Accurate graphics BRDF material properties and illumination for dirt and mudbrick structures

Investigating the Perceptual Consequences of Accurate Appearance Models

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Abstract

Many ancient archaeological sites consist of mudbrick structural remains. 3D shape models are needed to create accurate computer graphics renderings of such structures. Beyond shape, however, such structures exhibit appearance which is dependent on the natural materials used in their construction (dirt) and possible plastering. Ancient illumination was limited to sunlight, moonlight, and natural fire sources. We investigate and compare mudbrick architecture computer graphic renderings based on a simple color reflectance model versus an accurate measured bidirectional reflectance distribution function (BRDF) of geographically proximate samples of dirt, mudbrick, and plaster materials. We also compare the rendering appearance under sunlight and fire-lit sources, and examine the consequences of tone mapping. Our hypothesis is that the visual appearances of natural material structures will vary enough to be quantitively measurable, and be qualitatively visible to both expert and naïve observers. We conclude that BRDF material properties and proper physics-based illumination and renderings are important to the effective and accurate portrayal of ancient mudbrick structures, and that more detailed attention should be paid to these BRDF material factors in the graphical portrayal of mudbrick or adobe architecture.

Introduction

Before the discovery of electrical light, ancient people were limited to natural light from the sun and moon, and flames from hearths, fixtures or portable flammable materials (Happa *et al*. 2010). Lighting plays a crucial role in illuminating the spaces where people live, work, or worship. Enclosed spaces with covered roofs limited sunlight entrances to windows and doorways. Computational relighting simulations can aid the study of ancient space usage, *e.g.*, (Papadopoulos *et al.* 2015) and assessment of visual task feasibility, e.g., (Dawson *et al*. 2007). Sufficient physical light sources could be very effective in illuminating even large enclosed spaces (*e.g.* Kider *et al*. 2009).

We had access to architectural and surface dirt materials from the ancient Near East Godin Tepe Period VI:1 site, c. *3200-3050* B.C.E. located in central western Iran (Badler 2002). Local Godin Tepe construction methods were typical of the time period and consisted of mudbrick walls, wooden roofs (charred remains of roof beams were found in one room), and presumably lintels for modest structures. These physical constraints led to substantial walls (~*0.6* m thick), narrow doorways (~*0.5* m to ~*1* m wide), and limited width, few, or even no windows. Hence there were only limited openings for natural light to enter these enclosed living spaces.

Material BRDFs

Monumental architecture is often constructed in stone. Debevec (2005) measured marble reflectance properties *in situ* for a Parthenon reconstruction. More common structures in many ancient sites in arid climates are based on local soils and clays. Such materials, *e.g.* mudbrick, are mostly diffuse and play a role in spreading light though the structure interior. To accurately and realistically render a 3D geometric model of Godin Tepe using natural and indirect illumination, we captured the Bidirectional Reflectance Distribution Function (BRDF) of dirt, mudbrick, and plastered mudbrick samples (loaned by the Royal Ontario Museum in Toronto, Canada) from the actual site. We used a spherical gantry at Cornell University to obtain BRDFs directly from the samples. This gantry is a room-sized goniometer, consisting of two computer-controlled arms, one with a light source and the other with a DSLR camera, that sweep concentric shells around an object platform, as described in Badler et al. (2017).

Rendering

We used Renderman 22, a physically-based path tracer, to produce renderings of a Godin Tepe 3D model using both diffuse Lambertian surfaces and our accurate measured BRDF materials.

Fig. 1. Mudbrick/plastered walls and dirt ground, as seen from indoor and outdoor angles, modeled with brown color from an on-site reference photo using the Photoshop dropper tool (left) vs. accurate BRDFs under sunlight conditions (right).

In Fig. 1, six rendered images illustrate mudbrick/plastered walls and dirt ground, as seen from indoor and outdoor angles, modeled with brown color from an on-site reference photo using the Photoshop dropper tool (left) compared to accurate BRDFs under sunlight dome conditions (right). Beyond some clear variation in hue, very little visual difference can be perceived between the two materials when viewed in outdoor lighting. However, when looking at the reflection of light in dark or shadowed areas, the accurate BRDF materials reflect less light than the standard diffuse (Lambert) material in Autodesk Maya. This result is expected: the BRDFs take into account the microfacet distribution of the material, making it reflect less light than a smooth, Lambertian diffuse surface.

Fig. 2 illustrates photo-referenced (top) and actual BRDF (bottom) results before tone-mapping (Ferwerda et al. (1996)). The left images focus on the outside light, while the right images adjust to the indoor light. As can be seen in both Figs. 1 and 2, the radius of the arch of light reflected on the wall above the fire is larger in the photo-referenced scene, where a diffuse Lambertian material was used, while using the plastered mudbrick BRDFs resulted in a smaller radius light arch. The tone-mapped images in Fig. 2 emphasize these differences: the outside light from the doorway reflects more off the walls in the top scene which uses the

Lambertian material, as opposed to the bottom scene which uses the BRDF materials, where the light reflection is less prominent and dimmer to the human eye.

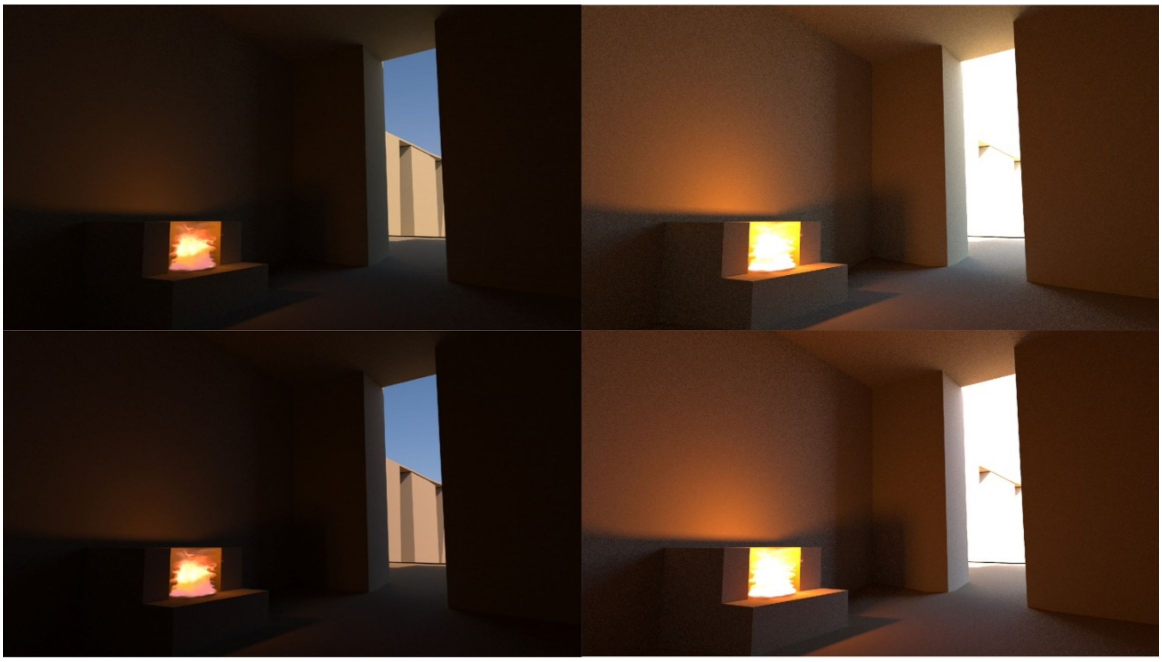

Fig. 2. Photo-referenced (top) and actual BRDF (bottom) results before tone-mapping (focusing on outside light; left) and after (adjusting for indoor light; right).

Discussion

We have shown that accurate BRDFs of a common mudbrick building material result in perceptable differences in surface appearance under natural sun and fire illuminants. This observation has already led support to a hypothesis that archaeological small finds may be found in perceptably dark places [BKM*17]. Our next steps are to créate user studies that test whether the illumination and appearance differences in such renderings are apparent to novice and expert observers, and whether the renderings convey more realistic portrayals of mudbrick architecture to knowledgeable experts.

References

Badler, V. R. (2002). A chronology of Uruk artifacts from Godin Tepe in central western Iran and implications for the interrelationships between the local and foreign cultures. In *Artefacts of Complexity: Tracking the Uruk in the Near East* (Vol. 5, pp. 79-97). Aris and Phillips Warminster.

Badler, V., Kider Jr, J., Moore, M., Walter, B., & Badler, N. (2017). Accurate soil and mudbrick BRDF models for archaeological illumination rendering with application to small finds. In *Proceedings of the Eurographics Workshop on Graphics and Cultural Heritage* (pp. 29-36), Eurographics Association.

Dawson, P., Levy, R., Gardner, D., & Walls, M. (2007). Simulating the behaviour of light inside Arctic dwellings: implications for assessing the role of vision in task performance. *World Archaeology*, *39*(1), 17-35.

Debevec, P. Making "The Parthenon". *6th International Symposium on Virtual Reality, Archaeology, and Cultural Heritage*, Pisa, Italy, December 2005.

Ferwerda, J. A., Pattanaik, S. N., Shirley, P., & Greenberg, D. P. (1996). A model of visual adaptation for realistic image synthesis. In *Proceedings of the 23rd annual conference on Computer graphics and interactive techniques* (pp. 249-258). ACM.

Happa, J., Mudge, M., Debattista, K., Artusi, A., Gonçalves, A., & Chalmers, A. (2010). Illuminating the past: State of the art. *Virtual Reality*, *14*(3), 155-182.

Kider Jr, J. T., Fletcher, R., Yu, N., Holod, R., Chalmers, A., & Badler, N. I. (2009). Recreating early Islamic glass lamp lighting. Proc. International Symposium on Virtual Reality, Archaeology, & Cultural Heritage (VAST).

Papadopoulos, C., Hamilakis, Y., & Kyparissi-Apostolika, N. (2015). Light in a Neolithic dwelling: Building 1 at Koutroulou Magoula (Greece). *Antiquity*, *89*(347), 1034-1050.