The Virtual Reconstruction and Daylight Illumination of the Panagia Angeloktisti

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Abstract
High-fidelity virtual reconstructions can be used as accurate 3D representations of historical environments. After modelling the site to high precision, physically-based and historically correct light models must be implemented to complete an authentic visualisation. Sunlight has a major visual impact on a site; from directly lit areas to sections in deep shadow. The scene illumination also changes substantially at different times of the day. In this paper we present a virtual reconstruction of the Panagia Angeloktisti; a Byzantine church on Cyprus. We investigate lighting simulations of the church at different times of the day, making use of Image-Based Lighting, using High Dynamic Range Environment Maps of photographs and interpolated spectrophotometer data collected on site. Furthermore, the paper explores the benefits and disadvantages of employing unbiased rendering methods such as Path Tracing and Metropolis Light Transport for cultural heritage purposes.

Categories and Subject Descriptors (according to ACM CCS): Computer Graphics [I.3.3]: Picture/Image Generation -Display Algorithms—Computer Graphics [I.3.7]: Three-Dimensional Graphics and Realism - Color, Shading, Shadowing, and Textures—Computer Graphics [I.3.8]: Applications—

1. Introduction

High-fidelity virtual reconstructions of cultural heritage sites are becoming increasingly important for cultural heritage preservation, educational and research purposes. They are used by academics, museums, and media to visualise the appearance of the sites for various periods in time. Physically-based 3D virtual reconstructions may be used for the study of existing or ruined cultural heritage environments under user-defined conditions. This may in turn enable archaeologists to interpret and deduce new knowledge about the past.

In this paper, we present a virtual reconstruction of the Panagia Angeloktisti; a Byzantine church located in the Kiti region, in the south east of Cyprus. We investigate methods to recreate interior daylight for the model through Image-Based Lighting (IBL) [Deb98] using High Dynamic Range (HDR) environment maps from HDR photographs, but also by interpolating new HDR environment maps from a sparse set of spectrophotometer data [Pho08].

Technical limitations in both light data capture and display technologies prevent the accurate presentation of low lit sites. However, with the introduction of HDR imaging [DM97, Deb98] and HDR displays systems [SHS*04], it is now possible to study dark cultural heritage environments such as the Panagia Angeloktisti, in order to reconstruct and study them in a visually correct manner [ZCBRC07]. Our motivation is to widen the understanding of interior illumination for enclosed cultural heritage environments such as this church. The purpose of this study is to investigate key aspects to consider when relighting interior cultural heritage virtual reconstructions with outdoor daylight.

The remainder of the paper is organised as follows. Section 2 presents related work. Typical characteristics that need to be addressed for reconstructions of Byzantine environments are detailed in section 3. Section 4 presents the model itself and the reconstruction approach. The illumination models implemented for this paper are presented in section 5. Section 6 explains the rendering techniques we used, while section 7 discusses the results of our renders. Finally, conclusions and future work are discussed in section 8.

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2. Related Work

Virtual reconstructions today may opt for simplified geometry, material and light models to convey a rough estimate of the appearance of the environment. Simple lighting models may lead to reduction in reconstruction and rendering time, however may also lead to misrepresenting the scene. There has already been significant research conducted that points out the importance of correct use of lighting in high-fidelity computer graphics for virtual archaeology, for example [RS04, SGGC05, ZCBRC07]. While these works discuss the simulation of light and its significance for cultural heritage reconstruction, they do not include detailed acquisition of sunlight data from the site to include with the illumination model of the interiors of the reconstruction.

There are several methods to model outdoor illumination. One approach is Image-based Lighting (IBL) [Deb98] either through HDR photography [DM97, STJ*04, JWG08], or by estimating light values in the skydome from spectrophotometer data. These two data sets are acquired differently, but can serve the same purpose. In the cultural heritage domain, the virtual reconstruction of the Parthenon [DTG*04, Deb05] is perhaps the most well-known example to date that makes use of IBL sky illumination.

Another method is to assign captured light data to windows and doors, and then project this light as area light sources, for example as *mkillum* does in Radiance [WS98]. This light data can be captured using a spectrophotometer and then be recreated in the virtual environment.

A third method includes simulating the physical sky by considering the sun and lighting the geometry model using a latitude and a longitude position on Earth. The *gensky* program in Radiance for instance, produces a sky derived from the Commission Internationale de l'Eclairage (CIE) standard sky distribution at the given date and local standard time [WS98]. An example of the use of this approach is the reconstruction of the Egyptian Temple of Kalabsha [SCM04]. Several commercially available physically-based sky models are already available in most common rendering packages, including Mental Ray [enMen07], (see Figure 10).

3. Byzantine Environments

Byzantine churches on Cyprus were mostly made of stone from nearby quarries and appear plain of the exterior. No paint was added to decorate the rough stone walls, and the lack of large windows adds to the compact characteristics of the buildings. This stands in direct contrast to the extensively decorated interiors with their abundance of highly-ornate sacral artwork and precious materials [HJK96].

From a virtual reconstruction standpoint, Panagia Angeloktisti stands out among the churches on Cyprus for primarily two reasons: Firstly, it is a church that has vastly changed its architectural features due to renovation work since it was first built in Byzantine times to the 1950s

[Fou04]. While the Byzantine architecture style may have been of overall provincial influence from the Byzantine capital - Constantinople, there is also evidence to show individual characteristics in Byzantine churches specific to Cyprus [Cur00]. Based on the physical evidence left at the churches today, we must also consider the fact that the churches on Cyprus were and are susceptible to potential damage from earthquakes, and how this may have influenced architectural features. Continuous preventative building and rebuilding of church walls, meant that in time, the buildings lost some of their original interior appearance in favour of increasingly bulkier, enclosed form.

Secondly, the Panagia Angeloktisti, compared to other Byzantine churches on Cyprus, has fewer wall frescos, but its mosaic is richly decorated with gold tesserae. In this paper all gold-like reflective surfaces have been approximated using the Ward Bi-directional Reflectance Distribution Function (BRDF) model [War92].

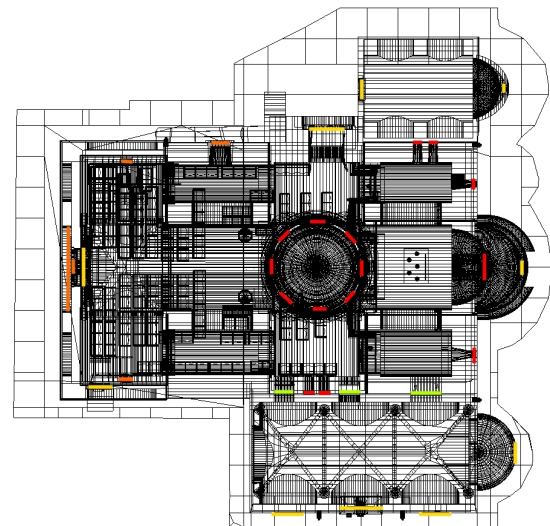### 3.1. Investigating Lighting Inside the Church

Figure 1: *Light source location diagram.*

Byzantine churches on Cyprus have small windows, and the geometry is enclosed. This makes the interior overall significantly darker compared to several other types of Christian churches. Figure 1 shows the locations where the light is coming from the outside. Yellow indicates the light coming from windows and doors at the ground floor. Orange signifies the light coming from the first floor, while the red signifies areas in which light enters the church from the top, what can be considered the second floor. Green highlights the areas that are interior windows and doors. These are openings to other sections inside the church, and allow sunlight to pass through to the main section.

The interior illumination was likely designed to provide

people inside with a dramatic visual effect aimed at engaging the viewer to approach God [PEE04, ZSMA07]. It can therefore be argued that the original church was built to reflect lighting in a manner that gives the perception of a holistic environment. It is believed the upper parts of the church symbolically represented heaven and were therefore better lit from the dome than the lower parts. In early Byzantium this was achieved with the aid of daylight through small openings in the upper parts of the walls as well. From middle Byzantium however, the buildings had less openings letting in natural light and these were replaced by oil lamps and candles [The01].

4. Reconstructing the Panagia Angeloktisti

The Panagia Angeloktisti is still in use today. Tourists and visitors frequently enter the church to admire or pray inside. To estimate and model the walls and ceiling geometry, a laser distance meter [Lei07] was used to acquire the height values which were useful in the modelling stage of the project. This approach was chosen to avoid disrupting the everyday events at the church. The 3D reconstruction was manually modelled using Autodesk Maya 8.5 [Aut07], and rendered using in-house implementations of existing rendering algorithms such as Path Tracing [Kaj86] and Metropolis Light Transport [VG97]. Mental Ray [enMen07], a rendering package that exists within Maya was also used. This is further discussed in Section 6.

Two types of camera equipment were used; conventional DSLR cameras and a SpheronVR [Sph07]. A Spectrophotometer [Pho08] was employed to capture luminance and spectral radiance values of the sky. Measurement tape was used for more accessible objects such as icons, chairs and ornaments found inside the church. Photographs were primarily used to model the geometry shapes and details as there were no references such as blue prints available. However, they also aided in understanding how light changes in the interior of the church during the day. These photographs were taken in an as naturally diffusely lit environment as possible. The texture maps were carefully captured avoiding light from light bulbs, shadows, specularities, caustics and colour bleeding.

Throughout the process of reconstructing the environment, continuous cross-referencing material that might indicate errors were taken. This involved anything from the visual materials captured earlier, such as photography, but also input from experts and local caretakers. Figure 2 shows a perspective view of the finished model in wireframe and flat shaded.

5. Illuminating the Church

Interreflection of sunlight is a large portion of the total illumination for most interior cultural heritage environments. The only additional light would come from flame light such as candles and oil lamps. While the visual perception of
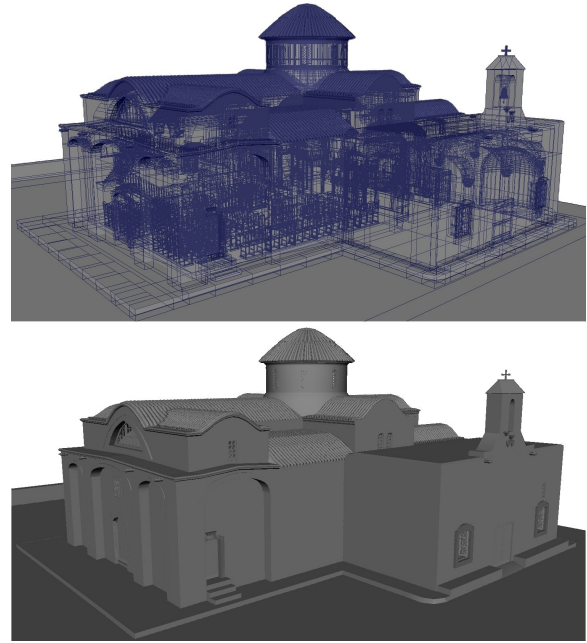

Figure 2: *Top: Wireframe. Bottom: Flat Shaded.*

flame light most likely had a significant impact for Byzantine art [ZCBRC07], the majority of light inside the church does not come from these flames. Exterior and interior sunlight illumination is investigated. HDR Environment Maps, HDR DSLR Photography and spectrophotometer data of the sky were used in the process of relighting the church.

5.1. Capturing HDR environment maps

HDR environment maps were captured using the SpheronVR camera [Sph07] in the latitude-longitude panoramic format [BN76]. Due to inaccessibility to the roof of the church and lack of taller buildings in the nearby area, the environment maps were acquired at approximately ten meters distance from the main southern entrance. Here, there is a great distance to any other large object, yet it still remains as physically close to the church as possible. This approach also captured as much of the sky as possible.

Between 5:30 and 09:00 an environment map was captured every 30 minutes due to the vast changes in light. Between 09:00 and 17:00 one environment map was acquired every hour. After 17:00 to sunset at 20:30, the process was repeated every 30 minutes again. Figure 3 shows the first, mid-day and last capture during the outdoor capturing day, June 18th, 2008. Indoor spherical panoramas were acquired for reference purposes at mid-day on the 19th June 2008, see Figure 4.

Figure 3: *3 of 24 HDR Spherical Panoramas taken on June 18th, 2008 outdoors. Here in top-down order: a) sunrise (05:30), b)12:00 & c) sunset (20:20).*

Figure 4: *3 of 12 of HDR Spherical Panoramas taken inside the church on June 19th, 2008. Top: first floor, Middle: ground floor, centre of the building, Bottom: altar area.*

5.2. DSLR Camera - HDR Photograph

The purpose of having HDR photographs was as a reference against which the rendered images could be compared. Locations with strong difference of contrast in light inside the church were chosen. The location is below the church dome, facing the north entrance of the church is the one specifically chosen for this study. The selected photograph is shown in Figure 5. Figure 6 shows the orientation of the church in relation to Cardinal directions. This photograph was deemed the most appropriate due to the presence of direct and indirect illumination from inside and outside the church. It was taken at mid-day on 19th June, 2008.

5.3. Creating a Skydome from Spectrophotometer Data

The spectrophotometer was set to acquire and average out 10 individual samples for each of the single 8 measurement values. Each of the 10 samples took less than a second to measure. The samples were averaged as the area measured is not a single point, but a rather large area in space. On average the time between M1 and M8 was less than 5 minutes apart. Figure 6 illustrates locations of where spectrophotometer data was acquired. The device was mounted on a tripod, then aimed at a 45° angle towards the sky away from the church.

An outdoor skydome HDR environment map was created from the eight measured spectrophotometer values. The values were first converted from XYZ to RGB (although from

Figure 5: *HDR photograph of the north entrance.*

spectral radiance to RGB is also an option), then, a nearest-neighbour interpolation of the eight RGB values was computed for all other neighbouring pixels in the assembled environment map. The map is of the same pixel resolution as the HDR photograph. Figure 7 shows the output HDR environment map produced using the interpolation approach.

Environments lit with predominantly blue values inherently renders the scene considerably blue. This is due to the absence of the sun. Light values deviate significantly in the area occupied by the sun because of its vast brightness compared to the rest of the image. In the HDR photograph, the
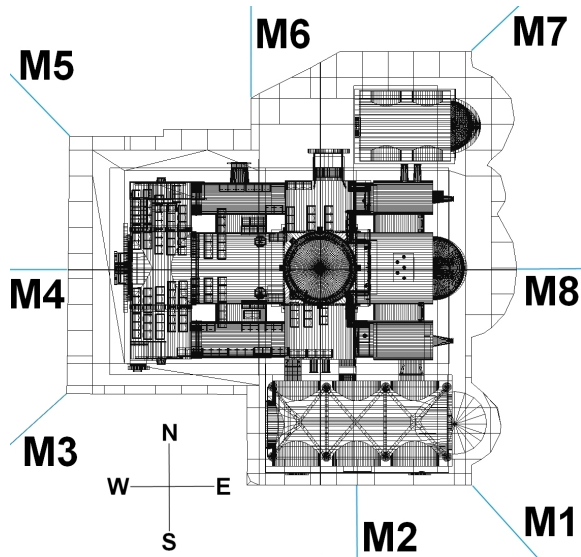
Figure 6: *Locations of where spectrophotometer data was captured from, each aimed at a $45°$ angle towards the sky.*

Figure 8: *The approximated sun based on an exponential growth compared to the same exposures in the HDR photograph, shown at various exposure levels.*

sun has close to an exponential growth in light values expressed as an ellipse. The sun values are therefore approximated and assembled into the environment map based on the RGB values found in the HDR photograph in order to compensate for the much brighter light values. Figure 8 illustrates this point by showing the approximated sun along with the photographed sun at various exposure levels. The same was done for the ground bricks in the lower section of the image in Figure 7.
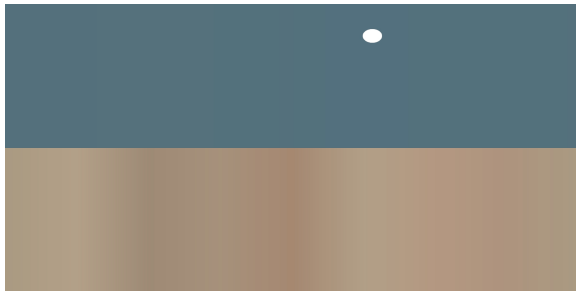

Figure 7: *The assembled HDR image with spectrophotometer values from 12:00.*

6. Rendering

[A PARAGRAPH TO EXPLAIN UNBIASED RENDERING, IN MATHS FORM AND TEXT. TO BE ADDED BY TOM.] Methods are considered unbiased in that the expected value of the error is zero.

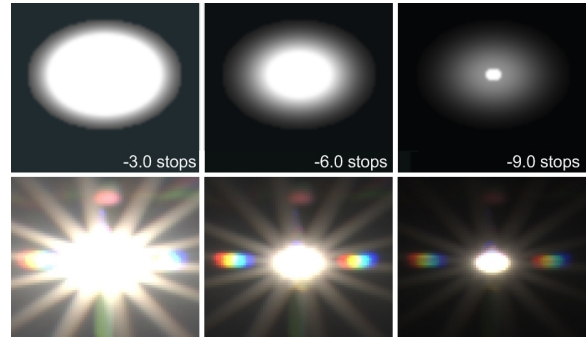Path tracing [Kaj86] and Metropolis Light Transport

(MLT) [VG97] were implemented to render the interior of the church reconstruction. Path tracing is an unbiased stochastic rendering algorithm which numerically solves the rendering equation. Rays starting at the eye are traced through the scene in order to create a path from the eye to a light source, and the contribution of these paths forms an image on the camera. Metropolis Light Transport is an extension to Path Tracing based on the Metropolis-Hastings method from computational physics. Previous path information is used to guide the current path (via mutations to the previous path) in order to more efficiently explore path space. These new paths are probabilistically used as the basis for further paths via carefully chosen statistics. Finally, for comparison Mental Ray [enMen07]; a rendering package that already exists within Maya for realistic rendering of synthetic scenes was also used.

Using commercial renderers allows users to specify rendering and lighting properties for an image for ease-of-use through graphical user interfaces. It was decided however to implement these rendering algorithms to have better control of the rendering application itself. Matte materials were approximated as diffuse BRDFs, while all glossy and specular materials such as the gold painted icons and tile floor have been approximated using a Ward BRDF [War92].

7. Results and Discussion

A collection of rendered images both on the interior and exterior of the church are shown in Figure 10. These images illustrate the level of realism and correctness that is obtainable through unbiased rendering methods. Such methods presents great opportunities that have not yet been fully exploited in the cultural heritage reconstruction domain. When lighting synthetic objects lit by direct illumination, the image converges relatively fast, depending on the object level of detail and surface reflectance properties.

This virtual reconstruction is an example that shows how such dark environments demand a significant amount of

computational power to converge to a satisfactory image. Accelerating rendering for interior scenes predominantly lit by indirect sunlight is currently a difficult problem in unbiased rendering algorithms such as Path Tracing. As a consequence, it takes several interreflection computations before the light is traced back to the light source. This increases rendering time to the overall image substantially.

Grainy noise will remain present until the image appears converged. Figure 9 illustrates the visual impact of this noise. In this case, it was necessary to leave the scene to render for several hours on a cluster of computer nodes to accumulate more than 16,000 samples per pixel.

Figure 9: *Bottom: Two Path Traced images combined into one. Top half: 200 samples per pixel. Bottom half: 16,000 samples per pixel. Top: Comparison of the door way.*

HDR environment maps have a dense data set that do not need any interpolation. Problems often arise however, during the sampling stage while rendering interior environments. Importance sampling for instance tend to favour areas of the greatest luminance values (such as the sun), rather than estimating a representative distribution of light in the scene. This is usually appropriate for relighting objects using interior HDR environment maps, or use of synthetic light sources inside an object. However, most paths in unbiased rendering methods will struggle to reach the light source via narrow entrances such as windows and doors.

The approach of using a nearest-neighbour inspired HDR environment map, is an attempt at a more uniform distribution of light. Traditional HDR environment maps also contain incident illumination conditions for a particular point in space. This interpolated approach however, uses incident light entering the church at key locations (doors and windows) of the church. While this method is not fully physically correct, it generates a simple, easy-to-implement approximation of a skydome to be obtained from relatively few measurements. Collecting larger data sets and using more advanced interpolation methods would likely increase precision of the assembled skydome.

8. Conclusion and Future Work

In this paper we have investigated the use of HDR IBL lighting for a cultural heritage site; the Panagia Angeloktisti, a Byzantine Church in Cyprus. The full reconstruction pipeline was detailed, and approaches to render interior low lit environments were presented. Unbiased rendering algorithms deliver photorealistic and accurate images, despite this, these approaches are rarely used in the cultural heritage domain due to long computation times and are not easily implemented.

A method to assemble an HDR environment map from interpolated spectrophotometer data was also presented. While the method discussed in this paper is not physically correct, it presents an alternative approach based on interpolating real world RGB values. This approach can complement traditional use of image-based lighting, especially in cases where a lack of roof-access or open spaces prevent capturing of ideal HDR environment maps. Future work may investigate other interpolating approaches to improve the accuracy of the model.

Modelling physically accurate gold for cultural heritage items is a difficult task due to the level of complexity often found in golden items. Icons and mosaics are painted, but the items themselves have also deteriorated over time. A more accurate representation of the reflectance properties of the gold is a subject for future work.

The current model is a representation of the church as it stands today. Future work will consider how the site and its lighting may have changed through the ages. This will include a measure of uncertainty to inform the viewer what is known from existing and contemporary evidence and what is expert conjecture. It is not possible to verify the light captured today is the same as it would have been in the past. Future research will also consider investigating the changes of light scattering due to pollution, positioning of the sun, climate changes and the amount of participating media throughout various periods in time.

References

[Aut07] AUTODESK: Company and software: Maya 8.5 website. http://www.autodesk.com/maya, 2007. 3

[BN76] BLINN J. F., NEWELL M. E.: Texture and reflection in computer generated images. *Commun. ACM 19*, 10 (1976), 542–547. 3

[Cur00] CURCIC S.: *Middle Byzantine Architecture on Cyprus: Provincial or Regional?* The Bank of Cypurs Cultural Foundation, 2000. 2

[Deb98] DEBEVEC P.: Rendering synthetic objects into real scenes: bridging traditional and image-based graphics with global illumination and high dynamic range photography. In *SIGGRAPH '98: Proceedings of the 28th annual conference on Computer graphics and interactive techniques* (1998), pp. 1–10. 1, 2

[Deb05] DEBEVEC P.: Making "The Parthenon". Invited Paper: VAST '05: 6th International Symposium on Virtual Reality, Archaeology, and Cultural Heritage, Pisa, Italy,, 2005. 2

[DM97] DEBEVEC P., MALIK J.: Recovering high dynamic range radiance maps from photographs. In *SIGGRAPH '97: Proceedings of the 24th annual conference on Computer graphics and interactive techniques* (New York, NY, USA, 1997), ACM Press Addison-Wesley Publishing Co., pp. 369–378. 1, 2

[DMAC03] DRAGO F., MYSZKOWSKI K., ANNEN T., CHIBA N.: Adaptive logarithmic mapping for displaying high contrast scenes. In *Proc. of EUROGRAPHICS 2003* (Granada, Spain, 2003), Brunet P., Fellner D. W., (Eds.), vol. 22 of *Computer Graphics Forum*, Blackwell, pp. 419–426. 6

[DTG*04] DEBEVEC P., TCHOU C., GARDNER A., HAWKINS T., POULLIS C., STUMPFEL J., JONES A., YUN N., EINARSSON P., LUNDGREN T., FAJARDO M., MARTINEZ P.: Estimating surface reflectance properties of a complex scene under captured natural illumination. USC ICT Technical Report ICT-TR-06.2004, 2004. 2

[Fou04] FOULIAS A.: *The Church of our Lady Angeloktisti at Kiti*. Nicosia, 2004. 2

[HJK96] HEIN E., JAKOVLJEVIC A., KLEIDT B.: *Zypern. Byzantische Kirchen und Kluster. Mosaiken und Fresken*. Melina-Verlag, Ratingen, 1996. 2

[JDD*01] JENSEN H. W., DURAND F., DORSEY J., STARK M. M., SHIRLEY P., PREMOŽE S.: A physically-based nightsky model. In *SIGGRAPH '01: Proceedings of the 28th annual conference on Computer graphics and interactive techniques* (New York, NY, USA, 2001), ACM, pp. 399–408.

[JWG08] JACOBS A., WITTKOPF S., GROBE L.: Per-pixel sky luminance with HDR photography. 7th International Radiance Workshop Fribourg, 2008. 2

[Kaj86] KAJIYA J. T.: The rendering equation. In *SIGGRAPH '86: Proceedings of the 13th annual conference on Computer graphics and interactive techniques* (New York, NY, USA, 1986), ACM, pp. 143–150. 3, 5

[Lei07] LEICA: Leica disto a6 laser distance meter comany website. http://www.leicadisto.co.uk/, 2007. 3

[Men07] MENTAL IMAGES: Mental images, mental ray company website. http://www.mentalimages.com/, 2007. 2, 3, 5

[PEE04] PEERS G.: *Sacred shock: Framing visual experience in Byzantium*. Pennsylvania State University Press, 2004. 3

[Pho08] PHOTORESEARCH: Pr-680 spectrophotometer, company website. http://www.photoresearch.com/current/pr680.asp, 2008. 1, 3

[PSS99] PREETHAM A., SHIRLEY P., SMITS B.: A practical analytic model for daylight. In *SIGGRAPH '99: Proceedings of the 26th annual conference on Computer graphics and interactive techniques* (New York, NY, USA, 1999), ACM Press Addison-Wesley Publishing Co., pp. 91–100.

[RS04] RUDOLFOVA I., SUNDSTEDT V.: High Fidelity Rendering of the Interior of an Egyptian Temple. In *CESCG 2004. 8th Central European Seminar on Computer Graphics 2004* (Slovakia, 2004). 2

[SCM04] SUNDSTEDT V., CHALMERS A., MARTINEZ P.: High fidelity reconstruction of the ancient Egyptian temple of Kalabsha. *Proceedings of the 3rd international conference on Computer graphics, virtual reality, visualisation and interaction in Africa* (2004), 107–113. 2

[SGGC05] SUNDSTEDT V., GUTIERREZ D., GOMEZ F., CHALMERS A.: Participating media for high-fidelity cultural heritage. In *VAST 2005: Symposium on Virtual Reality, Archaeology and Cultural Heritage* (2005). 2

[SHS*04] SEETZEN H., HEIDRICH W., STUERZLINGER W., WARD G., WHITEHEAD L., TRENTACOSTE M., GHOSH A., VOROZCOVS A.: High dynamic range display systems. *ACM Trans. Graph. 23*, 3 (2004), 760–768. 1

[Sph07] SPHERON: Hdr spherical panorama camera, company website. http://www.spheron.com/, 2007. 3

[STJ*04] STUMPFEL J., TCHOU C., JONES A., HAWKINS T., WENGER A., DEBEVEC P.: Direct HDR capture of the sun and sky. In *AFRIGRAPH '04: Proceedings of the 3rd international conference on Computer graphics, virtual reality, visualisation and interaction in Africa* (New York, NY, USA, 2004), ACM, pp. 145–149. 2

[The01] THEIS L.: Lampen, leuchten, licht. In *Byzans - Das Licht aus dem Osten* (2001), Degenhaart J., (Ed.), Verlag Philipp von Zabern. 3

[VG97] VEACH E., GUIBAS L. J.: Metropolis light transport. In *SIGGRAPH '97: Proceedings of the 24th annual conference on Computer graphics and interactive techniques* (New York, NY, USA, 1997), ACM Press/Addison-Wesley Publishing Co., pp. 65–76. 3, 5

[War92] WARD G. J.: Measuring and modeling anisotropic reflection. *SIGGRAPH Comput. Graph. 26*, 2 (1992), 265–272. 2, 5

[WS98] WARD G., SHAKESPEARE R.: *Rendering with Radiance: The Art and Science of Lighting Visualization*. Morgan Kaufmann Publishers, 1998. 2

[ZCBRC07] ZÁNYI E., CHRYSANTHOU Y., BASHFORD-ROGERS T., CHALMERS A.: High Dynamic Range Display of Authentically Illuminated Byzantine Art from Cyprus. In *VAST 2007. The 8th International Symposium on Virtual Reality, Archaeology and Cultural Heritage* (Brighton, 2007). 1, 2, 3

[ZSMA07] ZÁNYI E., SCHROER C., MUDGE M., A. C.: Lighting and byzantine glass tesserae. In *EVA London 2007 Conference Proceedings* (2007), pp. 11–13. 3

Figure 10: *Various interior and exterior renders of the church. Left images (top-down order): 1) Path Tracing with HDR Env. Map (12:00), 2) MLT with with HDR Env. Map (12:00), 3) Path Tracing with spectrophotometer data skydome (12:00), interior render. 4) Path Tracing with spectrophotometer data skydome (12:00), exterior. Right images: Path Tracing at 1) Sunrise, 2) Mid-day and 3) Sunset. 4) Physical sky render in Mental Ray.*