative and quantitative assessment of the lighting in any space by performing some post-process analysis with per-pixel data analysis techniques.

(Per Pixel Data) Lighting Analysis

We can use per-pixel luminance data of any photo realistic HDR images to quantify or even qualify the lighting conditions in the space.2 There are different types of analysis of a luminous environment that can be obtained from an HDR image. Those that can be useful during the lighting design process can be categorized as follows:

- Single image analysis
  We can do the following analysis for the whole image or we can do it just for a region or regions of interests like visual field of view.
  - Numerical analysis
    - Visually
      It shows luminance (or illuminance) distributions and can be demonstrated as falsecolor images, iso-counter lines, or iso-counter bands.
    - Mathematically/statistically
      - The whole or part of a scene
        By finding the maximum, minimum, average, median, standard deviation of the scene, we can calculate the luminance ratios, luminance contrast, histogram diagram, or some other statistical analyses.
      - Task to background luminance ratio

[2] Mehlika Inanici, 2005, p. 4

Find the ratio between a task, and immediately adjacent surrounding or remote (non-adjacent) surfaces.

- Luminance to brightness conversion
  The link between brightness and luminance in a scene follows a power law. Its formula is $B=kL^n$ where B is the brightness magnitude, K is a constant, L is the luminance of the stimulus (cd/m^2), and N is an exponent [3]
  Although the differences for the value of the exponent between different people are large, "for small targets subtending less than 2°, in dim surrounds, the exponents found by different experimenters range from 0.23 to 0.31."[4]

- Glare / sparkle analysis
  Variables such as the size, position, luminance of any light sources or bright surfaces, plus the ambient luminance of the scene, are defining factors for categorizing them as glare or sparkle sources. Sparkle can be considered a positive form of glare, positive in that it stimulates people rather than causing them discomfort.5 By creating physically based HDR images with an 180˚ fish-eye lens, or together with measuring vertical eye illuminance at the camera point, we can calculate some glare metrics such as Unified Glare Index (UGI), Daylight Glare Index (DGI), Daylight Glare Probability (DGP), etc.
- Masking analysis
  This is about filtering the original HDR images via a binary image that has the same resolution6, or by applying some mathematical or statistical operations, such as filtering all the pixel lower or/and higher than a specific value.
- Human visual sensitivity simulation
  To approximate the appearance of a high dynamic range image in a low dynamic range image based on the human visual sensitivity properties, a tone-mapping operator can applied.

- Multiple image analysis
  - Image subtraction, addition, and multiplication
    This kind of analysis is the most useful in testing lighting with a limited number of fixtures when we place fixtures in different positions and take photos to demonstrate the outcomes of each position. By adding all the images together we can create an HDR image including all the fixtures in all positions.
- HDR image based Daylight Coefficient
  This technique that is recently developed allows us to establish a statistics based daylight coefficient model for an existing space by capturing photos in a limited period of time. Its main advantage is that it neglects the need for a 3d model of the space and materials characteristics of each object in the model for the studied scene.[7]
- HDR image based rendering

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3 Peter Boyce, 2014, p. 198

4 Ibid, p. 198

5 Ibid, p. 208

6 Mehlika Inanici, 2005, p. 15

7 Mehlika Inanici, 2013,, p. 3392

This technique allows us to use an 180˚ fish-eye HDR image as sky model in light/daylight simulation software for an un-built project. One of its main advantages is that it contains all the surrounding obstructions with realistic materials. However, its disadvantage is that it is time dependent and only valid to the time that the image was taken.[8]

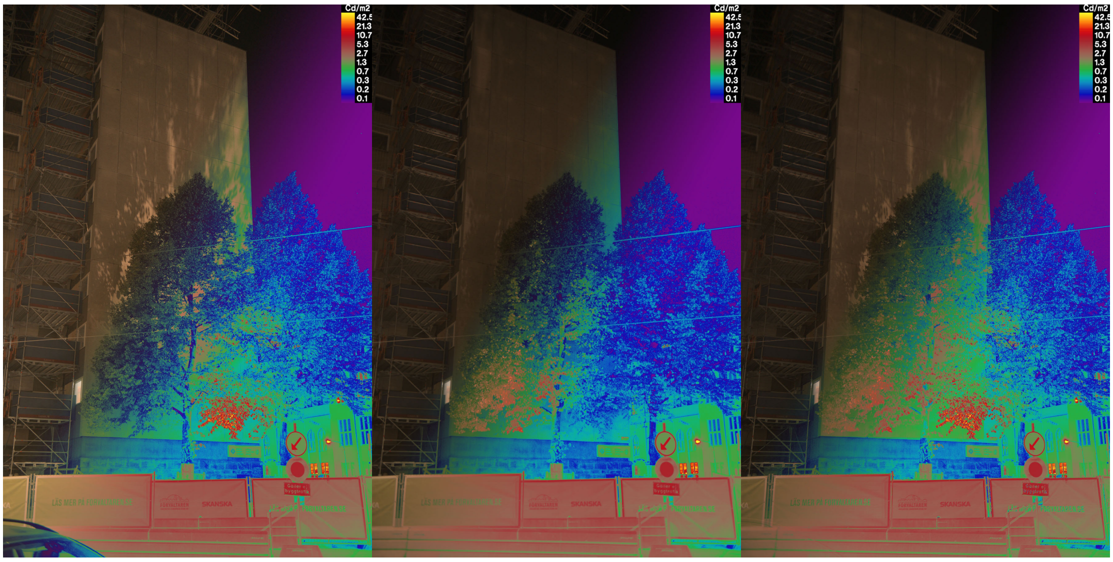

Figure 2: Applying the HDR image technique during a test lighting. We had just one in-ground uplight and wanted to see what would happen if we used two of them to light the trees.

Available HDR Assembly and Analysis Tools

There are some tools available for creating physically based HDR images and analyzing them. Some of them are mentioned in table 1.

	HDR Assembly	HDR Analysis	Operating System	Internet Address
Photosphere	√	√	Mac OS X	http://www.anyhere.com/
WebHDR	√	X	via Internet[9]	http://www.jaloxa.eu/webhdr/
Aftab	√	√	MS Windows/IOS[10]	http://aftabsoft.net/
Wxfalsecolor	X	√	MS Windows	http://tbleicher.github.io/wxfalsecolor/
HDRscope	X	√	MS Windows	http://courses.washington.edu/hdrscope/

Table 1: Comparing the function and operating system of some HDR software

Using computer software for HDR image assembly and analysis needs both digital cameras, and computers, while all can be done using mobile phones. The disadvantage of using mobile phone apps is their accuracy. However, since mobile camera technology has been developing very quickly recently, it is possible that in the near future we can achieve more accurate values.

[8] Mehlika Inanici, 2009, p. 369

[9] It uses Photosphere as its assembly engine.

[10] As the Iphone App is newly developed by the author, at the time of writing this paper it cannot compete other computer software regarding stability and accuracy.

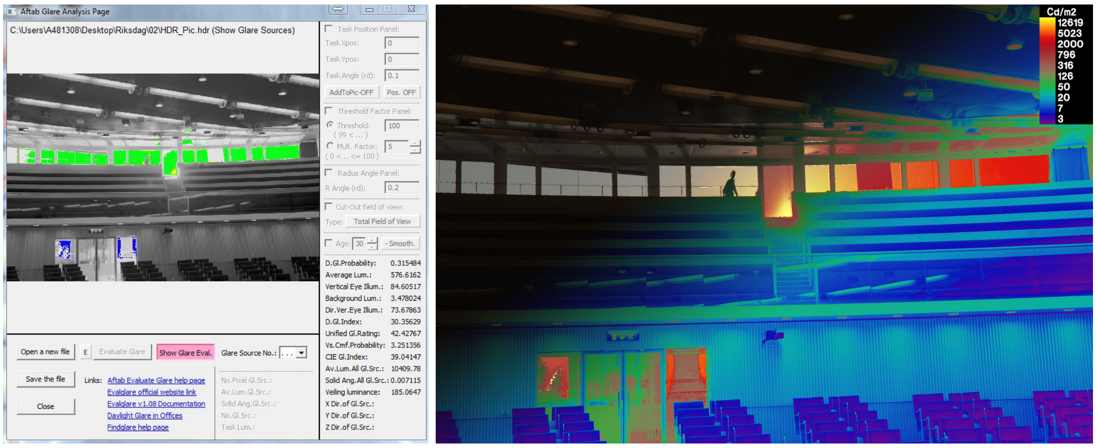

Figure 3: Right: Testing different fabrics to block the sunlight and then create an HDR image for each. Left: Measuring DGP glare from each of the HDR images to decide which fabric works well in this space

Rules and recommendations:

There are some regulations and recommendations that need to measure luminance values. Some of them are as follows:

- Measuring the minimum acceptable and preferable background luminance (surrounding walls and ceilings) for the offices (30 cd/m^2 for the former and between 60 cd/m^2 and 100 cd/m^2 for the latter[11, 12, 13])
- Measuring the following luminance ratios for offices:
    - Between a paper task and an adjacent Visual Display Terminal (VDT) screen: 3:1 or 1:3.
    - Between a task and immediately adjacent surroundings: 3:1 or 1:3.
    - Between a task and remote (non-adjacent) surfaces: 10:1 or 1:10[14].
- Measuring the access zone luminance (L20) that is recommended by the guide for the lighting of road tunnels and underpasses CIE 88:2004
- Measuring obtrusive light permitted for exterior lighting installation based on the European standard of EN-12464-2 or CIE 150:2003
- Measuring average road luminance and longitudinal uniformity of road surface luminance in regard to the road lighting European standard of EN-13201

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11 W. Dau, G., et al., 2012, p. 8

12 Sheedy et.al., 2005, p. 1127

13 Goven. et. al., 2007

14 W. Dau, G., et al., 2012, p. 8

Figure 4: Measuring the average surface luminance of an advertisement sign to comply with CIE 150:2003 or EN-12464-2

HDR Images in the Lighting Design Process

If we study diagram 1, we can see that the first step to take is finding the most appropriate views that can represent the lighting condition of the space (step A). Based on where and when the design is needed, we can then decide on what types of analysis we need to investigate (step B). Now if the space is already exists, we should go to step H, otherwise we should continue (step C). We must then choose which tools or software that is available will satisfy our needs (step D), and then investigate the three main problems that can reduce the quality of our lighting design in the space (functionally, environmentally, or aesthetically) (step E). Finally, we should look for the source of problems (step F), and if we can access and fix them, or consider them as hindrance in our design (step G).

A. **Define Views**

(B_1. **Interior or Exterior** B_2. **Day time vs. Night time**) → B_3. **Which Type of (Per-pixel) Lighting Analysis**

C. **New Construction or Refurbishment**
(If it is new construction, go to step H.)

D. **Tools ->** Photosphere, ,webHDR, Aftab

E. **Finding Problems / Obstacles**

E_1. **Function**
Obtrusive Light or Glare

E_2. **Environment**
Light Pollution

E_3. **Aesthetics**
Unwanted light on the surfaces

F. **Find the source of problem**

G_1. **Change the fixture to solve problems**

G_2. **The problems cannot be fixed**
Inform the client / keep in mind as a future threat

H. **New Design**

I. **Prepare the 3d model of the space in the lighting analysis software**

J. **Specify the right materials for each surface**

K. **Import the relevant photometric files of future and/or existing light fixtures**

L. **Evaluate different design variants**

M_1. **Function**
Based of existing regulations
Luminance / Illuminance
Usually no need for any HDR images

M_2. **Environment**
Based on environmental certification systems
Luminance / Illuminance

M_3. **Aesthetics**
Luminance
Convert Luminance to brightness
M_{3a}. **Real test lighting for complex spaces**

N. **Final evaluation of design**

Diagram 1: Using HDR images during a lighting design process

Now we can start our new lighting design (step H). The first step in this stage is to prepare a 3d model of the space in lighting simulation software like Radiance, Relux-pro, Dialux-evo, etc (step I). Then we need to specify some physical properties (like reflection, specularity and roughness) of each of the surface materials. To do so, sometimes we need to have real test lighting, or use some special tools such as goniophotometer (step J). In this stage, we need to import the relevant photometric files of future and/or existing light fixtures (step K). Now it is time to evaluate different alternatives by considering each of these three factors: Functions, Environment, and Aesthetics. For the first two, we can measure luminance or illuminance, however, for the third one, luminance is more relevant. For the Aesthetic, if we convert the luminance values to brightness values, our assessment will be more relevant. However, to get the best evaluation of the design, we need to do some test lighting on site too.

Conclusion

Since brightness and luminance are corresponding with each other and, as we know, what we see is more relevant to brightness rather than amount of luminous flux on the surface (lux), therefore, doing luminance-based analysis can be much more helpful to understand the lighting condition of the space. Furthermore, with developing physically based lighting calculation tools and HDR assembly software together with their ability to analyze the lighting condition of the space, we can apply luminance based lighting analyses much more than before, and, consequently, educate ourselves with a better understanding of luminance values and its relationship with brightness, glare, sparkles and dull spaces.

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