


Article

Sustainable Illumination for Baroque Paintings with Historical Context Considerations

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Abstract: The topic of museum illumination and conservation has been richly developed in recent years to take steps toward a zero-energy building concept. Most artworks preserved in museums' expositions were designed for specifically defined light contexts, wherein daylight and seasonal changes were part of the artistic effect, an issue which has received little scholarly attention. From this premise, this paper aims to prove that defining the original illuminative context of artworks is required for a sustainable conservation, perception, and ultimate interpretation. To do this, a selection of seventeenth and eighteenth century churches and palaces from Europe, the Americas, and Asia will be presented using modern conservation frameworks for artworks. The results demonstrate that both aspects, chosen materials and light exposure, were connected, allowing the spaces to be effective without consuming too much electric lighting. This leads to a discussion about if museum displays should incorporate this context, if it is a more sustainable solution, and if it presents the artworks more accurately to visitors, even as other problems may arise.

Keywords: museum sustainability; museum lighting; painting display; art perception; Caravaggio

1. Introduction

Museums have received much attention regarding their sustainability in recent years, thus providing a broad perspective on the topic. Pop and Borza articulated the ideal equilibrium between four sorts of sustainability in these institutions: cultural, economic, social, and natural [1]. Although this categorization was published previously, they provided a detailed list of indicators that allow us to define each group [2]. Both this study and many others have highlighted the importance of maintaining the conditions of conservation, located within the cultural category, an issue in which light plays a key role. The deterioration of artworks through light exposure likewise has received scholarly attention starting in the second half of the twentieth century [3], being examined regularly thereafter [4–8]. In this sense, the CIE standard 157:2004 “Control of Damage to Museum Objects by Optical Radiation” articulates the most recent recommendations. Generally, while it recommends low-level illumination as necessary for damage control, higher light levels might be needed for better visual appreciation. To balance this, three main aspects have been considered. On the one hand, recommended illumination is 50 lx for high/medium light sensitivity and 200 lx for low light sensitivity [9]. Correlated colour temperature (CCT) is preferred between 3600 and 5700 K, which is below that of daylight (6500 K) [9]. Finally, optical radiation has been addressed by different scholars, who consider 75 $\mu\text{W}/\text{lm}$ as the maximum allowable, while 0–10 is more common [10]. These three lighting characteristics, alongside other elements, contribute to the relative damage factor (RDF), which is crucial for the sustainability of the artwork's preservation [9]. Trying to balance conservation, efficiency, and perceptive quality, many proposals have been carried out in recent years based on the possibilities of new equipment [11] and visitors' preferences, a topic only very recently but widely examined [12–18]. Even in this case, lighting functions decoratively, depending on the curators' tastes and contemporary trends.

The historical spatial context, for which every piece was designed, remained insignificant, probably as a result of the lack of studies in this field until the most recent decades. Recent scholarly attention on this issue from historical, analytical (in situ), and digital (simulations) perspectives have shown different stages in architectural history regarding light management, although the lack of a broader range of examples makes this approach still rather perilous [19]. Despite the lack of general views on the topic, different studies have already addressed various medieval and early modern buildings, allowing us to develop a tentative framework. Some of these studies have been made from digital simulations, it thus being important to examine their accuracy and limitations. Applying them to non-existent structures brings up several problems. First, working from historical sources allows for only approximate spatial reconstructions. Second, material reflectivity can barely be included due to the lack of this information in most cases. Thus, for example, it is difficult to understand the exact behaviour of glass. In addition to these problems with the digital reconstruction, software also presents limitations, as previous studies have already shown [20,21]. It usually simplifies the examined space, requiring a model under 64,000 faces. These programs focus on illuminance analysis, the amount of light on a surface, but not on the surfaces' radiometric quantities, which are more relevant in examining damage. Some architectural characteristics, such as semi-circular openings, can be not included, and other aspects such as celestial conditions might be not correct for certain geographical contexts. As a result, previous studies have shown that the margin of error is less than 30 percent, in the worst case scenario, although this could increase in certain historical cases. Therefore, these results cannot be considered as definitive, but as tentative approaches to undervalued aspects, which is acceptable for current objectives.

This current review of light in museums from different perspectives, namely sustainability, optimal perception, and concerns of conservation, requires a new aspect to be considered. Thus, this paper aims to prove that historical lighting of artworks was crucial for their design and therefore, critical for their modern perception and understanding. Thus, these factors must be taken into consideration in a museum setting as part of any culturally sustainable display.

To do this, recent studies on museum lighting and sunlight analysis of historical spaces will be examined, providing both existing simulations and new case studies: that of Capella Contarelli in San Luigi dei Francesi in Rome, where three paintings by Caravaggio are preserved, and the now-lost Alcazar in Madrid. As has been pointed out, discussions in museology have centred mainly on novel electric light equipment and questions of conservation, even though simulations are rare. With regard to historical lighting studies, unfortunately they were developed with different approaches and aims, which makes it difficult for them to reach a cohesive conclusion. Nonetheless, their data and results can be brought together to achieve a broader perspective. To make this approach accessible, only architectural spaces at similar latitudinal lines and shared cultural backgrounds will be compared, i.e., Mediterranean buildings and some Asian and American edifices from regions then under European control, while disregarding North European examples. To enhance these results, this paper provides a new simulation of two buildings. This analysis has been made possible through a manual CAD reconstruction of the structures and a subsequent simulation using Dialux software. The other edifices were only sketched, since any reconstruction would likely have little effect on these spaces. Artificial light has not been included in the simulation. Although electric light analysis has been carried out by various scholars, this is not crucial for artworks from this time period because candles were used mainly for symbolic purposes, not for general visibility in most celebrations. Exceptions can be made for several cases, such as courtiers' nocturnal parties or specific masses, although they are exceptions to the general rule of using only natural light. Material reflection has been simplified to 50%, although most of the edifices' furniture are constructed from marble, slightly increasing its luminance. The time of day noted corresponds to the current time, bearing in mind that we must deduct one or two hours due to the use of solar time four-hundred years ago. The surrounding buildings were also ignored, though they likely would not affect the results. Finally, interior decorations were not included to make digital processing easier, them not being a crucial element in this instance.

2. Method and Materials: Simulation of Paintings' Original Spaces

Museum light management has been focused on conservation. In this context, some materials such as miniatures, watercolours, or drawings are considered to be highly sensitive to light and are not recommended to be exhibited in contexts greater than 50 lx. Higher levels, up to 100 lx, are acceptable for oil or tempera paintings, while metal can tolerate 300 lx [9]. While this is accepted by the profession, other factors have been recently incorporated into the discussion, such as the Correlated Colour Temperature, "CCT of the accent lighting on the paintings", the background colour, and the hue of the artwork [17]. Regarding CCT, this and similar studies have shown that people prefer a range between 3500 and 5000 K, higher than the recommended, and closer to the natural light, although these results can be affected by contextual aspects such as personal taste or cultural framework. Regarding background, this experiment does not find much difference among the possibilities provided, i.e., white, grey, and black, although the last is slightly preferred. They also showed that the painting's hue was relevant in connection with the background. All these perceptual conclusions note that the space where the piece is displayed must be analysed to improve understanding. However, this should not be a question of contemporary taste or preference, because artists usually designed their works for specific interiors with little variability in terms of lighting. For this reason, it is time to incorporate historical management of light in different spaces, namely domestic, courtly, religious, and exterior, to the discussion and subsequently to the exhibition.

Art History has been generally interested in light, although from now-superseded subjective perspectives [22]. Previous studies have provided a solid foundation to show generally how European architecture developed a natural management of light until the diffusion of artificial devices, from ancient times to the early nineteenth century. Moullou, Doulos, and Topalis have developed fruitful studies on the topic for late antiquity, showing that artificial illuminance of a room must not have exceeded 12 lx, far from the 250 lx–300 lx common today [23]. Most preserved artworks of this time were not paintings or polychrome sculpture, so this fact may not affect their exhibition in museums.

Much more interesting for this field are later Byzantine churches, which were built to naturally shine at the altar at a desired time of day [24,25]. Both during these special occasions and daily celebrations, artworks were exhibited in a dark space under a contrasting spotlight produced by a sunbeam or candles. According to Moullou et al., a beeswax candle (0.5 cm wick thickness) would produce 19.43 lx tilted at 25 cm. Considering that six candles were liturgically common at main altars, the luminance here would exceed the nave. While the space would be decorated with wall paintings or furniture with low light reflectivity, the main piece at the altar would be painted with gold, a powerful reflector that increases contrast. This space reinforces the piece's attraction through the contrast between the dark background and the gilded surface, an environment that is difficult to replicate with modern displays of 200 lx in a museum.

During the medieval period, some other examples have been scrutinized, such as Romanesque churches or Spanish Gothic cathedrals. Romanesque architecture is characterized by a small number of little windows that illuminate the interior of the worship space. This produced very dark interiors, where electric lighting might play a role. Although results provided by scholars for some examples in Segovia might be affected by changes in the buildings' surroundings and interior renovations, it is clear that average luminescence is very low, with some exceptions of 250, 350, or 1000 lx [26]. Future studies must examine this question further, especially if these data reflect the intention of illuminating the altar during a special celebration. As a conclusion, it can be said that Romanesque interiors emphasized shady spaces that used light to emphasize important spaces akin to the Byzantine framework. As a result, devotional pieces of art usually were decorated with gold to contrast them with their surroundings. These dark religious spaces were replaced by a Gothic aesthetic, wherein light has been traditionally seen as a crucial element. In contrast to this common interpretation that these types of buildings were full of light, a site analysis produces illuminance levels under 30 lx along the central naves in Gerona, Seville, Toledo, and Leon [27]. Stained glass windows also impact these data, although further digital simulations would be difficult to perform with modern software. The same

study proposes just 69.44 lx as total mean lighting for the Sainte-Chapelle (Paris, France), one of the outstanding examples of the Gothic style. This new manner of designing windows would make it difficult to create a natural spotlight on specific places. On the contrary, the space remained dark, allowing candles to highlight the gilded devotional pieces. This purpose is drastically reduced when the museum exhibition increases illumination levels.

Renaissance architecture rejected interest in darkness in favour of dynamic spaces. Previously employed stained glass was avoided in favour of a slightly brighter result. Thus, significant examples such as San Lorenzo in Florence by Filippo Brunelleschi proposed an homogenic atmosphere around 50–75 lx for midday on the summer equinox, according to preliminary simulations developed by this study. The presbytery would be better illuminated than the nave in a crescendo display from the entrance of the church. A similar example from a later date, previously analysed, is that of S. Bento de Cástris, a sixteenth century church near Evora in Portugal [28]. It seems that light was used homogenically, avoiding drastic contrasts and spotlights. Some areas were better illuminated than others, with a slight unconsciously perceived increase along the nave. In addition to architecture, the history of painting is a good manner to see this change.

At the end of the sixteenth century, the importance of light increased, it being considered a key feature of baroque art and architecture. Levels of illuminance were reduced to reinforce some dramatic effects, being generally under 100 lx. An excellent starting point to see such change is Contarelli Chapel, the first major public commission of Michelangelo Merisi da Caravaggio (1571–1610), the light analysis of which is provided here [29]. The contract with the painter was signed on 23 July 1599, with the installation of the side paintings having been completed by July 1600, where they have been preserved to this day. The central piece is slightly later and was first exhibited in 1602. Shortly after this signature work, Caravaggio was probably able to visit the space during the feast of Saint Matthew, the saint to whom the chapel was dedicated, on 21 September. Much has been written about how the light impacted these paintings, but until now, no digital simulation of different dates has been performed [30]. Considering the current space, a digital simulation of sunlight incidence has been done with Dialux. This must be considered merely a preliminary proposal because a 3D scanning and later analysis would provide more accurate conclusions. The results can be seen in Figures 1–4. In the morning, *The Martyrdom of Saint Matthew* (1599–1600) is traversed by a spotlight of 10,000 lx, surrounded by a general context of 200–300 lx and peaks of 1000 lx on the upper part. This amount would not be affected by the light coming from the main nave, as some scholars have proposed [30]. This effect would highlight the two main characters of the painting's scene. At this moment, the rest of the chapel would remain at 100 lx (Figures 1 and 2).

The effect is replicated at 2 p.m. on the same day at the other side, where *The Calling of Saint Matthew* (1599–1600) hangs (Figures 3 and 4). Again, the general 100 lx context is traversed by a spotlight of 10,000 lx. It forms a diagonal on the painting which does not correspond with the painting from the window but highlights the contrast in colour. It seems unlikely that the lighting designed by Caravaggio was replicated with natural light, although a similar pattern would appear at winter solstice (i.e., 21 December at 13:30–15:00). These two paintings have a very clear flash of light spanning the composition, in a very personal manner, but the third canvas, *The Inspiration of Saint Matthew* (1599–1602) does not. Its position in the chapel makes it impossible to connect its light with the window, it being usually exposed to a 200 lx average, securely subdued by the altarpiece's front.

All this demonstrates that Caravaggio was not trying to paint the real light coming from the window, but he could use it to emphasize the chiaroscuro effects, something impossible in the third painting due to its exhibition. The general context in which the paintings were placed was usually under 100 lx, which underlined spotlights that were sometimes 100 times brighter.

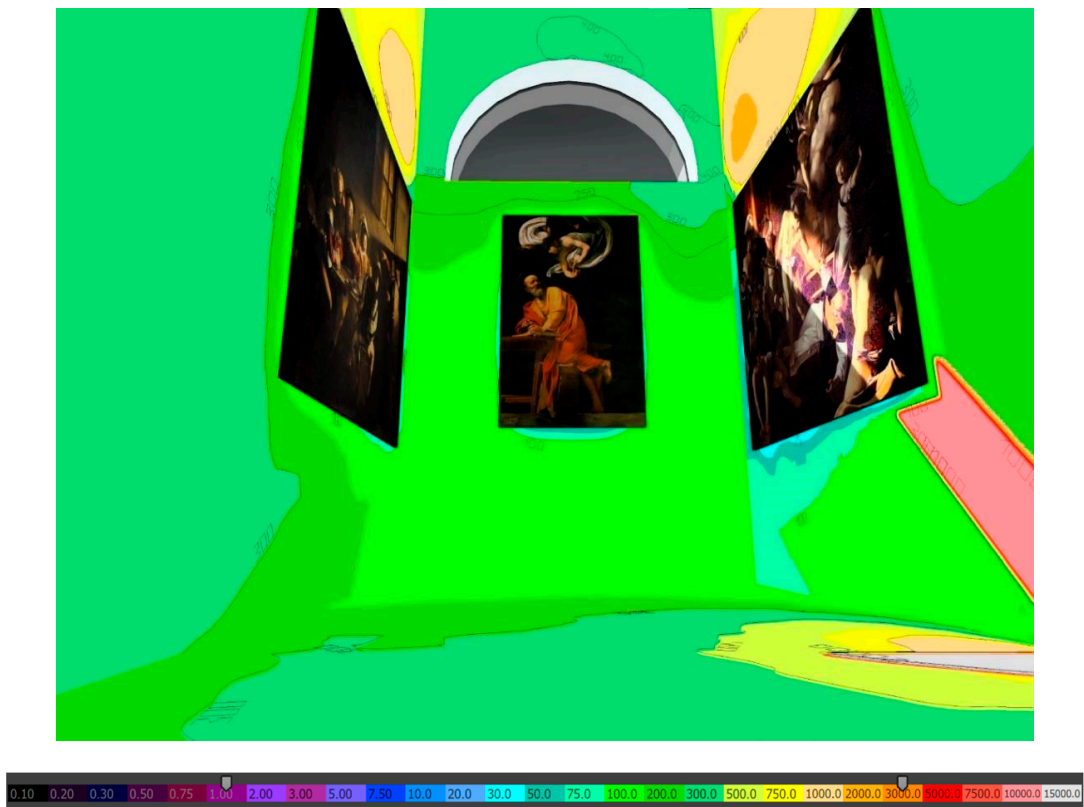


Figure 1. Light analysis of Contarelli Chapel for 21 September, feast of Saint Matthew, at midday, including paintings by Caravaggio. Simulation with Dialux by the author.

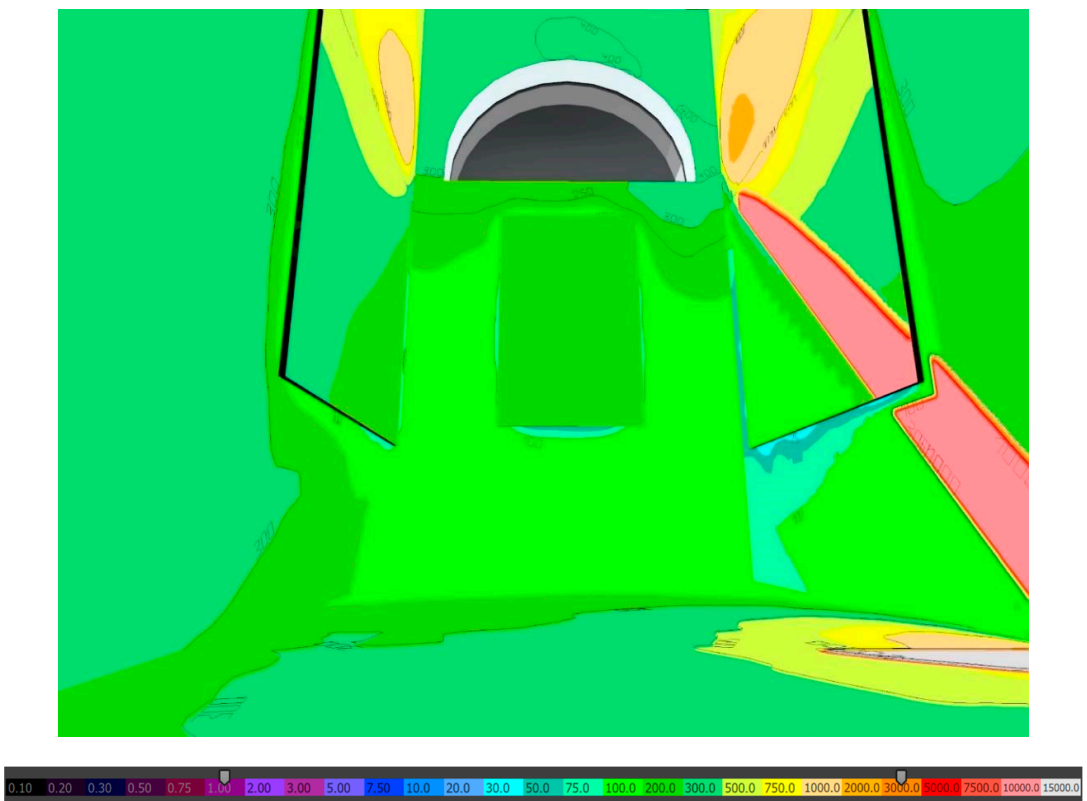


Figure 2. Light analysis of Contarelli Chapel for 21 September, feast of Saint Matthew, at midday, removing paintings by Caravaggio. Simulation with Dialux by the author.

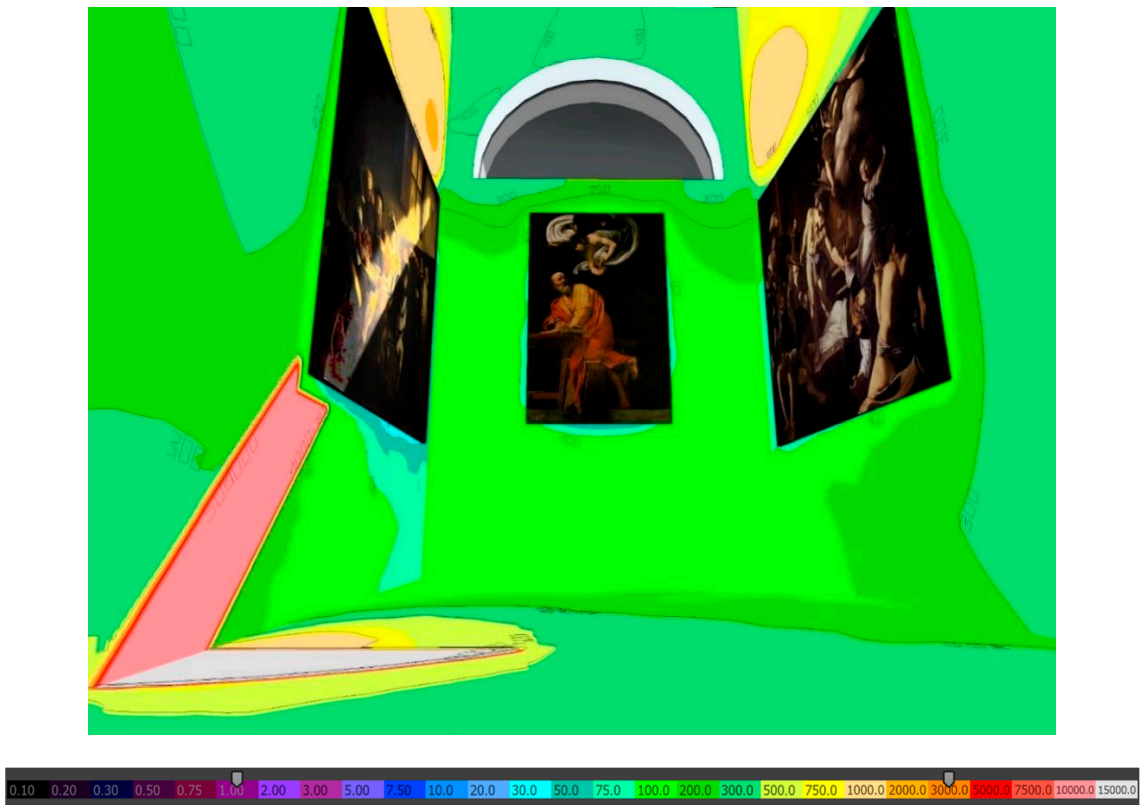


Figure 3. Light analysis of Contarelli Chapel for 21 September, feast of Saint Matthew, at 2 p.m., including paintings by Caravaggio. Simulation with Dialux by the author.

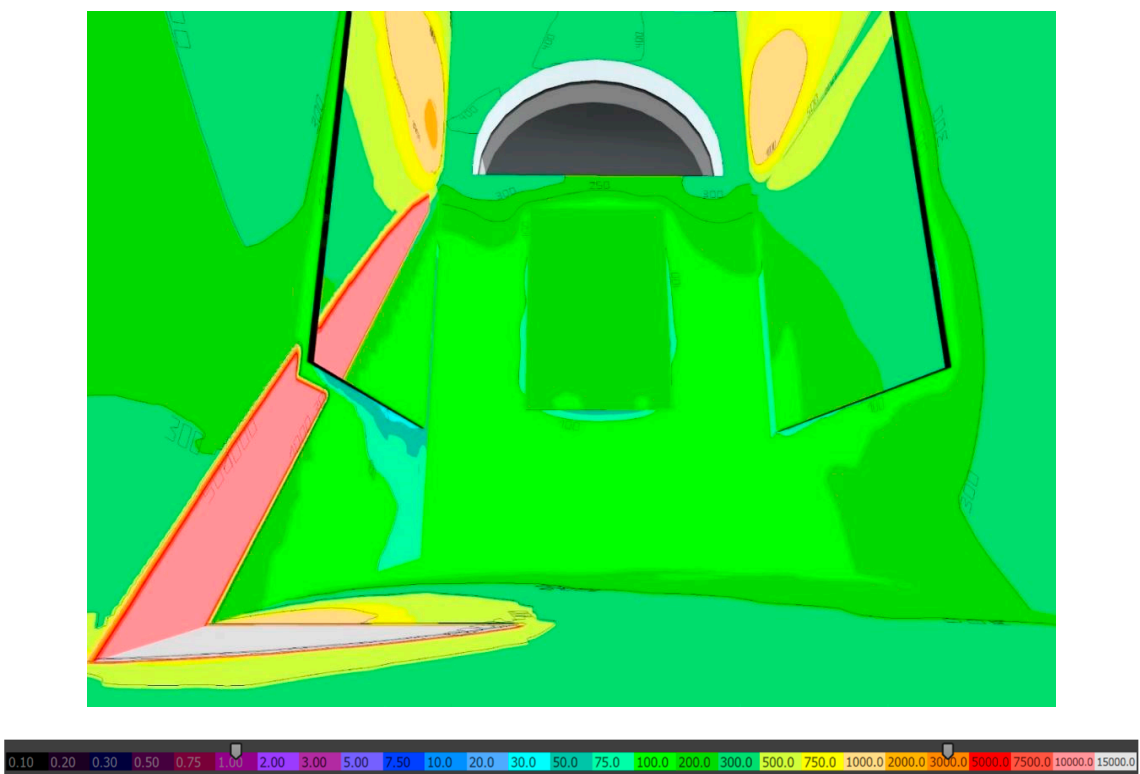


Figure 4. Light analysis of Contarelli Chapel for 21 September, feast of Saint Matthew, at 2 p.m., removing paintings by Caravaggio. Simulation with Dialux by the author.

The worship space can be considered a different atmosphere when compared with courtly intentions. For this reason, although these sorts of locations have not been analysed with regard to illuminance until recently, a preliminary simulation has been made for this study on the Alcazar of Madrid. This medieval building, which was continually renovated until the beginning of the eighteenth century and then, destroyed by the fire in 1734, hosted one of the most noteworthy painting collections of the time [31,32]. Displayed in the usual manner of a continuous panel full of pieces, interior light was low, as contemporary paintings such as that of Diego Velázquez's *Las Meninas* shows. A digital simulation, considering every window open, shows that the walls of these rooms facing the south façade were around 100 lx at the summer equinox at 12:00, and 300 lx at the vernal equinox at midday. Inner dependencies were even darker, which probably impacted the visual effect of the paintings on visitors. In these courtly palaces, the spotlight effects described for the Caravaggio example seem unlikely, mainly because of their display.

Previous examples show that *baroque lighting* incorporated a drastic contrast in natural lighting with clear expressive intentions. It was probably not trying to copy natural light's behaviour but instead to make the exhibited scene seem more realistic and boost its visual effects. In a more general sense, the aforementioned 100 lx average was progressively increased to 200–250 lx, apart from the described spotlights. This can be found both in Spain's European territories as well as those overseas.

This increasing tendency continued in other seventeenth and eighteenth century cases, although here, local deviations have been found [33,34]. While the Iberian foundations, both in the Peninsula, American, or Asian buildings, preferred dark presbyteries with brighter naves, Italian edifices opted for more homogeneous interiors wherein the natural light effects connected to the liturgical calendar were more common [35–37]. In the Iberian examples, naves during the seventeenth and early eighteenth centuries averaged around 60 lx, while the main altar remained at ca. 30 lx, e.g., in San Jacinto (Seville) [35]. Once the Italian and the Spanish cases are considered, it is important to note that this same plan was somehow transferred to American and Asian buildings in the Philippines. Meaningful examples can be found throughout the eighteenth century. For instance, the Guadalupe Basilica in Mexico City, built between 1695 and 1709, shows an average of 200–250 lx in the entire building at midday during the summer solstice [37]. Second, the church of San Juan de Dios in Manila puts out an average of around 100 lx at 9:00 a.m. on 22 December [36]. Third, the Cathedral of Manila, built between 1751 and 1761, provides an average of 200 lx in the nave [36]. More interesting is the long development of works in the Cathedral of Cadiz. Started in 1722, it was finally finished after several modifications in 1838. The first plan clearly marks a novel way of dealing with light, with an average of 500–1000 lx at the main nave, reaching 2500 lx at the presbytery. During the works, windows were an integral part of the discussions. After analysing the final proposal, the nave was illuminated with a more homogenic average of 1000 and 5000 lx at the transept, although illumination decreased at the presbytery reading only 1000 lx. As can be seen in this final example, the situation changed at the end of the eighteenth century, with a preference for a much brighter space. Rococo architecture opted for marble instead of wooden furniture, for gold and white over chiaroscuro, and more sculpted decorations than painted ones. This can be due to the increase in lux beyond 250 lx, which severely damaged previously used materials. Likely, the perils of conservation were empirically known by this time and interior furniture and decoration turned toward more resistant materials.

Until the beginning of the nineteenth century, gas lighting was not used for streets and large buildings. From this time forward, artificial devices broadened the possibilities of sunlight, which was connected to the calendar. Progressively, artworks would be illuminated by a constant light source, probably changing the artists' approach.

3. Results: An Initial Approach to Light in Historical Interiors

The above presented examples provide clear results but are, at the same time, too few to provide a solid perspective on how light was used in southern Europe and some overseas examples for such a long chronological period. Only a broader analysis can support these preliminary results properly.

Even so, these materials show that museum lighting has not paid attention to the original illuminative context of the artworks and thus, might be displaying pieces inaccurately. Even when perceptive issues have been proposed, the artist's intention is marginalised in favour of modern taste. This can now be revisited thanks to studies on historical lighting from digital simulation. These works show that a progressive change of function and average levels of light can be found in the history of architecture from ancient to early modern times. In addition to this increase, it is important to note that all these buildings were designed with a clear interior plan in mind. Entering the space from one access point and leaving through another provides a different feeling compared with the opposite route. Finally, some eras preferred to use sunlight as a spotlight, producing an extraordinary effect (Table 1). As a result, it seems obvious that including the original context, if known, is required to provide an accurate display in a museum setting. Nevertheless, its ultimate application offers a range of perils that might be discussed.

Table 1. Preliminary results for general light context in worship and courtly spaces according to styles found in Mediterranean territories and overseas buildings.

Period	General Lux Average	Spotlights
Ancient period	12 (only artificial)	No
Byzantine/Romanesque	30 lx	Yes
Gothic	<70 lx	No
Renaissance	<100 lx	No
Baroque	100–250 lx	Yes (worship space) No (courtly space)
Late eighteenth century	1000 lx	No

4. Discussion

Reconstructing historical light in a museum display would require taking several steps. First, when pieces are organised chronologically, it would be reasonable to change the general lux depending on the period. Although this is technically possible and meets conservation requirements, it is probably not comfortable for the viewing public and may not even be accessible for people with disabilities. Something similar occurs with CCT, which might be increased both from historical and perceptive perspectives but would negatively affect conservation. Although sunlight should be the historical reference in most cases, it is not a suitable solution for modern museums due to its optical radiation. Even so, some of its unique features can be simulated with new equipment. The colour temperature of sunlight goes from 3500 K at sunrise/sunset to 9000 K in a blue sky. In any event, these levels are higher than recommended for accurate conservation, but many efforts have been made recently to increase these levels without increasing damage to the artefact. Something similar can be said about optical radiance. In contrast to providing a general illumination, every piece might be treated differently. From a darker background, early modern paintings can be more dramatically lighted, according to studies, when possible. Again, this is technically possible and should not affect public comfort, but in some cases, these efforts could damage the pieces, which must be avoided. Exposing some parts of the canvas to 300 lx or higher might affect them, so it must be adapted using the capabilities of new equipment.

If preservation issues might be affected by this proposal, perception must also be taken into consideration. In recent years, several scholars have developed empirical studies on how fine art is perceived by users under different lighting circumstances [15,16,38,39]. Their conclusions are clear, but these studies were made without the energy of a museum visit or even the piece's historical function. Thus, museum itinerancy might be discussed in this context. Designing an unencumbered visit, wherein the user decides the order of rooms he or she visits might produce an incorrect effect if light is displayed to imitate the historical reality. As it happens in any building, light is perceived relatively, as increasing or decreasing, rather than at the level of lux. For this reason, entering a room with 70 lx for Gothic pieces would be considered darker if coming from a brighter space, which is probably not the ideal

way of explaining light use in this period. Therefore, providing a scientifically designed light space in museums affects the freedom of visitors to plan their own experience.

A final option would be making these light exposures temporal, as originally designed. This can be used as an attraction to the public, but at the same time, might destabilise visit flows. In favour of this action, it must be said that *delight* is an increasing issue in tourism studies. Providing a changing context that promotes exceptional experiences attracts the public. This can be achieved sustainably, because no energy is required, and the historical explanation of the building and the pieces are more accurately depicted.

These results do not only affect museum display of artworks but also how churches and palaces are artificially illuminated today [40]. Until recently, conservation concerns and personal taste have been typical starting points for both fields. Now, restoring the original sunlight organisation of buildings should be considered an essential part of its architecture and the correct environment for its heritage. Even when contemporary lighting can provide solutions to modern requirements in terms of accessibility or liturgical preferences, the original atmosphere must be present in some form.

5. Conclusions

In sum, it can be said that artworks from ancient to early modern times were designed for a specific space, defined by light. This context can be considered crucial for their design and thus, it is critical for their current perception and understanding, even if one does not even attempt to replicate their illuminative context. Light in the museum and original buildings should not be a question of personal and contemporary taste but instead the result of scientific studies, both general and specific for each piece. As a result, lighting must be taken into consideration as part of a culturally sustainable display in a museum to improve the artworks' perception and understanding by the public, in a correct balance with other issues such as perception, conservation, and accessibility. Only then will the equilibrium of the cultural category be achieved and through it the desired sustainable proposal by museums.

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References

1. Pop, I.L.; Borca, A. Factors Influencing Museum Sustainability and Indicators for Museum Sustainability Measurement. *Sustainability* **2016**, *8*, 101. [\[CrossRef\]](#)
2. Stylianou-Lambert, T.; Boukas, N.; Christodoulou-Yerali, M. Museums and cultural sustainability: Stakeholders, forces, and cultural policies. *Int. J. Cult. Policy* **2014**, *20*, 566–587. [\[CrossRef\]](#)
3. Harrison, L.S. *Report on the Deteriorating Effects of Modern Light Sources*; Metropolitan Museum of Art: New York, NY, USA, 1954.
4. Cuttle, C. Lighting works of art for exhibition and conservation. *Lighting Res. Technol.* **1988**, *20*, 43–53. [\[CrossRef\]](#)
5. Cuttle, C. Damage to museum objects due to light exposure. *Lighting Res. Technol.* **1996**, *28*, 1–9. [\[CrossRef\]](#)
6. Cuttle, C. A Proposal to Reduce the Exposure to Light of Museum Objects Without Reducing Illuminance or the Level of Visual Satisfaction of Museum Visitors. *J. Am. Inst. Conserv.* **2000**, *39*, 229–244. [\[CrossRef\]](#)
7. Druzik, J.; Eshoj, B. Museum lighting: Its past and future development. In *Museum Microclimates*; Padfield, T., Borchersen, K., Eds.; National Museum of Denmark: Copenhagen, Denmark, 2007; pp. 51–56.
8. Piccablotto, G.; Aghemo, C.; Pellegrino, A.; Iacomussi, P.; Radis, M. Study on Conservation Aspects Using LED Technology for Museum Lighting. *Energy Procedia* **2015**, *78*, 1347–1352. [\[CrossRef\]](#)
9. Tuzikas, A.; Žukauskas, A.; Vaicekauskas, R.; Petrulis, A.; Vitta, P.; Shur, M. Artwork visualization using a solid-state lighting engine with controlled photochemical safety. *Opt. Express* **2014**, *22*, 16802–16818. [\[CrossRef\]](#)
10. Vázquez, D.; Fernández-Balbuena, A.; Canabal, H.; Muro, C.; Durmus, D.; Davis, W.; Benítez, A.; Mayorga, S. Energy optimization of a light projection system for buildings that virtually restores artworks. *Digit. Appl. Archaeol. Cult. Herit.* **2020**, *16*, e00128. [\[CrossRef\]](#)

11. Durmus, D.; Abdalla, D.; Duis, A.; Davis, W. Spectral optimization to minimize light absorbed by artwork. *Leukos* **2020**, *16*, 45–54. [[CrossRef](#)]
12. Balocco, C.; Volante, G. Lighting Design for Energy Sustainability, Information, and Perception. A museum Environment as a Case Study. *Sustainability* **2018**, *10*, 1671. [[CrossRef](#)]
13. Di Pietro, L.; Guglielmetti Mugin, R.; Renzi, M.F.; Toni, M. An Audience-Centric Approach for Museums Sustainability. *Sustainability* **2014**, *6*, 5745–5762. [[CrossRef](#)]
14. Scuello, M.; Abramov, I.; Gordon, J.; Weintraub, S. Museum lighting: Optimizing the Illuminant. *Color. Res. Appl.* **2004**, *29*, 121–127. [[CrossRef](#)]
15. Pinto, P.D.; Linhares, J.M.; Carvalhal, J.A.; Nascimento, S.M. Psychophysical estimation of the best illumination for appreciation of Renaissance paintings. *Vis. Neurosci.* **2006**, *23*, 669–674. [[CrossRef](#)] [[PubMed](#)]
16. Pinto, P.D.; Linhares, J.M.M.; Nascimento, S.M.C. Correlated color temperature preferred by observers for illumination of artistic paintings. *J. Opt. Soc. Am. A Opt. Image Sci. Vis.* **2008**, *25*, 623–630. [[CrossRef](#)] [[PubMed](#)]
17. Feltrin, F.; Leccese, F.; Hanselaer, P.; Smet, K.A.G. Impact of Illumination Correlated Color Temperature, Background Lightness, and Painting Color Content on Color Appearance and Appreciation of Paintings. *J. Illum. Eng. Soc.* **2020**, *16*, 25–44. [[CrossRef](#)]
18. Schielke, T. Interpreting Art with Light: Museum Lighting between Objectivity and Hyperrealism. *J. Illum. Eng. Soc.* **2020**, *16*, 7–24. [[CrossRef](#)]
19. Papadopoulos, C.; Moyes, H. *The Oxford Handbook of Light in Archaeology*; Oxford University Press: Oxford, UK, 2017.
20. Houser, K.W.; Tiller, D.K.; Pasini, I.C. Toward the accuracy of lighting simulations in physically based computer graphics software. *J. Illum. Eng. Soc.* **1999**, *28*, 117–129. [[CrossRef](#)]
21. Maamari, F.; Fontoynt, M. Analytical tests for investigating the accuracy of lighting programs. *Lighting Res. Technol.* **2003**, *35*, 225–239. [[CrossRef](#)]
22. Arnheim, R. *Art and Visual Perception: A Psychology of the Creative Eye*; University of California Press: Berkeley/Los Angeles, CA, USA, 1974.
23. Doulos, L.; Moullou, T.; Topalis, F.V. Lux in vitro: Artificial lighting conditions in houses of antiquity. In Proceedings of the EX ORIENTE LUX, IV. International Congress of International Lychnological Association, Ptuj, Slovenia, 15–19 May 2012; ILA: Ptuj, Slovenia, 2012.
24. Potamianos, I. *Light into Architecture: Evocative Aspects of Natural Light as Related to Liturgy in Byzantine Churches*; University of Michigan: Ann Arbor, MI, USA, 1996.
25. Nesbitt, C. Shaping the sacred: Light and the experience of worship in middle Byzantine churches. *Byz. Mod. Greek Stud.* **2012**, *36*, 139–160. [[CrossRef](#)]
26. Díez-Pastor Iribas, C.; Arroba Fernández, M.; Alañón Olmedo, P.; Grau Enguix, J.; García, J. Light as a Symbolic Definer of Spaces in Romanesque Architecture. In *Licht-Konzepte in der Vormodernen Architektur*; Schneider, P.I., Wulf-Rheidt, U., Eds.; Schnell & Stiner: Regensburg, Germany, 2011; pp. 305–322.
27. Medina, J.M.; Rodríguez, A.; Medina, E.; Cassinello, M.J. Factors defining Gothic lighting. Relationship between volume, structure and luminous result in Spanish cathedrals. *Revista de la Construcción* **2017**, *16*, 9–21. [[CrossRef](#)]
28. Martins, A.M.T.; Carlos, J.S. Essence of Daylight in the Cistercian Monastic Church of S. Bento de Cástris, Évora, Portugal. In Proceedings of the IOP Conference Series: Materials Science and Engineering, Prague, Czech Republic, 12–16 June 2017; Volume 245, p. 052012.
29. Pericolo, L. *Caravaggio and Pictorial Narrative*; Harvey Miller Publishers: London, UK, 2011.
30. Varriano, J. *Caravaggio: The Art of Realism*; Penn State University Press: University Park, PA, USA, 2010.
31. Barbeito, J.M. *El Alcázar de Madrid*; COAM: Madrid, Spain, 1992.
32. Checa, F. (Ed.) *El Real Alcázar de Madrid: Dos Siglos de Arquitectura y Coleccionismo en la Corte de los Reyes de España*; Nerea: Madrid, Spain, 1994.
33. Almodovar-Melendo, J.-M.; Cabeza-Lainez, J.-M.; Rodriguez-Cunill, I. Lighting Features in Historical Buildings: Scientific Analysis of the Church of Saint Louis of the Frenchmen in Sevilla. *Sustainability* **2018**, *10*, 3352. [[CrossRef](#)]
34. Panahiazar, S.; Matkan, M. Qualitative and quantitative analysis of natural light in the dome of San Lorenzo, Turin. *Front. Archit. Res.* **2018**, *7*, 25–36. [[CrossRef](#)]
35. Luengo, P.; Luengo, J. Fotogrametría y análisis lumínico. Interacciones en el estudio de la arquitectura barroca. *Artnodes* **2019**, *23*, 62–71. [[CrossRef](#)]

36. Luengo, P. Divine Shine. Light in Eighteenth Century Religious Architecture: Spain, Mexico and the Philippines. Available online: <https://www.chnt.at/wp-content/uploads/Divine-Shine.pdf> (accessed on 20 October 2020).
37. Luengo, P. Consideraciones iniciales sobre la gestión de la luz natural en la arquitectura del siglo XVIII. In *Vestir la Arquitectura*; Payo Hernanz, R.J., Martín Martínez de Simón, E., Matesanz del Barrio, J., Zaparaín Yáñez, M.J., Eds.; CEHA: Burgos, Spain, 2019; pp. 585–590.
38. Hårleman, M. *Daylight Influence on Colour Design: Empirical Study on Perceived Colour and Colour Experience Indoors*; KTH: Stockholm, Sweden, 2007.
39. Pelowski, M.; Graser, A.; Specker, E.; Forster, M.; Von Hinüber, J.; Leder, H. Does Gallery Lighting Really Have an Impact on Appreciation of Art? An Ecologically Valid Study of Lighting Changes and the Assessment and Emotional Experience with Representational and Abstract Paintings. *Front Psychol.* **2019**, *10*, 2148. [[CrossRef](#)]
40. Rodríguez Lorite, M.A. *Iluminación de Iglesias. Una Aproximación Metodológica*; Intervento Red SL: Madrid, Spain, 2016.

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