High Dynamic Range—A Gateway for Predictive Ancient Lighting

ALEXANDRINO GONÇALVES
Research Center for Informatics and Communications of the Polytechnic Institute of Leiria
LUÍS MAGALHÃES
University of Trás-os-Montes and Alto Douro, Institute for Systems and Computer Engineering of Porto
JOÃO MOURA
University of Trás-os-Montes and Alto Douro, Knowledge Engineering and Decision Support Research Center
and
ALAN CHALMERS
The Digital Laboratory, WMG, University of Warwick

In the last few years, the number of projects involving historical reconstruction has increased significantly. Recent technologies have proven a powerful tool for a better understanding of our cultural heritage through which to attain a glimpse of the environments in which our ancestors lived. However, to accomplish such a purpose, these reconstructions should be presented to us as they may really have been perceived by a local inhabitant, according to the illumination and materials used back then and, equally important, the characteristics of the human visual system.

The human visual system has a remarkable ability to adjust itself to almost all everyday scenarios. This is particularly evident in extreme lighting conditions, such as bright light or dark environments. However, a major portion of the visible spectra captured by our visual system cannot be represented in most display devices. High dynamic range imagery is a field of research which is developing techniques to correct such inaccuracies. This new viewing paradigm is perfectly suited for archaeological interpretation, since its high contrast and chromaticity can present us with an enhanced viewing experience, closer to what an inhabitant of that era may have seen.

In this article we present a case study of the reconstruction of a Roman site. We generate high dynamic range images of mosaics and frescoes from one of the most impressive monuments in the ruins of Conimbriga, Portugal, an ancient city of the Roman Empire. To achieve the requisite level of precision, in addition to having a precise geometric 3D model, it is crucial to integrate in the virtual simulation authentic physical data of the light used in the period under consideration. Therefore, in order to create a realistic physical-based environment, we use in our lighting simulations real data obtained from simulated Roman luminaries of that time.

Categories and Subject Descriptors: I.3.3 [**Computer Graphics**]: Picture/Image Generation—*Display algorithms*; I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism—*Virtual reality; color, shading, shadowing and textures*

General Terms: Algorithms, Experimentation, Human Factors

Authors' addresses: A. Gonçalves, Department of Computer Science, Research Center for Informatics and Communications of the Polytechnic Institute of Leiria, Portugal; email: alex@estg.ipleiria.pt; L. Magalhães, J. Moura, Engineering Department, University of Trás-os-Montes and Alto Douro, Portugal; email: {lmagalha, jpmoura}@utad.pt; A. Chalmers, The Digital Laboratory, WMG, University of Warwick, UK; email: alan.chalmers@warwick.ac.uk.

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1. INTRODUCTION

In these last decades computer systems have been developing in a reliable and consistent way. This evolution is sustained by technological achievements at hardware level and in the optimization of the software that uses such equipment. The impact of this advancement is such that, nowadays, computer systems are a major support of our global society. Yet, this evolution has no counterpart in a particular important area: visualization. Most of today's display devices still use the same color model from the middle of last century. This would not be a problem if that color model could digitally reproduce the whole dynamic range that the Human Visual System (HVS) can see in the visible electromagnetic spectrum (Figure 1). It cannot.

High Dynamic Range (HDR) imagery is a computer graphics field of research that aims to correct such inaccuracies. In order to achieve this goal, new techniques have been developed to produce, store, and visualize images and video that preserve the whole dynamic range capable of being seen by the HVS.

The work presented in this article intends to employ this new viewing paradigm where it has significant potential: in the realm of archaeological interpretation. Our aim is to generate accurate and perceptually valid HDR images of Roman frescoes and mosaics and to visualize them on an HDR display. The focus of our study is the House of the Fountains, in the Conimbriga ruins, Portugal. This was a great Roman residential house whose original construction dates from the beginnings of the first century. It still preserves some of the original magnificent mosaics, frescoes, and fountains (Figures 8, 9, 15, and 16).

2. OVERVIEW

2.1 RGB

The "true color" RGB model has the ability to combine several million colors. Some may think that this enormous quantity is perfectly suited to digitally represent the whole electromagnetic spectrum visible to the HVS. This is not quite true. There is a substantial portion of our possible dynamic range that could never be represented in this color model. Chromaticity diagrams usually illustrate such limitations [Devlin 2004]. Figure 2 presents the Commission Internationale de l'Eclairage (CIE XYZ) chromaticity diagram showing the color scope acquired by the HVS.

In this diagram the perceptible triangle embraces the color gamut visible in most of today's display devices. Therefore, any color outside of that "triangular spectra" needs to be mapped in order to have a representation in the display device's color gamut. This procedure obviously modifies the original color, leading to inaccurate reproductions of real scenes.

The diagram clearly illustrates that the RGB model cannot adequately represent what the HVS is capable of seeing. Thus new means to capture/produce, store, and visualize the entire dynamic range captured by the HVS need to be developed in order to achieve more accurate high-fidelity visualization.

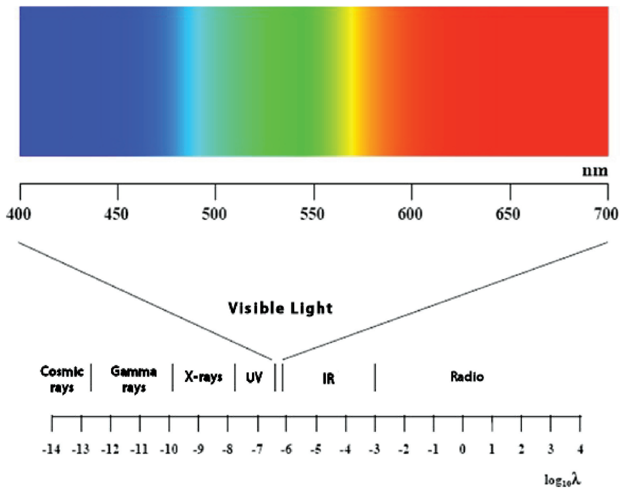

Fig. 1. Electromagnetic spectrum.

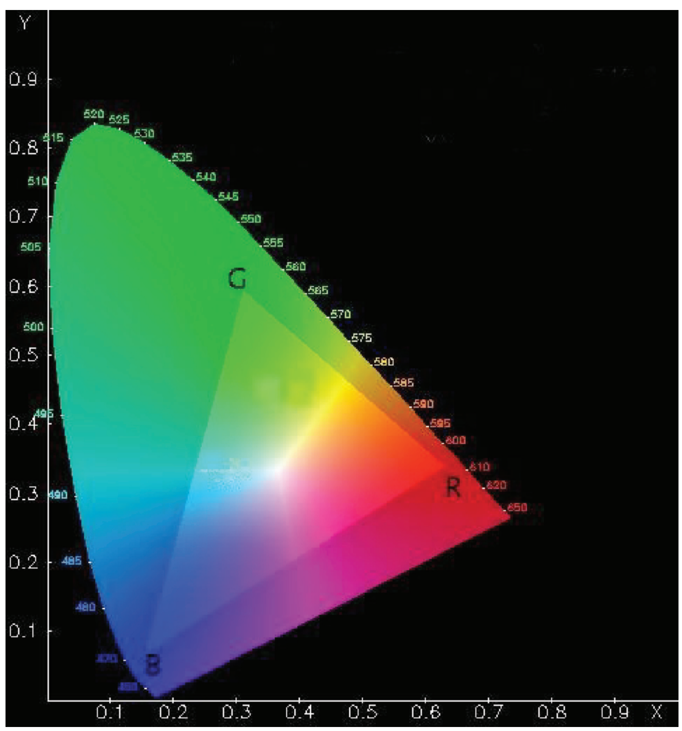

Fig. 2. RGB constraint in a CIE chromaticity diagram [Walter 1996]. Please note that the colors in this diagram are modified due to the limitations of the reading media, namely paper or screen.

2.2 High Dynamic Range

A real scene can hold a tremendous level of contrast and luminance. For example, a sunny day can present values higher than 10^5 cd/m^2 and a starlit night values around 10^{-3} cd/m^2 [Reinhard et al. 2005].

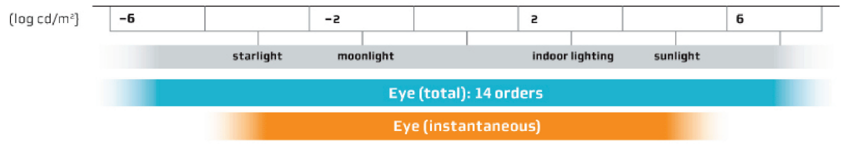

Fig. 3. Dynamic Range acquired by the HVS.

The HVS has the capacity to easily adapt itself to everyday scenarios. Instantaneously, it can capture contrasts of 10000:1 (4 orders of magnitude) and distinguish in a particular frequency about 10000 different colors [Ward 1998a]. With some time to adapt, it can achieve values of 14 orders of magnitude (Figure 3). This occurs because of the receptors present in the human eye. These receptors consist of about 120 million rods and 8 million cones [Blake and Sekuler 1994]. The former are highly sensitive to light but incapable of distinguishing color; the latter, with a different response to wavelengths, are responsible for perceiving color.

It is precisely this relation between these maximum and minimum values that defines dynamic range and it is this enormous range perceived by the HVS that is called *high dynamic range*.

Today's display devices are quite limited with respect to the range of luminance and color that can be presented. For example, a computer display can achieve brightness values up to 600 cd/m^2 and a contrast ratio of 10000:1 and state-of-the-art TV values can go up to 1500 cd/m^2 and 50000:1. Despite the increase of these values in the last few years, these are still far below the high dynamic range captured by the HVS presented in Figure 3. Thus, new ways to create, store, and visualize are needed in order to achieve a visualization experience closer to the one perceived by the HVS. This was the motivation for research into high dynamic range imagery.

The content that we may want to reproduce and visualize can be acquired from real or virtual scenarios. To create an HDR image of a real scene, we need to utilize all the visible information present in that same scene. However, it may not be possible to acquire this from a single photograph of the scene. Instead, this can be accomplished using several photographs of the same scene taken with different exposure times and then combining them in a single HDR image [Debevec and Malik 1997].

The first image (top left in Figure 4) has a short exposure time in order to capture the detail in the bright regions and the third image (top right) was taken under a longer exposure to acquire the detail in the dark parts of the scene. The final result is an image that combines the whole visual information present in all the others (bottom).

To create a synthetic HDR image, the rendering software used needs to simulate the physical process of light propagation (including any present participating media) and its reaction when hitting any kind of surface (reflection, refraction, and absorption). This is called physically-based rendering. Radiance [Ward and Shakespeare 2003] has such ability and is the rendering package used in our work (Section 6). Figure 5 looks like a photograph of a lobby, but in fact it is a rendered (with Radiance) virtual scenario.

In order to store all this new range of values that, as we saw in Figure 2, cannot be stored in the traditional RGB format without loss of information, new file formats have been developed. In Table I we present some features of the most important ones: RGBE [Ward 1991], LogLuv TIFF [Ward 1998b], and OpenEXR [Bogart et al. 2003]. The OpenEXR format is gradually becoming a de facto standard, perhaps due to the fact that this was the HDR file format adopted by the main graphics processor manufactures (nVidia and AMD/ATI).

It is in the field of visualizing HDR images that a lot of work still needs to be done. Brightside Technologies were the first to develop an LCD display that together with modulated back-panel LEDs can be considered an HDR display. This 37" display can present a contrast ratio of around 200000:1

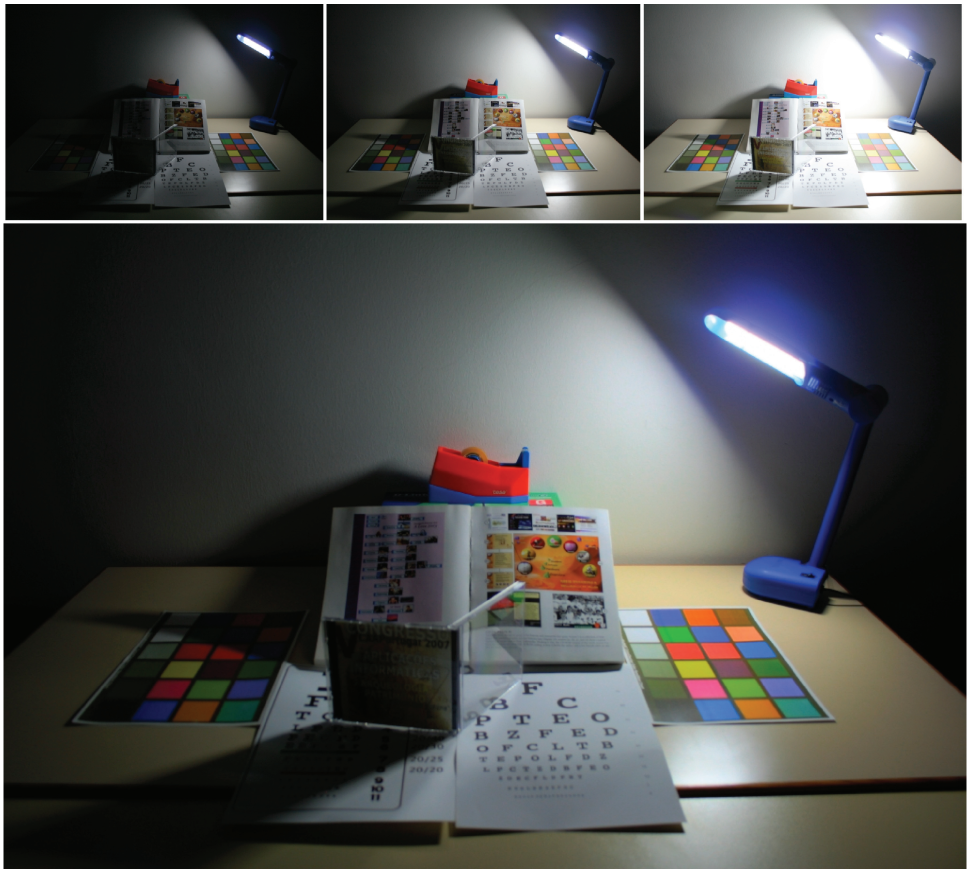

Fig. 4. HDR image obtained from several photographs taken under different exposure times [Urbano et al. 2008].

and brightness values that vary from 0,015 cd/m^2 to 3000 cd/m^2 [Dolby 2009]. In 2007 Brightside Technologies was acquired by Dolby Laboratories, Inc., and it is expected that commercial HDR displays will soon be available.

It is possible, however, to visualize HDR content on a common Low Dynamic Range (LDR) display. To do so, the contents need to go through the process known as tone mapping. Basically, this process maps the out-of-range data present in HDR content into that which can be displayed on the LDR display. Obviously, this tone-mapped version may be missing valuable visual information compared with the original HDR image.

3. RELATED WORK

In the last few years, the number of projects involving historical reconstruction has increased significantly (see Figure 6). Two main factors are responsible for this: the technological developments that allow such reconstructions to be accomplished more easily, with a larger impact, affecting a greater number of people, and the continuous and increasing interest in questions related to our cultural and architectural past. Several of these projects produced photorealistic views of reconstructed historical settings, but few attempts have been made to ensure that they are perceptually valid and thus a faithful simulation of how a given scene may have been seen in the past.

Fig. 5. Image rendered with Radiance [Radforum 2009].

Table I. HDR File Formats

Format	Bits/pixel	Dynamic Range	Luminance Steps
RGB	24	1.6	Variable
RGBE	32	76	1%
LogLuv	32	38	0.3%
OpenEXR	48	10.7	0.1%

To date there are very few projects involving archaeological reconstruction that attempt to physically reproduce how that historical setting might have been perceived in the period under consideration [Chalmers et al. 2000; Devlin and Chalmers 2001; Devlin et al. 2002; Chalmers 2002; Roussos and Chalmers 2003; Sundstedt et al. 2004; Bridault-Louchez et al. 2006] and less that utilize HDR imagery [Zányi et al. 2007] since access to HDR display technology, as described in the previous section, is quite recent.

4. CASE STUDY

4.1 Conimbriga

In 1899, Queen D. Amélia gave orders to initiate the archaeological excavations in Conimbriga (Portugal), but it was after 1930 that these excavations were complemented and deepened, in such way that they show undeniable vestiges of a city constructed by the Roman civilization [Gonçalves and Mendes 2003]. The amount and quality of the archaeological findings presented an architectural and cultural capital of such order that the site was designated a national monument and opened to the general public.

The archaeological evidence tells us that Conimbriga was inhabited, at least, between the IX century B.C. and VII–VIII A.D (Figure 7).

Fig. 6. Images of the virtual reconstruction of an ancient Egyptian temple (Kalabsha) [Sundstedt et al. 2004]. Virtual vs. real scenario (left). Some Egyptian hieroglyphics digitally reconstructed (right).

Fig. 7. Graphical representation of Conimbriga [Correia 2004].

When the Romans arrived in the second half of the I century B.C., Conimbriga was a flourishing village. Thanks to the peace established in Lusitania, a quick romanization of the indigenous population took place and Conimbriga became a prosperous town. Following the deep political and administrative crisis of the Empire, Conimbriga suffered the consequences of barbaric invasions. In 465 and in 468 Suabii captured and partially plundered the town, abandoned by part of its population [Conimbriga 2009].

4.2 House of the Fountains

The House of the Fountains is one the most impressive monuments in the ruins of Conimbriga. The fact that this was the house of a high-status personality in the city makes the entire architectonic ambiance, along with its numerous detailed mosaics and fountains in the inner garden, quite magnificent. The name given to this house comes precisely from those fountains that (in addition to their sophisticated and impressive look) were also used for climate control over the house [Correia 2003].

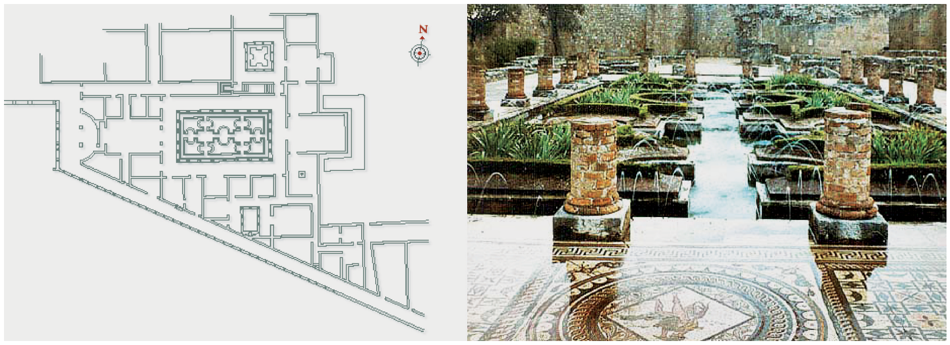

Fig. 8. A blueprint of The House of the Fountains, Conimbriga, (left) and the actual inner garden where we can distinguish some preserved mosaics and dozens of fountains that still work today (right).

Fig. 9. Some mosaics in the House of the Fountains, Conimbriga. On the left we can see a representation of the "Labyrinth of Crete, the myth of the Minotaur."

Today it is still possible to admire some of their fully intact mosaics (Figures 8, 9, and 16). They adorn the floors and were predominant in the recreation of heroic myths and hunting scenes.

Sala da Caçada. The "Sala da Caçada" (hunting room), named after the hunting scene portrayed in the floor mosaic (Figure 16), was located in the southeast of the house and is one of the rooms that has a huge fully intact mosaic. Besides this, we can also perceive the base and the lower section of the fuste of the columns. One of the reasons why this particular room was chosen as the case study of our work was due to the fact that it is the only room in the whole of the Conimbriga ruins that still has some walls with distinguishable remains of the frescoes that originally embellished them (Figures 10 and 15).

The original frescoes of this room, which were considered truly creative [Pedroso 1992], were located between the columns and enclosed a certain particularity. They were aligned establishing a corresponding sequence between some of them (Figure 11).

4.3 Roman Illumination

Up to the 18th century only two types of illumination were used by man: natural light (sun, moonlight) and a more artificial one using fire/flame (hearths, lamps, candles, torches, etc.) [Bridault-Louchez et al. 2006; Devlin et al. 2002; Forbes 1966]. Roman residential houses typically didn't have windows [Forbes 1966]. Consequently, to illuminate the inner chambers they used mostly candles and lamps.

Despite the existence of documentation that states that Romans used torches affixed to the walls to light a room, after a certain period this type of illumination become more unusual. One possible reason arises from the fact that such an illumination method was responsible for many house fires [Forbes 1966]. Thus to light a house, the Romans used mostly lamps or candles, since they were more stable,

Fig. 10. A view of "Sala da Caçada" today. We can perceive a portion of the fully intact mosaic and vestiges of some frescoes over the walls.

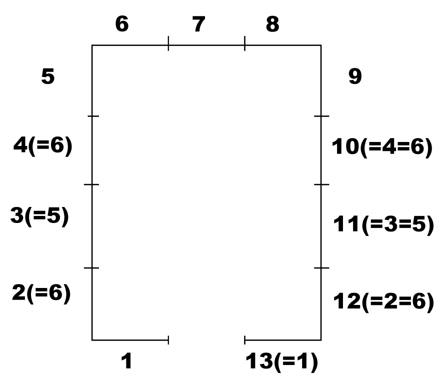

Fig. 11. The frescoes, corresponding sequence in "Sala da Caçada."

movable, and easy to manipulate. This fact is clearly confirmed in our case study (Conimbriga) where dozens of oil lamps were discovered during the several excavation periods (Figure 12).

It is believed that the Romans imported the use of oil lamps (lucerna) from the Greek civilization [Forbes 1966] given that there are only traces of them from the III century B.C. These lamps were manufactured mainly in clay or bronze and had a special spout for the wick (Figure 12).

The lucerna were positioned directly over the floor or in candlestick holders. Some could hold several lucerna, while others were just for one (Figure 13).

An important factor in this illumination method, and therefore with direct implication to the results of our work, is the fuel used for the lucerna. In addition to its use in the food chain, olive oil was the most common fuel used in the Roman era [Devlin and Chalmers 2001; Forbes 1966]. In fact, evidence shows this was the case throughout the Mediterranean region [Kimpe et al. 2001]. This vegetable fuel produces a better-quality flame when compared to others from animal sources [Forbes 1966] and

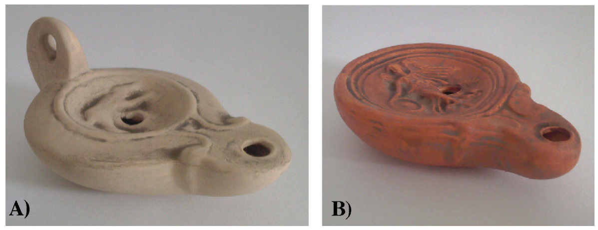

Fig. 12. Replicas of Roman oil lamps discovered in Conimbriga.

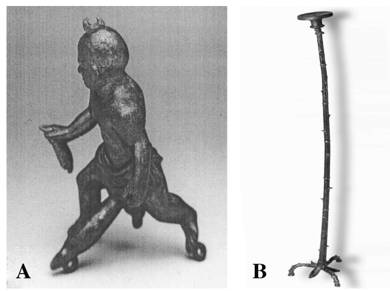

Fig. 13. Roman candlestick holders that support one lucerna (A) and several (B) (© R. Cornadó and Arxiu—Museu Nacional Arqueològic de Tarragona).

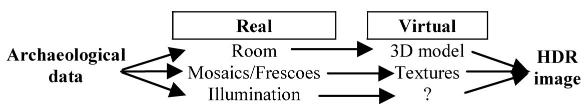

Fig. 14. Working pipeline.

when mixed with salt it produces a more stable and brighter flame [Gonçalves et al. 2008; Devlin and Chalmers 2001; Forbes 1966].

5. WORKING PROCESS

The "Sala da Caçada" is the focus of our work. Here we intend to generate HDR images of a reconstruction of the site using illumination of that period, thus allowing us to have a glimpse of the past and providing us with an enhanced viewing experience closer to how the artefacts may have been perceived by their local inhabitants.

With our goals clearly identified we need to define a methodology to achieve them (Figure 14). From an archaeological background, how do we create an accurate virtual reconstruction of that historical site?

The geometric 3D model of the room was obtained from precise measurements on site and with the collaboration of experts, mainly to reconstruct the upper fraction of the degraded walls and columns, since they are all in ruins and there are no traces of those (upper) walls.

As shown in Figures 10 and 15 the frescoes of the walls are in bad need of conservation. In order to replicate them in our virtual model we need to take great care in the process of creating the textures. Like a puzzle, the images were digitally assembled mostly with real elements extracted from the vestiges of the frescoes and settled with the collaboration of experts (Figure 15).

Fig. 15. One original fresco (left) and its digital reconstruction (right).

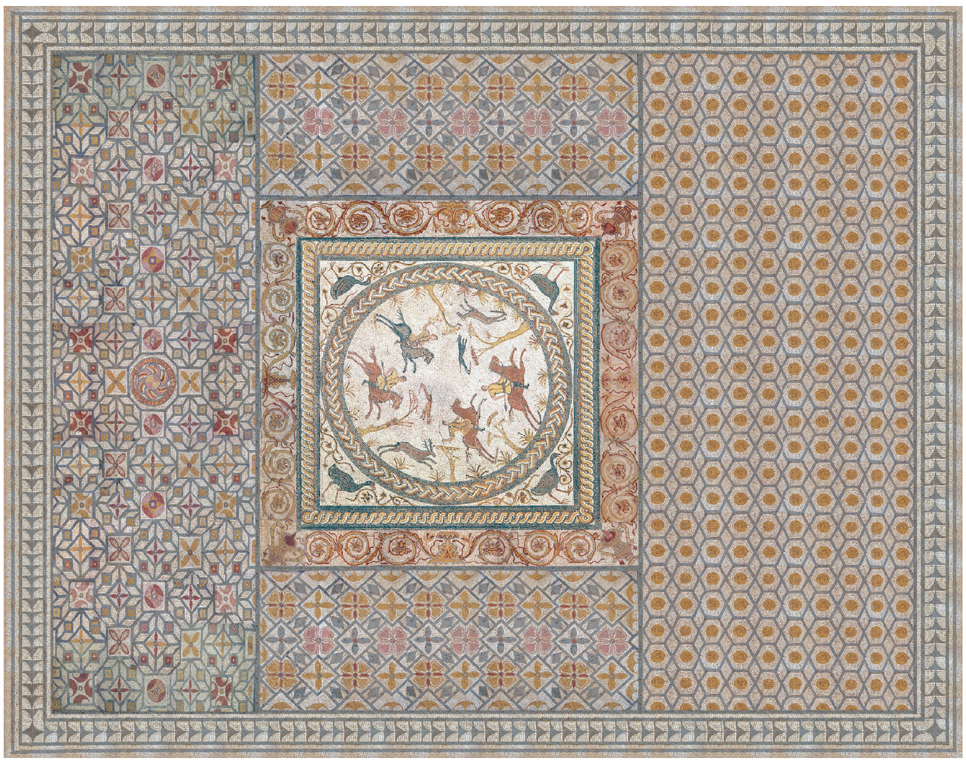

Fig. 16. The full mosaic of “Sala da Caçada” where we can perceive a hunting scene at the center.

One of the relics of this room is the fully intact mosaic floor. Since its dimension did not permit it to be acquired using a single, full high-resolution photograph, several high-quality pictures were taken and then with digital manipulation a texture was created with the whole mosaic (Figure 16).

A crucial element in our working pipeline is the reproduction of Roman illumination. To utilize real illumination data of Roman lamps, in a virtual model, we had to physically rebuild a lucerna in order to acquire the absolute value of their spectral properties and use them in the virtual scenario.

According to our references and the guidance of the experts, mainly the Director of the Monographic Museum of Conimbriga, we very thoroughly gathered all the components to utilize in our reconstructed lamp.

—*Lucerna*. Replicas of discovered lucerna found during the excavations in Conimbriga were kindly offered by the Monographic Museum of Conimbriga (Figure 12);

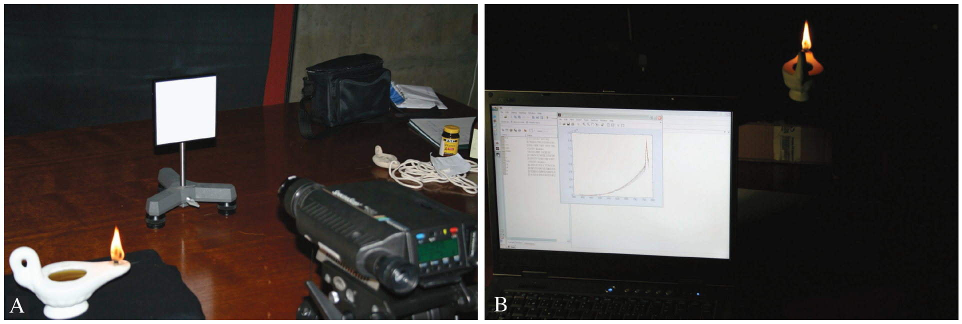

Fig. 17. A) The light emitted by the lamp (left) is almost entirely reflected on the white board (middle), which is then captured by the spectroradiometer (right); B) the spectroradiometer is connected to a laptop which collects the spectral readings.

—*Fuel*. As shown in the previous section, olive oil was the most used fuel for these lamps. For our tests we gathered three samples of pure (without any kind of additives) olive oil from olives from the region of Conimbriga (one of these samples comes precisely from olives of Conimbriga). Two of these samples were manufactured with old traditional methods (not allowed nowadays due to current-day "civilization" standards) in order to get a closer composition to the oil used back then. The remaining sample was made in a modern mill, making it closer to a common commercial olive oil.

—*Salt*. As explained in the last section, salt was usually added to the fuel. To maintain a thorough manner of gathering components more consistent with the ones used in Roman times, clear, pure salt was obtained directly from salt mines in Figueira da Foz (a coastal city in Portugal).

—*Wick*. Cotton and flax wicks of several widths were obtained.

With these components we believe that is possible to light a Roman lamp as close as possible to one of the original ones, and from that extract the spectral properties of the light emitted.

5.1 Lighting Measurements

The flame in a lucerna is produced when the fuel in combustion contacts the atmosphere. This flame has certain spectral properties which induce its color, brightness, shape, etc. (see Figure 17). Now, to achieve our goals we need to replicate these spectral properties in our virtual model. To do so we need to utilize a spectroradiometer to measure the absolute value of the spectral properties of the light radiated from that flame.

To conduct these lighting experiments a very thorough process needs to be prepared in order to acquire valid and accurate values. The final setup of the experiments was performed in the following conditions:

—a fully dark room;

—sealed room so there wouldn't be any drafts that could cause the flame to flicker;

—the burning lamp was placed against a board which was perfectly diffuse and processed a high reflectance factor (the one we used has approximately a 99% reflectance factor);

—measurements were made with all of our olive oil samples and with different configurations (salt and no salt);

—to prevent a misleading single reading, ten readings (with the spectroradiometer) for each configuration were made and an average value was calculated;

—measurements were made in intervals of 4 nm in the visible scope of the electromagnetic spectrum.

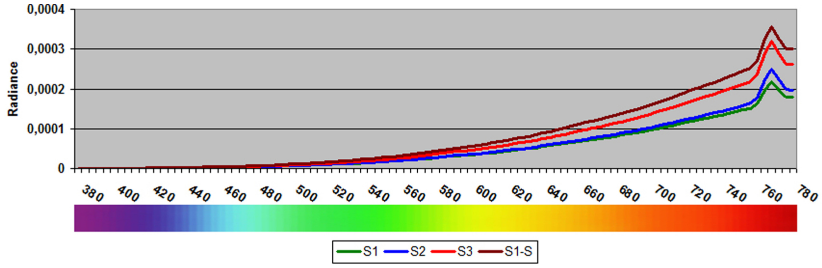

Fig. 18. Chart with the results of the lighting measurements with four different configurations.

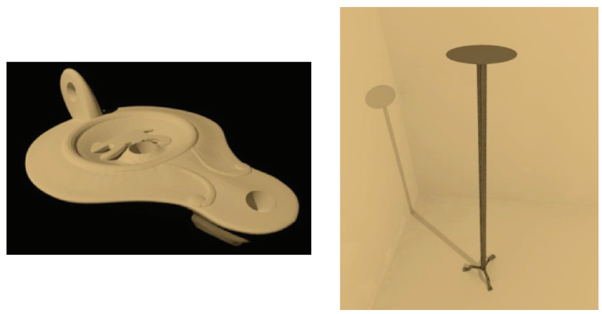

Fig. 19. These 3D models of a lucerna and candlestick used in our virtual scenario are replicas of real Roman artefacts. The lucerna is a copy of Figure 12(A) and the candlestick is, as suggested by the experts, very similar to Figure 13(B) and an exact replica of one from Ministerio de Cultura [1990].

The chart above discloses the results of these experiments (Figure 18). The green and blue lines illustrate the results obtained from the two samples of olive oil manufactured with old traditional methods (S1 and S2), which, as we can see, produce the lower-value results, thus lower light intensity. By contrast, the red line is from the sample closer to a common commercial olive oil since it's the one manufactured in a modern mill (S3). From these results, we can predict that the olive oil (fuel) manufacture procedure has implications in the light intensity produced by an olive oil lamp in a Roman residence or by any other civilization that used the same lighting method. Ancient methods of manufacture produced inferior values of intensity.

In Section 4.4 it was noted that Romans usually added salt to the fuel because it produces a more stable and brighter flame. Our experiment confirms that evidence. The oil for the brown line in the chart (S1-Salt), which produced higher results, was obtained from the first sample (S1), precisely the one that had the lower values. The most amazing fact is that there is a real increase in light intensity of more than 60%. This confirms the documentation evidence and the judgment of the experts.

6. VIRTUAL MODEL

Having a geometric 3D model, the textures, and the light information data, we have all the ingredients to assemble and create final setup of the scene (Figure 19). To achieve the objectives of this work, the software renderer used to generate the HDR images is crucial. The renderer has to be able to not only process a geometrical textured 3D model, but must also have the ability to physically simulate the light propagation and thus produce a viewing experience closer to how the artefacts may have been perceived in the past. Radiance [Ward and Shakespeare 2003], created by Greg Ward, is a state-of-the-art free open-source rendering package [Radiance 2009]. This renowned software is able to produce

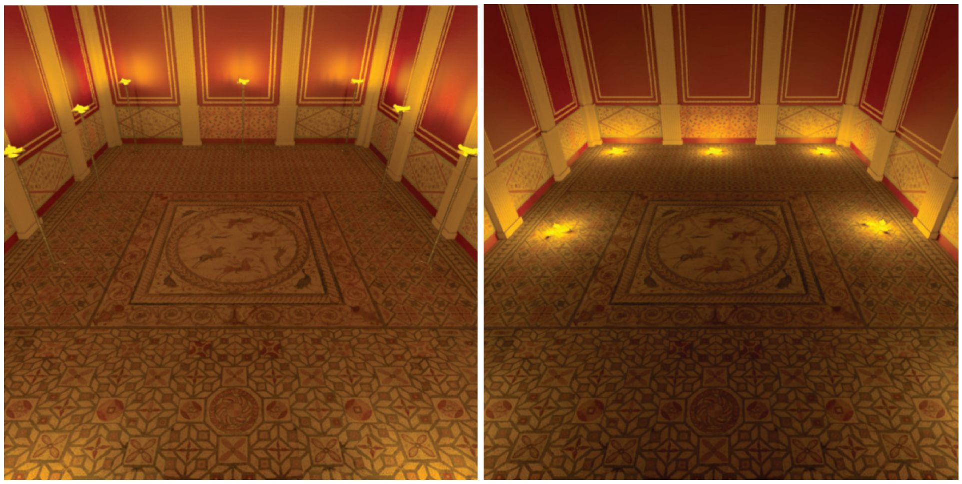

Fig. 20. Room illuminated by Roman lamps (lucerna) using the olive oil sample with salt as fuel.

lighting simulations, even with luminaries of flame combustion that accurately model the law of physics regarding light propagation and interaction with surfaces [McNamara et al. 2000]. Moreover, it produces images in their native file format with enough data to cover the dynamic range captured by the HVS.

All the steps of our working process were very precise and thorough. To accomplish our goals, the final steps had to be executed with the same rigor. Thus, a great deal of care was taken with the final renderings of our models. Some considerations are as follows.

—Due to the impossibility of physically evaluating the surface properties (roughness, specularity, etc.), these values were attained with a close collaboration with the experts, mainly the Director of the Monographic Museum of Conimbriga.

—The images were always rendered with high quality.

—All the images were rendered two or three times larger than the desired resolution and then redimensioned. This would minimize any aliasing, producing images with enhanced quality.

—The renders were made on a computer with a state-of-the-art quad-core Intel processor.

—Even with such sophisticated equipment, since Radiance is based on ray tracing which requires significant computational effort, a first high-quality rendering of an image can typically take several days to compute. Radiance has a feature where, during the rendering, it can simultaneously create an "ambient file" with the illumination calculations that have been generated for a particular rendering. Thus, in the next rendering it is not necessary to recalculate those lighting values. Using this option, the next similar renderings (a change in the observer viewpoint, for example) of a particular virtual scenario can take just a few hours.

Figure 20 presents images of the virtual reconstruction of "Sala da Caçada" from the entrance point of view. On the left the lucerna are placed in candlestick holders positioned around the room as suggested by experts and on the right we have the same scenario and viewpoint but with those same lucerna placed directly on the floor. To light these lucerna we utilize as fuel the olive oil sample 1 with the addition of salt (Figure 18).

Figures 21–24 present several renderings showing different perspectives and today's real versus virtual scenario.

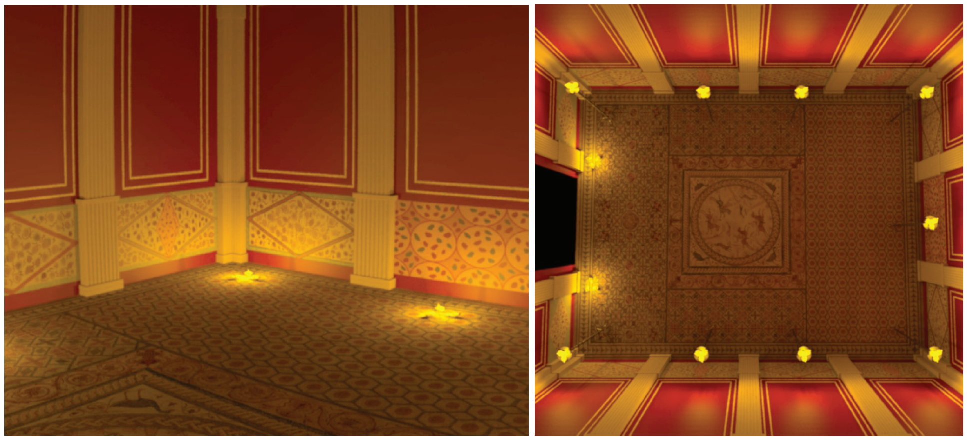

Fig. 21. A virtual representation of "Sala da Caçada" from a similar standpoint as in Figure 10 (left). A top view of the room (right).

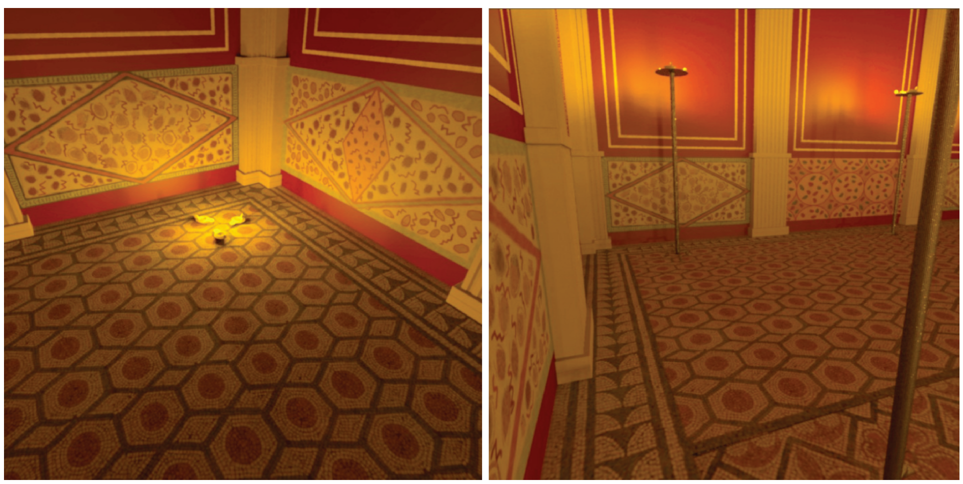

Fig. 22. The frescoes emphasized on the left and an interesting perspective on the right.

In Figure 25 we show the room illuminated by a modern fluorescent electric light of 111W. Comparing this image with the ones from Figure 20, the differences are substantial. The fact that the material surfaces are highly specular are quite emphasized when viewed under Roman illumination. This is not apparent in the electric light version. But the most obvious aspect when comparing these images is the differences in the perception of the artefacts (mosaic and frescoes) in both situations. The Roman light, due to its lower intensity and spectral properties, gives a warmer and cosy ambience to the whole room.

Figure 26 presents two images of the exact same setup of a rendering, and they only differ in the illumination used. Both use as fuel the olive oil sample 1 (Figure 18), but the rendering on the left uses the sample with the addition of salt and the rendering on the right uses the pure sample without any kind of additives. It is clear that the image on the left looks brighter. This occurs because there is a real increase in light intensity when the sample with salt is used, as we saw in Section 5.1.

Fig. 23. Back corner of the room (real vs. virtual).

Fig. 24. Side wall of the room (real vs. virtual).

Please note that all these images are tone-mapped copies from the original HDR images rendered with Radiance. As a consequence and as we saw in Section 2.2, they lose some visual information.

7. CONCLUSION AND FUTURE WORK

The last years have confirmed an increasing concern, mainly by important institutions such as UNESCO and the European Union, with regard to the preservation, interpretation, and spreading of the historical and cultural legacy of our ancestors. This has led to a new wave in computers where the use of technologies, such as virtual reality, has a larger role to play. The use of recent technologies has become a powerful tool to archaeologists for a better understanding of our cultural heritage legacy, to attain a glimpse of the environments in which our ancestors lived. However, to accomplish this, these reconstructions should be presented to us as they may really have been perceived by a local inhabitant of that time, according to the illumination and materials used back then and, equally important, the characteristics of the Human Visual System (HVS).

With these aims in mind, the visualization media of these reconstructions is crucial. The visual acuity of HDR imagery can present us with enhanced viewing experiences, closer to how historical settings may have been perceived in the past, which is not easily achieved by other means.

Fig. 25. “Sala da Caçada” illuminated by a modern fluorescent light.

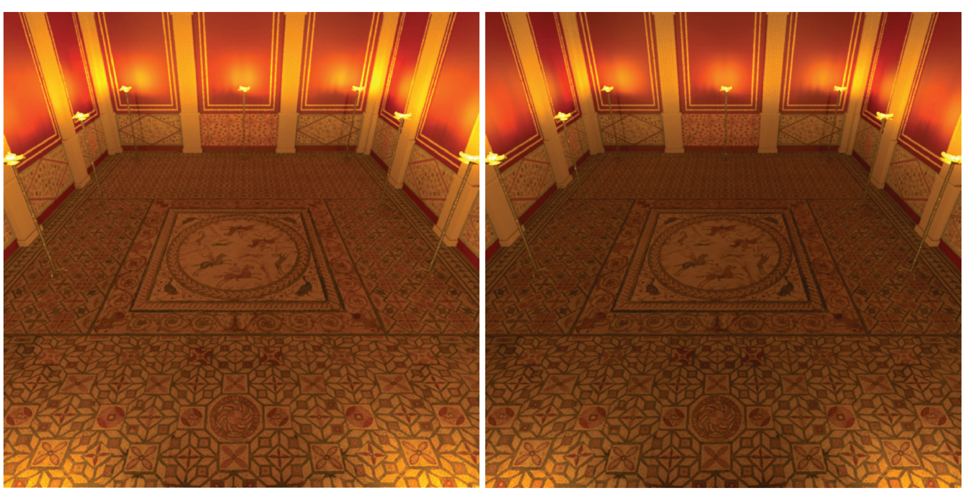

Fig. 26. The room illuminated with the same sample of olive oil: with salt (left) and with no salt (right).

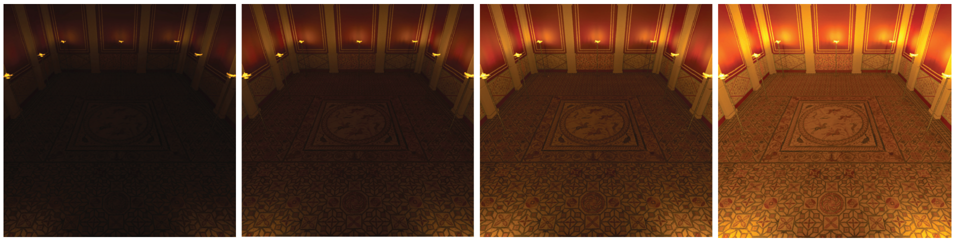

Fig. 27. A first approach of the human visual adaptation in dark environments.

Even though it is not possible to visualize HDR images within this article, it is clear that seeing ancient artefacts using light sources different than the ones used in the period under investigation produces significantly different visual results. The visualization of these artefacts under a Roman lucerna candlelight provides a considerable different way of interpreting that piece of our history. The specular surfaces combined with this lighting method show some subtleness which gives the "Sala da Caçada" in particular a very pleasant feeling, quite different from the rough and almost unnatural scenario perceived with modern electric light.

It is this sort of result that enhances our understanding of the past. This physically-based approach, together with other resources including documented evidence and the opinion of experts, can support several fields of archaeological investigations and promote a deeper knowledge about, in our case, the Roman civilization and way of life.

Another issue stands out regarding the use of HDR in this particular case study. The fact that, generally, Roman residential houses had very few exterior windows and the fact that oil lamps were used, traditionally with low light intensity, means that Romans perceived their frescoes and mosaics in quite dim conditions. This is precisely a matter where HDR features most emerge, since the visual acuity of the HVS in dark environments, even after a few minutes of adaptation [Ledda et al. 2004], cannot be perceived using a traditional low dynamic range display.

As future work, first we intend to improve the rendered images by adding features of how the human eye adapts over time (Figure 27). This will enable us to visualize the environments depending on how long the viewer has been in the environment. Furthermore, we intend to conduct a detailed perceptual user study using the HDR display mentioned in Section 2.2. These tests will focus on determining, in this same display, the perceptual differences between HDR images and their tone-mapped (i.e., their LDR) versions. With these experiments we intend to demonstrate that the loss of visual information which occurs in the tone-mapped image has significant implications in the visualization of ancient artefacts, particularly when viewed under extreme lighting conditions. In this way we will try to establish real benefits of using (true) HDR imagery in a cultural heritage context.

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