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# Optimized visualization of Château de Germolles' wall paintings using mobile augmented reality with co-lighting

Jean-Philippe Farrugia<sup>a,b\*</sup> and Christian Degriigny<sup>c</sup>

<sup>a</sup> IUT Lyon-1, département Informatique, F-01000 Bourg-en-Bresse, France

<sup>b</sup> Université de Lyon, CNRS, université Lyon-1, LIRIS, UMR5205, F-69622 Lyon, France

<sup>c</sup> Haute Ecole Arc Conservation-Restauration, HES-SO Haute Ecole Spécialisée de Suisse Occidentale, 2000 Neuchâtel, Suisse

\* Corresponding author: [jean-philippe.farrugia@univ-lyon1.fr](mailto:jean-philippe.farrugia@univ-lyon1.fr)

Presenting authors: Jean-Philippe Farrugia and Christian Degriigny

## ABSTRACT

This paper presents the design of an augmented reality visualization of the wall paintings (late 14<sup>th</sup> century) of the Château de Germolles. This visualization is done through a mobile application, does not require any external equipment, and considers the co-lighting: the decor can thus be visualized under several virtual ambient lightings, simulating different seasons, weather conditions and two times of the day as well as candle lighting. We present the methods and models that have enabled these simulations, as well as their results and limitations. We also briefly discuss the limitation of an approach based solely on physical plausibility in relation to the objective of a visit speech.

**Keywords:** *Château de Germolles, mural decorations, augmented reality, appearance rendering, co-lighting*

## INTRODUCTION

The Château de Germolles, offered to Margaret of Flanders by her husband Philip the Bold, Duke of Burgundy and brother of King Charles V of France, is both the best-preserved residence of these Valois princes, and the one that still displays unique wall paintings from the end of the 14<sup>th</sup> century. Rediscovered during World War II, they were partially conserved between 1989 and 1994. This intervention, although quite respectful, was not documented at the time. Thanks to archival documents and the in-depth analysis of the residual decorations (Degriigny et al. (2017)), the materials used and the painting technique could be better understood, especially for the metal decorations, which residues were partly masked during the conservation intervention. A partial de-restoration would make it possible to better visualize them, without however appreciably improving the global rendering.

In discovering these painted decorations, the public visiting the Château de Germolles is far from imagining the delicacy of the original rendering, despite the information transmitted. Therefore, the possibilities of augmented reality have been tested, based on newly acquired scientific knowledge, in order to propose hypotheses of rendering, evaluated by the site's managers, who are also heritage professionals, and then readjusted (geometry, colour and luminosity) for better conformity. The developed application is adapted to the private nature of the site: it uses a light and nomadic support (tablet), is non-intrusive (no visible markers or locating devices) and easy to use. It is, moreover, entirely controlled by the person guiding the visitors: it is indeed an accompaniment to the speech (Degriigny et al. (2020)).

In order to be convincing, an augmented reality application must solve three problems: co-location, which is necessary to align real and virtual elements, co-occultation, which allows the virtual elements to be masked by the real ones (and vice versa), and co-lighting, which allows luminous interactions between virtual and real. In the framework of this project, the co-location is managed by environmental geometric markers materialized by the decor itself, and the co-occultation is not considered insofar as the virtual elements to be inserted are plane and directly visible without occultation. On the other hand, co-lighting required more advanced treatments which are the subject of this article.

In order to restore the original decor, it is necessary to enhance it with adequate models of materials and lighting. Three difficulties have to be reconciled: the limited computational capacities of the tablets, the complex models to obtain a satisfactory physical realism, and the adequacy with the visual expectations of those responsible for the monument. To satisfy these constraints, we have opted for the following solutions:

- A material model widely used in the industry, light and easily parameterizable while being physically plausible.
- An ambient lighting modelled with high dynamic range (HDR) environment maps.
- A daytime local lighting modelled by an area light source, approximated by a set of point sources obtained with importance sampling.
- A local night lighting modelled by animating the photometric solid of a candle.

The whole was integrated with Unity software and deployed on an Apple iPad Air 2 tablet.

After a state of the art around augmented reality and physical based rendering for heritage enhancement, this paper introduces the modelling of ambient lighting and the obtaining of HDR environment maps as well as the modelling of night lighting. The presentation of the results is accompanied by the appreciation by the public of the approach followed. Finally, we conclude by giving some perspectives for future development.

## **STATE OF THE ART**

By modelling historical light sources (Chalmers et al. (2006), Gutierrez et al. (2008), Rodrigues et al. (2014)) to illuminate virtual archaeological sites (Devlin and Chalmers (2001)), it has been shown that lighting and, more generally, the ambient lighting has a significant impact on the perception and understanding of a historical or archaeological scene. The ambition is to restore the historical visual sensation of the site. Although it is rather difficult to formally validate these results, they seem convincing from an archaeological and perceptual point of view (Goncalves et al. (2009)).

Other work by Callet focuses on light-matter interaction, especially colour, metallic effects and spectral simulation (Cerise et al. (2012)). They concern both monuments (Callet et al. (2010)) and historical artefacts (Robin et al. (2010)). The method is very rigorous from a physical realism point of view, but is too complex to be implemented in an augmented reality application, where the computing power of the devices involved is often limited.

Concerning mobile applications for heritage enhancement, initiatives have multiplied since the advent of modern smartphones (Lesaffre et al. (2014)) but few of them offer realistic visualization functionalities with dynamic lighting. Among the most high-profile projects is the Gunzo project, which aims to reproduce the Abbey of Cluny (Père et al. (2013)), or the Abbey of Jumièges (Jumièges 3D (2018)). However, most of these applications are not in real time and present only pre-calculated

images, inducing a strong constraint: the user can only observe around a fixed point without being able to move. Immersion, and therefore the impact on the visitor, is then limited.

## **EXPERIMENTATIONS**

Our goal was to create an application that removes the limitations of previous achievements. The heritage to be valued at Germolles is a courtly and bucolic wall decoration, that of the dressing-room of the dukes' daughter-in-law, Margaret of Bavaria, alternating white letters (initials of the Dukes' first names) and thistles (symbols of protection and fidelity) now of the same white colour but which were once metallic and golden in appearance, all on a green background. The application must be able to reproduce the supposed visual sensation of this decor, under different lighting conditions and without restricting the user's freedom of movement. The main constraint is that the chosen platform, a tablet, does not allow physical calculations as advanced as those presented in the previous section, it is for example impossible to perform spectral calculations. It was therefore necessary to find a compromise between physically realistic results and real-time computations. At the same time, this project also allowed to test whether physical realism is a necessary condition for such a mediation.

In order to be convincing, the rendering of the virtual decor integrates three determining models: materials, ambient lighting, and night lighting detailed in the following.

### **Materials**

The materials model we used is the one present in the Unity engine. It is a micro-facet reflectance function (based on Walter et al. (2007)) whose objective is not an exact physical reproduction of materials at the molecular scale, but only the reproduction of their visual appearance. It has the advantage of being very widespread, easily parameterizable, while being physically plausible. The different parameters of metallic character, colour, and roughness can be modulated by textures. This model also allows to alter the local geometry of the surface to add mesoscopic details. For ease of editing, we used the Substance Designer software to design the materials in collaboration with the managers of the château. Three materials were designed, for the letters, thistles, and background. There is no certainty about the composition of the original materials, only hypotheses. The model had to be parameterized to test these hypotheses visually and iteratively (Degriy et al. (2020)).

### **Ambient lighting**

The ambient lighting model is based on a well-known technique in image synthesis: Image-Based Lighting. This technique consists in using a panoramic HDR image from the real environment to illuminate the virtual decor to be enhanced (Debevec (1998)). In the application, we want to visualize the decor under four different weather conditions for each of the four seasons, at two times of the day, i.e. a total of 32 HDR images. These images were captured with a Canon Powershot 230S camera whose internal software has been modified to allow bracketing for HDR reconstruction. Multiple shots were taken using a photographic stand and then assembled into a panorama with the PTGui Pro software. Figure 1 shows examples of reconstructed panoramas, in spring and for two weather conditions.



Figure 1: An example of two HDR panoramic image in Margaret of Bavaria's dressing-room taken on a rainy day (a) and on a sunny day (b), both in spring.

However, in this project, the HDR panorama alone does not faithfully render the lighting in the room. The main light source, the original open window of the north wall in figure 1, is under-represented and does not contribute sufficiently to the appearance of the decor. We have therefore added an additional rectangular light source to the scene, representing a virtual version of the window in the room. Unfortunately, Unity engine does not allow the use of non-uniform area light sources. We therefore chose to opt for an approximation based on point sources, positioned on the plane of the source and whose characteristics (colour and position) are defined by importance sampling an HDR image of the window. Figure 2 shows a representation of this sampling with the corresponding image.

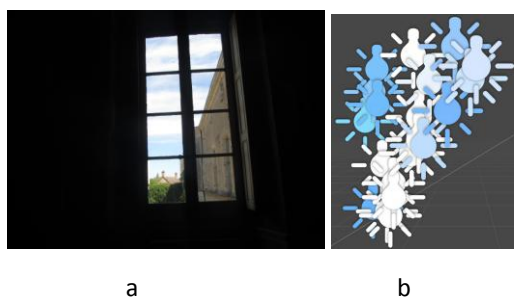


Figure 2: An image of the window of the north wall (a) and point source sampling (b). The colour of the point light sources reflects the dominant blue colour of the window.

### Night lighting

The application must also be able to simulate candlelight at night. In contrast to the ambient lighting in the previous section, in this case the light source is dynamic and cannot be simulated with HDR images. We have chosen to take up the work of Bridault-Louchez et al. (2008) and port it to the tablet. This technique is based on the use of a candle flame photometric solid applied to a point light source in order to modulate its intensity in a non-uniform manner. On the tablet used for the application, however, it is not possible to simulate the dynamics of air flow to obtain the flickering of the flame, which is an obvious clue of this type of lighting. In order to reproduce this effect, we chose to alter the photometric solid with small random rotations (Degriigny and Farrugia (2020)).

### RESULTS

The application itself is a classical mobile augmented reality application. Depending on the season, outdoor weather conditions and time of day (32 options in total), the user chooses the most suitable ambient lighting conditions. The tablet is pointed towards the decor (only the west wall of the dressing-room is currently being considered). By pressing on the touch screen, the reconstructed virtual decor is gradually superimposed on the real decor (directly seen by the tablet camera). No

placement is imposed in the room, the user is completely free to move around, the virtual view of the decor being calculated and adjusted in real time. Figure 3 shows an example of lighting with the environment map only (a), and with the environment map plus the light source of the window area (b), showing the addition of the latter. The chosen ambience is a sunny summer morning.

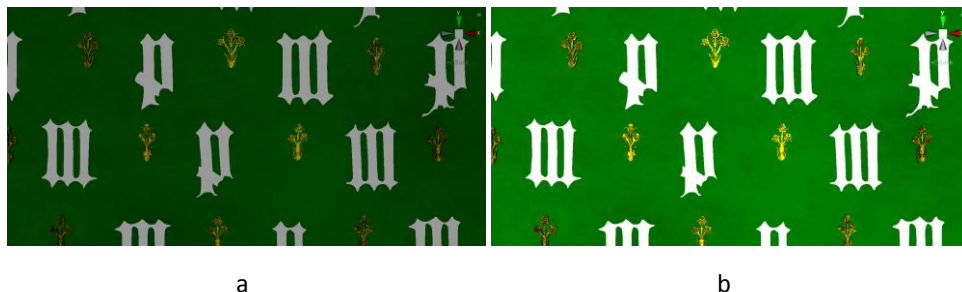


Figure 3: The virtual decor lit with environment map only (a) and with environment map and area light (b).

The application is only shown, during the tour, after the description of the paintings, the history of their rediscovery and conservation. This is a user experience designed to help visitors understand the visual rendering of the paintings beyond words. The speech used remains accessible despite the technological contribution. However, visitors are made aware of the possibilities and limits of augmented reality, while insisting on the hypothetical nature of the approach, even if it is based on historical and scientific knowledge accompanied by cutting-edge research on the light-matter interaction.

## CONCLUSION

This article presents a mobile augmented reality application that provides a historical visualization of a medieval decor. This application, currently used on site, is one of the few to allow dynamic and realistic lighting of virtual elements on a general public device, without restricting the user's freedom of movement or requiring intrusive elements on the site. It can still be improved on many points: it is, for example, possible to carry out the process of capturing ambient lighting with the tablet via a dedicated function within the application itself, without external intervention.

The effects of the application on the dynamics of the visits are noticeable. The visualisation of the decor in its original state via augmented reality creates an effect of surprise and renewed attention from the audience. The appreciation by the public, although difficult to quantify, is enthusiastic. The next step could be a more formal evaluation of this appreciation, through user experience and dedicated instrumentation of the application in order to collect relevant indicators.

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