

## **Daylight in the Museum: Luminance distribution study using hdr photographs**

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**ABSTRACT:** Daylight is essential when experiencing architectonic spaces; its proper integration and suitable distribution creates a spatial dimension which passes well-being onto people. Therefore, lighting strategies are key in a museum, as they need to guarantee a stable luminous room, giving a good vision of the works. Restrictions to conserve works have led to a limited use of daylighting, favoring the design of artificially-lit spaces making it increasingly more complex to unite daylight and architectonic design. This research looked to study how to bring together daylight, architectonic design and artificial lighting through the analysis of light distribution in the Chilean Pre-Columbian Art Museum, located in Santiago de Chile. The main goal was to analyze the light-space relationship of the exhibition area, starting from the conversation criteria of the works. Different settings were evaluated to get to know the lighting variations among the different architectonic elements and the elements exhibited in the observer's field of vision. High Dynamic Range (HDR) photographs were taken in the museum to provide a better understanding of the lighting in regards to the performance of human visual perception. The results allowed finding the positive and negative effects in the exhibition area's light-space relationship.

**Keywords** *Lighting – museum – high dynamic range*

## 1. INTRODUCTION

Daylight does not just create a sensation of well-being; it allows saving in energy by needing less artificial lighting to light up our spaces. The impact of light on the museum and artistic exhibition galleries conditions the light settings of the exhibition space housing them. The integration of natural light is complex due to the dynamics of light, its daily and seasonal variations, since stable lighting conditions are required in the exhibition area with a uniform distribution and without sunlight penetrating through.

The photometric characteristics of daylight cannot be replaced by artificial means, since its visible spectrum and color performance permit an excellent chromatic reproduction that favors the perception of the exhibited works. Its architectonic integration must be done considering the specific criteria of perception and conservation, where the objective is allowing that the exhibited elements are clearly perceived without causing any type of degenerative effect on the material of the exhibited works. On introducing daylight as a strategy for lighting exhibition areas, conditions must be created to obtain the visual comfort of the people visiting the museum and, at the same time, to reduce the damage to the exhibited objects as much as possible. The correct use of light in the exhibition area setup is key, as its integration enhances the lit room and, with this, the exhibition itself.

This investigation is focused on the light evaluation of an architectonic intervention at the Chilean Pre-Columbian Art Museum (MCAP), where we find pieces made from diverse materials, like stone, textiles, a variety of pigments, wood, metal and others, some of which date back more than three thousand years. The idea of analyzing the light-exhibition area relationship starts from the conservation criteria of the works. The evaluation is done through high dynamic range photographs, a method which allows accurately reproducing the light setting. Different scenes were evaluated to find out the luminance variations between the different architectonic elements and the exhibition elements in the observer's field of vision.

## 2. LIGHT AND CONSERVATION IN MUSEUMS

Light and conservation are entwined in a museum. Light is associated to an energy which can irreversibly change the physical properties of the materials, and can also provide unfavorable environmental conditions for their conservation. This generates damage through accumulation and an irreversible degenerative action in the exhibited objects, so we must take care that the lighting level falls within recommended limits (Thomson, 2013). An object which is exposed to intense light for a prolonged period of time will be subject to a higher global radiation intensity and the uniformity of the light on the object will be lower; it is recommended to base the design on a simple principle: the lesser the exposure, the lesser damage will occur (Michalski, 1997).

To evaluate the object's degree of exposure to light, the illuminance (lux) is considered. In Table 1, the maximum levels of illuminance recommended for the museums are shown, pursuant the type of object exposed considering the conservation criteria.

Table 1 Illuminance range for each material without exposing it to damage (source: Rodríguez Alvarez, 2016).

Material	Max. recommended value	Lux/hour per year
Watercolors, fabric, paper, engravings, tapestries	50 lx	54,000 lx
Oil paintings, tempera, bones, marble, leather.	200 lx	500,000 lx
Stone, metal, ceramics, wood, photos	300 lx	Depends on the exhibiting conditions.

Light distribution and contrast are equally important in the visual perception of the exhibited objects. The distribution of luminance in the visual field affects the visual comfort of the people visiting the museum. Luminance ( $\text{cd/m}^2$ ) or photometric brightness was considered as a relevant factor within the lighting of the museums. This expresses the brightness of the light sources or of the objects lit, determining the visual sensation produced at the scene (Sanz, 2011). It is considered the luminances that are too high can lead to glare; on the other hand, contrasts of luminances that are too high can cause visual fatigue due to the constant readapting of the eyes and, finally, luminances and contrasts of luminances that are too low can lead to a monotonous and not very stimulating room (IDAE Guía Técnica, 2005).

Luminance is evaluated in regards to the contrast between the object and the background. In museum rooms, a favorable ratio between the luminance reflected on the object and the luminances of other surfaces around the field of vision create suitable perceptions of the exhibited objects (Boyce, 2003). A balance between the object and the background or surrounding space can be: between the object and the darkest setting 3:1; between the object and darkest distant surfaces 10:1; and a maximum contrast of 40:1 (IDAE Guía Técnica, 2005). According to Steven Hefferan (2008), the appropriate luminances ratio for a museum cannot surpass 3:1 between the object and its immediate surroundings.

In this study, the luminance on the object and on other surfaces in the visual field will be evaluated through High Dynamic Range (HDR) photographs of the different scenes or settings within the museum, evaluating whether these comply with the luminance ratio defined.

### 3. LIGHT IN THE CHILEAN PRE-COLUMBIAN ART MUSEUM

Two relevant exhibition spaces were chosen to evaluate lighting in the Chilean Pre-Columbian Art Museum (MCAP). The first, the "Chile before Chile" room is in the museum's basement (Fig. 1-2). The lighting in this exhibition area integrates daylight in a diffuse manner in the sculptures area and uses artificial lighting to highlight the display cabinets with ceramics, all harmonized with an opaque and dark color on the walls and ceilings that emphasizes the dim lighting on entering this space. The second is the "America" room, located on the second level of the oldest part of the museum (Fig. 1-2). This has bilateral lighting: on one side of the room, direct lighting is given by the windows and, on the other, indirect lighting comes from a light well that has a diffuser screen covering it. Both exhibition areas have ceramics, stone, wood and fabrics.

The measurements were made on October 28<sup>th</sup> and 29<sup>th</sup> 2015, under clear skies in the city of Santiago. The measurements of both luminance and illuminance were made at three times of the day (12, 3, 6 pm) which covers the museum's opening times. In Figure 2, the views considered in each one of the two exhibition areas analyzed are shown. The light evaluation is done on two scales: the first considers the perception at a spatial scale of the exhibition area, analyzing the objects-space ratio and the second considers a closer scale, analyzing the object-exposed background ratio.

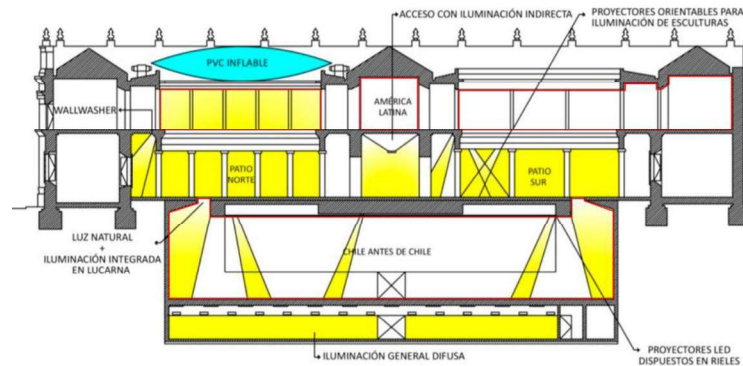


Figure 1. MCAP Cross-section view. The zones outlined in red are the ones that were evaluated, with their corresponding lighting strategy (source: own preparation).

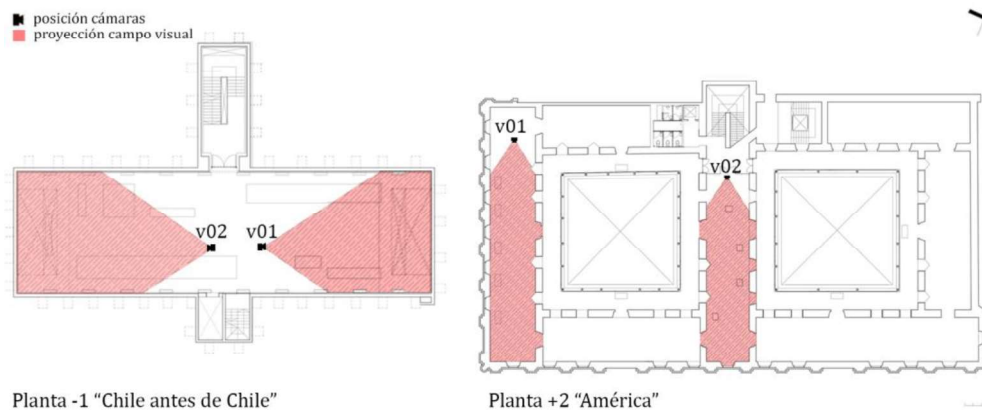


Figure 2. Views and visual field analyzed in regards to the exhibition space (source: own preparation).

### 3.1 Exhibition area measurements using HDR photographs

The high dynamic range (HDR) photographic method consists in taking a series of photographs which capture luminosity over a broad range with a calibrated conventional camera; the very dark and very bright areas of a light setting are stored in a single image. This series of photographs allows the construction of an HDR photograph where it is possible to evaluate the luminance of the spaces and the elements being exhibited. This method has been developed and validated by several researchers through different laboratory tests. These investigations have shown that the values captured in each pixel in

an HDR photograph accurately correspond to the physical characteristics of the real luminance of the captured scene (Anaokar & Moeck, 2005; M. Inanici & Galvin, 2004; M. N. Inanici, 2006; M. Inanici, 2010; Piderit, Cauwerts, & Diaz, 2014).

A Canon EOS REBEL Ti3 camera was used for this study. It was placed on a tripod and in order not to move the camera when taking the photographs, it was programmed using software with an automatic trigger. A series of photographs, between 6 and 10, were captured for each moment, using the Low Dynamic Range (LDR). The opening of the camera's shutter was left fixed and the exposure ranges varied to capture the space's luminosity. Each series of LDR photographs (.jpg format) captured is converted into a single HDR photograph (.hdr format), using the Radiance software (**Erro! A origem da referência não foi encontrada.**), then the false color maps of each scene were built to



evaluate the luminance obtained.

Figure 3. Sequence of photographs with different exposure ranges with final image in HDR (source: own preparation).

#### 4. EVALUATION OF THE CHILEAN PRE-COLUMBIAN ART MUSEUM'S EXHIBITION AREA

##### 4.1 Exhibition Space - Object Light Evaluation

In the "Chile before Chile" room, the exhibition area's evaluation was done in two views that are relevant within the setting, View 1 considers the evaluation of the Pre-Columbian totems and View 2 is focused on the exhibition area of Pre-Columbian tapestries and jewels (see Fig. 2).

In Figure 4, which corresponds to View 1 "Chile before Chile", we can see the strong impact of the zenith lighting on the exhibited objects, the skylight does not have screen, causing a luminance area with values above  $37.5 \text{ cd/m}^2$  for all the times evaluated. According to the 3:1 luminance ratio, between the object and the darkest setting, this is inverted, with a background with luminances over  $37.5 \text{ cd/m}^2$  and figures with luminances between  $22\text{-}17 \text{ cd/m}^2$ , having a luminance ratio close to 2:1 as a result, highlighting that the heads of the totems also have similar luminances at the base. The dark finish of the walls and the bright floor create a light atmosphere over the exhibition area, as can be seen at 3pm in the false color image, and the totems are lost within this luminous atmosphere. At 6pm, the light allows seeing the light and shaded zones, highlighting the shapes of the totems, where we see that the luminances are reduced on most of them.





Figure 4. View 1 "Chile before Chile" - 12, 3 and 6pm - Exhibition Area. A) HDR Images b) False Color (Source: own preparation).

In Figure 5. View 2 "Chile before Chile" 12, 3 and 6pm - Exhibition Area. A) HDR Images b) False Color (Source: own preparation).

, View 2 "Chile before Chile" has a filtered zenith light entrance; it is seen that the luminances values allow creating a difference between the background and the exhibited object, with a 3:1 ratio between them. The luminance of the exhibited object is above 37.5  $\text{cd}/\text{m}^2$  and the background of the observer's field of vision has luminances below 12.5-17.5  $\text{cd}/\text{m}^2$  providing, in this way, a luminance ratio of close to 3:1 between the object and the darkest setting. As a result, it can be seen that the objects are the protagonists within the exhibition area of the area analyzed.

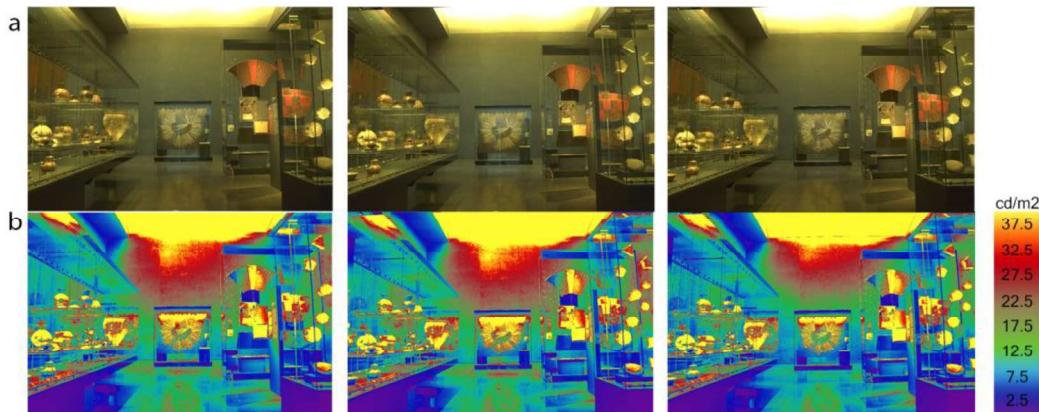


Figure 5. View 2 "Chile before Chile" 12, 3 and 6pm - Exhibition Area. A) HDR Images b) False Color (Source: own preparation).

Two scenes were selected from the "America" exhibition area located on the second floor, which has bilateral lighting. In View 1 "America", on one side, the window rhythmically lights the space and, on the other face, indirect lighting shines through from the hallway which is related to the light well. In the case of View 2 "America", this has indirect lighting on both sides from a light well (see Fig. 2).

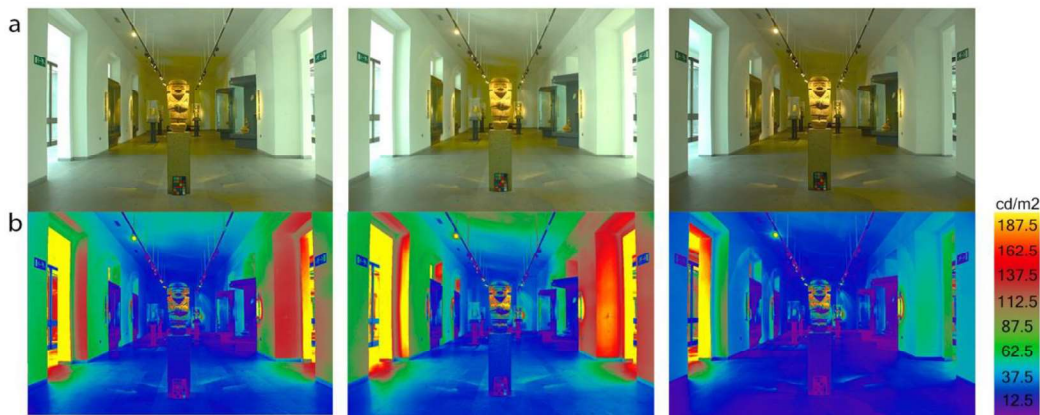
In Figure 6, View 1 "America" 12, 3 and 6pm - Exhibition Area. A) HDR Images b) False Color (Source: own preparation)., corresponding to View 1 "America", we can see in all the periods evaluated that there is not a great contrast between the surrounding area and the exhibited objects. The luminance values of the objects are low, between 12-15  $\text{cd}/\text{m}^2$ , and

the luminance of the surrounding walls is between 37.5-87.5 cd/m<sup>2</sup>, with an inverted luminance ratio between the background and the exhibited object. The background has higher luminances than the objects, which does not favor their perception.



Figure 6, View 1 "America" 12, 3 and 6pm - Exhibition Area. A) HDR Images b) False Color (Source: own preparation).

In Figure 7. View 2 "America" - 12, 3 and 6pm - Exhibition Area. A) HDR Images b) False Color (Source: own preparation)., which corresponds to View 2 "America", it is seen that the contributions of daylight are higher than the ones the exhibition area provides. Luminance values in the indirect lighting areas are over 162.6 cd/m<sup>2</sup>; this raises the luminance of the surrounding walls, which have values between 62.5-112.4 cd/m<sup>2</sup> at the different times. According to the 3:1 luminance ratio, 4:1 is given, while the central sculpture has luminance values above 150 cd/m<sup>2</sup> from the artificial light in regards to the background of



the space observed and we can see that the other objects melt into the space.

Figure 7. View 2 "America" - 12, 3 and 6pm - Exhibition Area. A) HDR Images b) False Color (Source: own preparation).

#### 4.2 Evaluation of exhibited object - background light ratio

The luminance ratio of the exhibited object and the background of the "America" room are evaluated with HDR photographs, where daylight has a strong impact on the exhibition area, with much higher luminances. These are completed with vertical illuminance

measurements on the glass displays at the height of the observer, to evaluate whether the illumination levels fall within the ranges recommended for the conservation.

The false color images of the three moments evaluated are shown in Figure 6. Views on "America" Displays 12, 3 and 6pm - Object and background ratio. False Color Images (Source: own preparation)

. On analyzing the luminances ratio between exhibited objects and the background, this is inverted in terms of the recommendations (3:1) on the four displays evaluated (see Table 2). The background has luminances which exceed 162.5 cd/m<sup>2</sup>. Negative effects are produced on facing the display, since our eye physiologically directs the look to the area with the highest luminances, which produces visual discomfort and the exhibited objects are not clearly read.

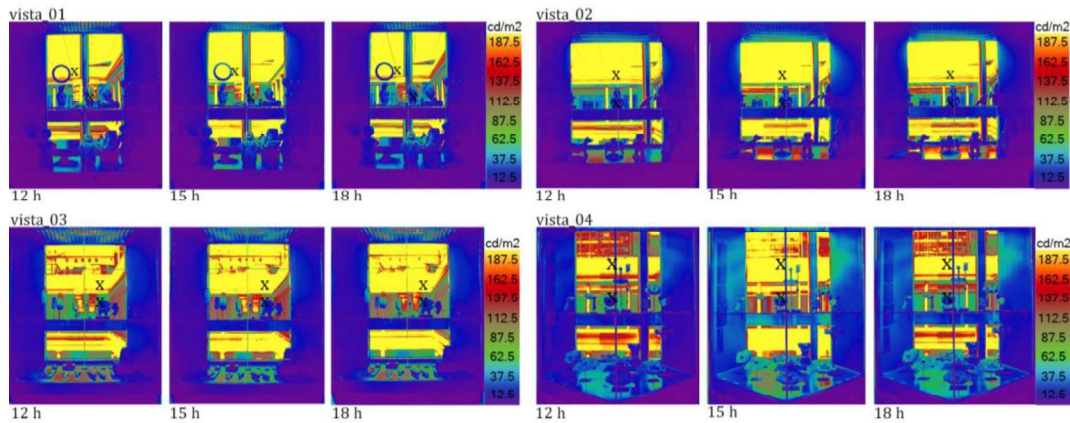


Figure 6. Views on "America" Displays 12, 3 and 6pm - Object and background ratio. False Color Images (Source: own preparation)

In regards to the illuminance, we can see that in all the displays evaluated, the exhibition has illuminance values within recommended ranges (under 300 lux) for a suitable conservation (see Table 2). However, these are low in relation to the background, which does not favor contrast and the proper showcasing of the objects.

Table 2. Luminance and illuminance values at 12, 3 and 6 pm. Object and background ratio. Views in "America" Displays (source: own preparation).

	Times	Object cd/m <sup>2</sup>	Background cd/m <sup>2</sup>	lux		Times	Object cd/m <sup>2</sup>	Background cd/m <sup>2</sup>	lux
Display 01	12	33.4	923	199	Display 02	12	43.7	1200	223
	15	35.7	1480	189		15	38.9	1890	275
	18	25.9	760	165		18	48.8	1840	232
Display 03	12	12	266	163	Display 04	12	36.5	261	180
	15	14.5	742	190		15	36.8	244	264
	18	11.5	474	165		18	37.4	214	255

The false color images of two scenes which exhibited objects in the hallway are shown in Figure 7. Views in "America" hallway at 12, 3 and 6pm. Object and background ration. False Color Images (source: own preparation).



. This object is lost in the lit background. In the scene Hallway 1, the luminance ratio of 3:1 does not occur at any time. However, in the scene Hallway 2, a luminance ratio of close to 3:1 is given. The exhibited object has an artificial light source which allows increasing the light contribution. In the two hallway scenes, the objects exhibited there have illuminance values evaluated that are above the recommended maximum value (see Table 3).

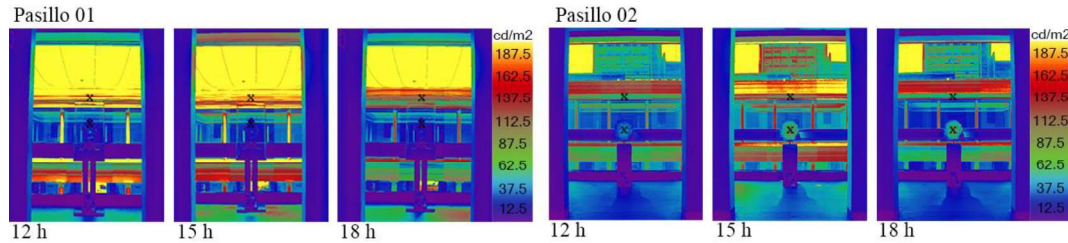


Figure 7. Views in "America" hallway at 12, 3 and 6pm. Object and background ration. False Color Images (source: own preparation).

Table 3. Luminance and illuminance values at 12, 3 and 6pm. Object and background ratio. Views in "America" Displays (source: own preparation).

	Times	Object cd/m <sup>2</sup>	Background cd/m <sup>2</sup>	lux		Times	Object cd/m <sup>2</sup>	Background cd/m <sup>2</sup>	lux
Hallway 01	12	53.5	1330	445	Hallway 02	12	138	408	311
	15	72.3	3980	923		15	136	241	321
	18	97	2740	840		18	126	243	280

## 5. CONCLUSIONS

In regards to the evaluation of the exhibition space "Chile before Chile", it is concluded that dim lighting contributes to creating an atmosphere where the objects are highlighted by the contrast despite the luminances being low, especially in View 2. The architecture, with its dark wall and floor finish, greatly contributes to the objects being the protagonists, helped by weak artificial lighting, but that despite this, is enough for its correct understanding. It is important to highlight, in an exhibition space, that even though the luminances are low, our visual system will adapt, being able to clearly recognize the highlighted objects. In regards to the exhibited object - background evaluation in the "America" exhibition, we find that the luminance differences between the object and background is completely inverted. The background presents very high luminances, the 3:1 ratio is not given, so the exhibited objects are not protagonists in the space.

This investigation, in spite of its limitations, used photographs that provide a method which allowed us to quickly make measurements in a space where people move through. It also allowed us to display the real effect of light, as this intervenes in the exhibition area to, in this way, be able to distinguish accurately the luminances of the exhibition area.

The museum analyzed has one of the largest museographic works in the history of Museums in Chile. It is difficult to have complete control of the environmental parameters that intervene in the conservation, like temperature and humidity. A complementary study would enhance the information collated by this work. The perception could be

complemented with perception surveys of the people visiting the museum. This has been suggested for a future project.

## 6. ACKNOWLEDGEMENTS

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