

# Structural and Lighting Models for the Minoan Cemetery at Phourni, Crete

C. Papadopoulos<sup>1</sup> and G. P. Earle<sup>2</sup>

<sup>1</sup> PhD Student, University of Southampton, School of Humanities, Archaeological Computing Research Group,  
cp5v07@soton.ac.uk

<sup>2</sup> Lecturer, University of Southampton, School of Humanities, Archaeological Computing Research Group,  
graeme.earle@soton.ac.uk

---

## Abstract

*The importance of death to the living is of interest to scholars in a range of disciplines. This paper describes a computer-based research project undertaken to create a series of alternative readings of the dataset from the Minoan cemetery at Phourni, Crete. This attempted to evaluate the tombs' architecture, use, visual impact, their capacity as well as the contribution of illumination to their interior, by using computer graphic methodologies. However, since the software deployed is primarily developed for use in other fields, there are certain limitations and difficulties for a virtual reconstruction of such an archaeological site, which can prevent production of a model that is accurate in every detail. This paper will discuss the results and these constraints. It will also address problems and innovative components, suggesting potential solutions and recommending additional work for the future.*

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

Keywords: Minoan Crete, Virtual Archaeology, Lighting Analysis, Global Illumination

---

## 1. Introduction

Virtual archaeology, when it is deployed by archaeologists can be a way of approaching controversial datasets that not only produces engaging imagery but provides direct answers to research questions. One focus of such research can be to approximate to the past reality as much as possible, using the present as a correlate to ancient conditions. However, the process of building such analogues and the inevitable incompleteness of the archaeological record make such an attempt problematic.

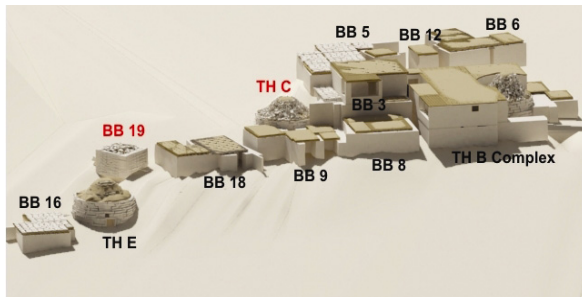
Since no similar efforts had been undertaken to visualise Greek burial buildings, this project gave a new insight into the Minoan burial cult, by creating a virtual reconstruction of Tholos Tomb Gamma (THC) and Burial Building 19 (BB19) located in the cemetery at Phourni, Archanes (fig. 1). It also considered the possible interpretations of the available archaeological evidence, while providing a written and visual companion for

approaching intriguing archaeological records, and addressing the principles or ethics according to which they should be confronted.

Phourni is a low ridge to the north-west of the town of Archanes, on the island of Crete. Tholos C, which is one of the most well preserved Pre-palace (3000-2000 BC) tholos tombs in Crete, was erected as a freestanding building and was used as a typical collective tomb for a large number of successive burials over a prolonged period. It was built of large and small stones laid in irregular rings, having a low east side entrance and a window immediately to the south. The first burials were placed on the floor and were accompanied by a large number of offerings, whilst in a later period, the first burial containers were introduced [Pap05]. Burial Building 19, the smallest tomb in Phourni, is the only apsidal burial building in Crete and was used for burials and depositions. The study of the deposits revealed two successive burial strata, containing some two hundred burials, accompanied by a large number of grave offerings, reducing the already limited space [Mag94].



**Figure 1:** General view of the Phourni cemetery from North. Courtesy of Sakellarakis, Y. & Sapouna-Sakellarakis, E. [SS97]



**Figure 2:** Schematic reconstruction of the Phourni cemetery during its last phase. View from Southeast. Red colours indicate the two burial buildings under examination.

To a degree, we must accept that the burial structures and the cemeteries reflect the way that the living manipulated the dead. However, many questions remain unanswered largely because traditional means of examining the archaeological remains cannot offer a sufficient solution or alternative readings to issues of spatial organisation and burial practice in this context.

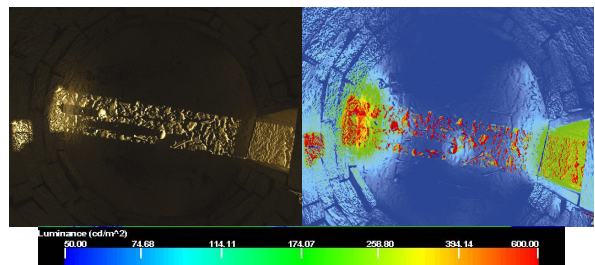
Researchers cannot be sure about the number of people who were in charge of one burial and the exact capacity of a tomb at its different phases (ergonomics) (fig. 3). For example, how many people could enter simultaneously to practice a ceremony



**Figure 3:** Burial Building 19 at the second phase. A narrow path seems to have been created from the entrance to the right side to facilitate human movement during the initial depositions.

or prepare the place for forthcoming burials? We know even less about the implications of these features in the use of the structures. In addition, it is intriguing to know how a building full of corpses looked and the limitations of staying and moving inside such a structure. Each of these issues can be addressed through simulation of the architecture of the tombs. As a consequence, an accurate study of the tombs' interiors demands a high level of accuracy regarding the various structural models.

The reconceptualisation of the impact that natural and flame illumination has in the interior of the burial buildings in connection to their orientation is imperative, in order to consider if the various lighting effects identified were connected with a specific perception of the afterlife or if they had specific practical roles [Goo01, Goo04]. The latter practical impact can be addressed directly via digital comparison of the effects of light under varying conditions, such as the addition of luminaires or alternative architectural features (fig. 4).



**Figure 4:** First phase of Tomb C. 30th April at 7:00 2007. It is at this time of day that a ray of light directly enters the interior of the tomb. Rendered image & luminance values in LUX.

## 2. Background

Many of the virtual archaeological projects completed to date do not incorporate physically accurate natural or flame lighting. This is usually because it is not considered necessary since photorealistic results can be achieved without knowing the physical properties of light. In addition research in this field, and especially regarding combustible materials, is still in its preliminary stages and remains complicated for researchers. Finally, the commonly available software does not always provide tools to accurately handle natural and flame illumination, beyond some common lighting solutions which are used in engineering and architecture. Prominent exceptions include work by Chalmers [Cha02] and Devlin [DC01, DCB02] who examined the realistic visualisation of archaeological site reconstructions based on experimental archaeology and physics. Roussos [Rou03, RC03] made a comprehensive study of small scale flames and different fuel types, based on his own scientific and psychophysical investigations, Sundstedt worked on the ancient Egyptian temple of Kalabsha [SCM04], and Zányi [Zan07] studied flame illumination of Byzantine Art in Cyprus. Most of this work is focussed on the perceptual differences of an archaeological site lit by different types of lighting instead of producing a lighting analysis in terms of calculating the amount of light in an ancient environment.

### 3. Modelling Process

#### 3.1 Theoretical Aspects

Each and every virtual reconstruction should be based on comprehensively reviewed archaeological records and well studied comparators in order to provide a fertile basis for a faithful construction of prehistory. For this reasons the decision making process for some of the models produced is now discussed, in the context of the results.

Although there is a significant number of Early Minoan tholoi tombs in Crete (3000-2100 BC), which together provide considerable architectural information, none of them is preserved to a sufficient height in order to clearly present either how the vaulted roof was constructed or indeed if there was a vaulted roof at all. Part of the case for accepting a vaulted roofing system has long been the existence in modern Crete, on the upland of Nidha, of circular houses with vaulted stone roofs, called *mitata*. These are circular stone houses in which the shepherds make their cheeses and which are used as temporary dwellings for the summer months when the flocks move to high altitudes [Val88]. Closer points of comparison, apart from the stone work, are the general form, circular plan and size, as well as details like the inward curvature of the walls inside and the low doorway with lintel slab (fig. 5). However, it cannot be assumed that all of the tombs were vaulted. Indeed, although collapsed stonework is found inside the tombs, not nearly enough of it has been found in such a position as to complete a stone vault. As a result, there remains controversy regarding the technique by which Minoan tombs were roofed. This has led to alternative ways of exploring the problem, including a light, flat roof built of wood which could easily be removed when tombs had to be fumigated [Hoo60, Bra70, War73, Bra94, War07]. However, the most prominent theory to date based on archaeological data is that the Minoan circular tombs incorporated a full vault made of stones. The latter is supported by architects studying prehistoric architecture. For an alternative way of dealing with the validity of virtual structural models see [CD05].



**Figure 5:** Left - Close up view of the reconstructed east side of tholos Tomb C. The door is defined by a trilithon (three stones); Right - The interior of Tholos Tomb C from the South West side.

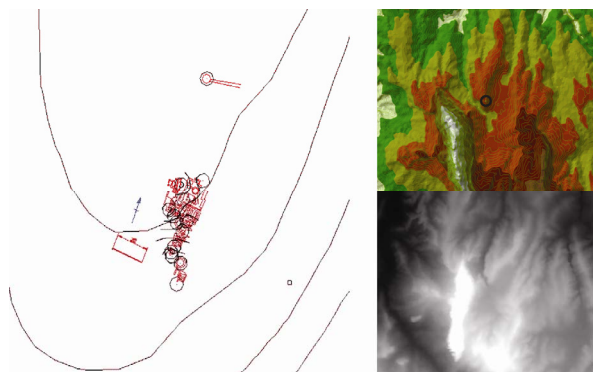
As far as Burial Building 19 is concerned, it has been considered to be a unique structure with no parallels, making the decision making process far more complicated. Although it has characteristics of the constructions known as House Tombs, it was published and reconstructed as a semi-vaulted structure [Mag94]. However, the way that the reconstruction was done, is in conflict with the available data from Cretan *mitata* or other vaulted structures, since a corbelled roof cannot stand if a

counterweight is not put on top of it to counterbalance the forces exerted by the vault. Despite this issue, the idea for a building with a peculiar shape should not be totally excluded; according to some comparators, a semi-vault is possible, on the condition that there are enough stones or other heavy materials on it to counterbalance the basic pressures which are exerted in three directions, inwards, outwards and downwards. This can happen mainly when the exterior face forms a rectangle, the interior forms a vault, and the gap between the two is filled with stones. These architectural features are also confirmed by archaeological and ethnographic correlates. A good parallel comes from the Spanish *barraca*, which are stone shelters in vineyards and combine a rectangular exterior and a vaulted interior, while the gap between the two is filled with earth and stones [Juv04].

#### 3.2 Technical Aspects

The software *3ds Max 2009* was used to create three-dimensional models according to the digitised drawings, by using geometric primitives, adding materials and textures. All of the structures with the exception of tholoi tombs were created using relatively simple geometry, which was then augmented as necessary and optimised. As there was no need for an exact visual representation of the cemetery as a whole, standard *3ds Max* materials were used for the exteriors and the scene was rendered with the Scanline Renderer and Radiosity solution (fig. 2). Only energy-conserving rendering techniques were applied in the interior (specifically the Mental Ray renderer [Men09]).

One of the most crucial issues was to create a reliable terrain model in order to position the virtual reconstruction. In order to accomplish this task, the available data were combined. These were: ESRI format GIS datasets [Esr09], including a Digital Elevation Model (DEM) with a resolution of 20m of the area 4-5 km around the site and contour lines with intervals of 10m, some measurements derived from personal observations, and the documentation of the excavation (fig. 6). Limitations in the resolution of these data meant that it was not possible accurately to represent all of the variations of the slope.



**Figure 6:** Contour lines and digitised plan of the cemetery in AutoCAD (left), Terrain & Contour lines (TIN) and Digital Elevation Model in Arc MAP (right).

In order to create the stones of the main buildings, with various shapes and roughness, a noise modifier was used, making each stone unique. The end product, although inducing complexity at some areas of the exterior face due to the various shapes of stones to fit, was far more accurate and realistic, as far as the



visual appearance and the illumination of the interior were concerned. The realism was enhanced by manually positioning the stones in the appropriate way and then, using *Reactor* [Aut09] to create a more physically-defined result, respecting the physical qualities of each object. This introduced considerable, valuable complexity into the modelling process, mainly because the vaulted roof could not stand if the stones were not correctly positioned and, generally speaking, if the digital construction did not follow the real process. Stones had to be positioned in groups with some overlapping others below to act as a counterweight for the different forces exerted by the masonry. An alternative building method using a wooden former was considered but not implemented. Although true finite-element modelling was considered for the purposes of this project *Reactor*, employed carefully and with considerable structured variation in parameters, was deemed sufficiently accurate. It was able to consider forces acting in multiple directions, friction and varying centres of gravity. It did not consider structural validity in terms of compression and breaking point of the construction materials employed.

The realistically-shaped stones positioned on the top of the vaulted roof resulted in a high polygon count. This caused problems during processing and rendering. As a solution, some of the stones were amalgamated once resolved as 'stable' by *Reactor* or replaced by soil. Extant parallels suggest that this latter approach may well have been used in the real construction. These modifications reduced the number of polygons and enhanced the performance of the software, without significantly impacting the physical realism of the modelled environment. The same process of high complexity modelling followed by interactive optimisation was applied to the creation of ceramics and other objects within the scenes.

These modelling issues directly stimulated experimentation with alternative structural models, which might have been used as several comparator sites suggest. As a result, not only were the software and hardware limitations overcome, but a thorough archaeological study was produced, creating a series of different visual perceptions of the structures, and resulting lighting models.

As a final component to the modelling it was decided to incorporate human models in the reconstruction. This was not in order to populate the cemetery and counter the frequently 'dead' nature of virtual environments, or even to try to justify the sex or the social status of the participants, but in order to consider the tombs' capacity and ergonomics.

#### 4. Non Modelling Methodologies

For our analysis global illumination was used throughout, adding more realism to the three-dimensional scenes. As a consequence of its energy-conserving basis *Mental Ray* was used as the rendering engine, employing *Final Gather* in the final render pipeline, with comparison between results with different solutions carried out throughout. *Final Gather* shoots additional rays into a scene in a hemisphere above the sampled point. Incident illumination is collected from the global illumination of the surrounding geometry and environment leading to improved simulation of indirect illumination. In order to produce accurate renderings of daylight scenarios two special photometric lights and an environment shader were used. The

*Mental Ray* (mr) Sun photometric light is responsible for the direct light from the sun, whereas the mr Sky simulates the phenomenon of indirect light created by the scattering of sunlight in the atmosphere. The mr Physical Sky was used as an environment shader, with Haze Driven as a sky model to define the typical brightness distribution of the skylight.

The built-in 3ds Max daylight system, which works with both *Mental Ray* and other forms of lighting, cannot calculate the position of the sun before AD 1583 and as a consequence *Alcyone Ephemeris* was used. This is an extremely accurate astronomical ephemeris calculator covering the period 3000 BC to AD 3000. 3ds Max does not enable manual input of the appropriate values defining the sun's position. As a consequence, the solution was provided by aligning the daylight system on a line which was positioned according to the azimuth and altitude values obtained by *Alcyone*.

Most computer graphics images represent scenes with illumination at daylight levels. Relatively few are created with physically accurate twilight or nightlight. Accurate night illumination is far more complicated than daylight with physically-accurate night-time renders rare. Jensen attempts a physically-based simulation of the night time sky taking into account the moonlight, which accounts for most of the available light at night, the sunlight which scatters around the edge of the Earth, as well as light received from the planets and stars, zodiacal light, airglow, galactic light and cosmic light [JPS\*00, JDS\*01]. Although Jensen and his team completed extensive research on this issue our work was not able to benefit from a similar breadth of illuminance data. As a result this part of the project was based on limited information mainly found in online resources [Har74, APW76]. According to our research it was roughly estimated that the light during a clear night is less than 10.3 lux. However, it should be taken into account that the resultant image is a depiction of how a camera exposes and captures a scene, without considering the human eye's adaptability in different lighting conditions (photopic, mesopic and scotopic vision).

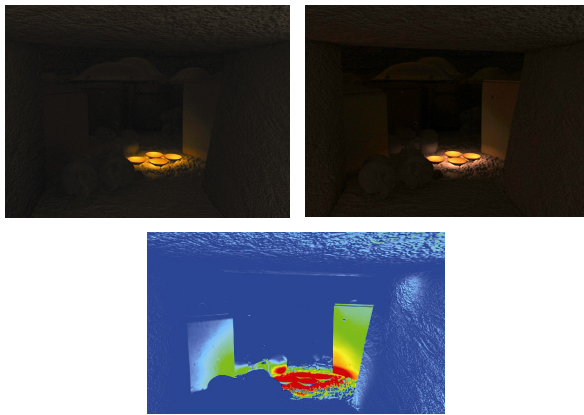
One of the most crucial questions in computer graphics is how to reproduce the real colour of light sources in a rendered environment. In order to obtain an estimation of the original lighting in an archaeological representation, two factors must be addressed: Firstly, the spectral composition of the light, in other words the colour of the light given off by the burning fuel and secondly, the distribution of this light around a scene. The study of the flame illumination was based on primary data obtained

Fuel Type	X	Y	Z	RGB
Beeswax	1.8268 – 1.48275	1.35252	0.1680256	R 54.5 – 45.17
				G 21.48 – 27.18
				B 0.13 – 0
Olive Oil (Plain)	6.7875	5.1091	0.4392	R 104.28
				G 48.61
				B 0
Olive Oil (Organic)	6.14	4.4981	1.47925	R 98.12
				G 44.30
				B 25.26
Sesame Oil (Organic)	5.6436	4.2569	0.545673	R 95.12
				G 44.2
				B 0.75

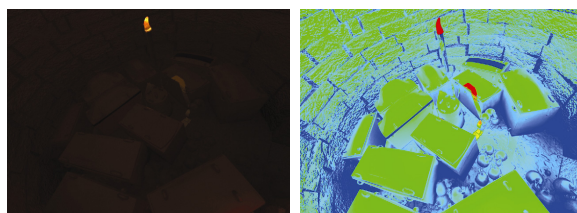
Figure 7: X, Y & Z channels and the corresponding RGB values for each type of fuel (Adapted from Roussos work).

by Roussos during his research, examining the perception of beeswax lamp, olive oil lamp (organic), lamp burning fat, sesame oil lamp (organic) and torch, in comparison to modern luminaires. The distribution of all such flames with the exception of torches was considered to be isometric. The luminous intensity value was given by the spectroradiometer and was cross checked by psychophysical experiments by Roussos to 199 candelas.

For this project, it was decided to use the luminaire data provided by Roussos and to convert it from scratch to RGB values according to the standards of the *Commission Internationale de l'Éclairage* (CIE) (fig. 7). The combustion of wood proved more problematic. Wood may be considered one of the most complicated fuels to model, as the colour and intensity variation is highly dependent upon its species and a range of factors relating to its treatment. The absence of any appropriate data constrained this part of the work to a rough approximation of wood's intensity according to the light emitted from a fireplace which can reach 5000 candelas. As a consequence, it was estimated that a burning timber/ torch can produce an average of 1500 candelas. However, this remains a somewhat arbitrary assumption (fig. 9).



**Figure 8:** Flame Lighting in Tholos Tomb C (2<sup>nd</sup> Phase) Left – Beeswax, Right - Olive Oil. According to the luminance values the lamps provide illumination locally, which means that it can be used for a specific task, rather than to illuminate the tomb as a whole. See [LD06] for the CGI reconstruction of Thule whalebone houses and impacts on activity.



**Figure 9:** Torch with intensity of 1500 candelas providing flame lighting of approximately 100 lux.

The initial aim of this research was to use the geometric model of the cemetery at its various phases in order to observe if the software employed could efficiently handle the complicated phenomena of indirect illumination. However, several problems of the archaeological record impacted this. For example, the

height and the construction techniques of the buildings, and the vegetation of the palaeo-environment remain totally unknown.

After several attempts at using the actual geometry or using test scenes and changing parameters, it was realised that this kind of illumination study needs further research by experimentally comparing the various results to some reference data. It cannot be based solely on the software used, since the outcome proved variable when more structures were added. Changing the parameters (e.g. decay value) may have provided a realistic and more appealing but not physically accurate result, which was not the purpose of this project. As a consequence, it was preferred to constrain the lighting study to only an approximation of the lighting levels, without reaching any specific conclusions relating particular lighting values to beliefs or rituals.

## 5. Results

A faithful three-dimensional model, based on well-studied and comprehensively reviewed archaeological evidence, is considered as one of the most important factors in order successfully to address controversial issues, consider various hypotheses and discuss the results of complicated research processes, which otherwise would have been impossible by using traditional archaeological means, such as drawing and photography. We have described a workflow based on physically based modelling, luminaire physical properties and orientation, rendering, and iterative analysis that could be readily applied to other archaeological contexts.

The results of this research were mainly presented by high-quality rendered images of the 3D models. As far as the illumination is concerned, a Macbeth colour chart was created and rendered in the scenes offering a colour comparison standard. In particular this offered improved subjective comparison of colour bleed and variations in luminaire colour. In addition, rendered images using Pseudo Colour Exposure Control were used as a lighting analysis tool. This provided a way of visualising and evaluating the lighting levels in the various scenes by using a graded colour map expressing luminance.

The virtual reconstruction of the two burial buildings offered valuable information regarding the architecture, use, capacity, ergonomics and illumination of the ancient structures. In order to overcome the absence of essential data which are needed for such a detailed study, information derived from comparator archaeological sites and similar buildings was used. The result was a comprehensive study of the buildings' architecture (fig. 12-13) forming the basis for additional experimentation regarding the mobility of people visiting them, the changes in ergonomics during their various phases, as well as the illumination of the interior contributing to a further understanding of any components of this research.

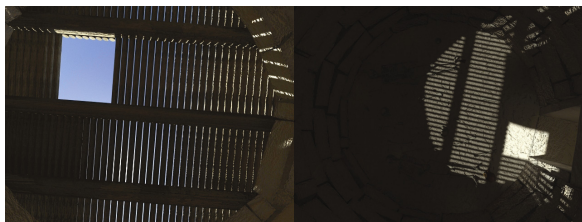
Since the structures are not fully preserved a definitive conclusion about their architecture cannot be drawn. However, it seems likely that architecture is closely related to illumination in this context. For example, a structure built with a wooden roof or without a capstone may have facilitated the ventilation of the tomb during rituals or clearing activities. The archaeological evidence from Minoan burial contexts suggests that the living entered the tombs to practice rituals, clearing activities and to make room for forthcoming burials. Such

distinctive architectural features have a dramatic impact to the luminance values obtained (fig. 10-11). The results also suggest that the rising sun directly entered the interior of the tomb in the morning during spring and summer months (fig. 4, 14). Such periods may have characterised the ‘times of the dead’ [Goo04], with the first light entering the tomb identifying or being identified with the times of seasonal or funerary rituals at the tomb sites. The dates of the alignments may have served as chronological or economic markers, or may reflect ideas about what happens to the dead and thus indicate tomb builders’ intentions. However, the amount of light that reached the interior of tholoi also suggests a complimentary form of artificial illumination (fig. 8-9).

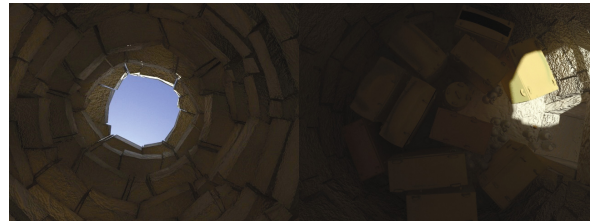
The creation of several structural models with different sizes, forms and materials gave the only chance – apart from a future thorough archaeological study and physical reconstruction – to observe the advantages and disadvantages regarding the depiction and interaction of light in the various scenes (fig. 11-12). Although there is not any reliable way for testing the illumination results, with the exception of psychophysical experiments, it seems from comparator architectural datasets that the lux values obtained are quite reasonable for spaces with such features (e.g. small openings). Lighting results derived from the different architectural models represented a discrete series of spatial conditions, which may in turn have reflected on the livings’ attitude towards death.

As a consequence, not only did the methodological approaches produce results, but through them we managed to expand the research questions. Structurally we have offered valuable information regarding the impact of alteration of the various elements, such as the roofing techniques. Reactor proved an excellent modelling tool and although structural comparisons using other software or physical reconstruction were not performed our assessment is that used carefully the physics engine produces a good assessment of stability and structural interdependence. In terms of illumination solstices and equinoxes from the past did not seem to be associated with significant variations to the broader range of dates simulated (a sample of more than 100 dates derived from the present and the past).

The slight differences resulting from the study of flame illumination are unlikely to have defined diversity in the perception of the structure. Also, we have no evidence that people chose a specific fuel based only on the colour emitted since the slight variations identified may not have been distinguishable by human vision.



**Figure 10:** First phase of Tholos Tomb C with a wooden roof without earth on top and a small opening (30<sup>th</sup> July at 15:00 2007).



**Figure 11:** Second phase of Tholos Tomb C without a capstone (30<sup>th</sup> July at 15:00 2007).

## 6. Conclusions and Recommendations

Physically accurate simulation of lighting in archaeological environments is clearly of vital importance to studies of ancient activity. Photorealistic simulation is insufficient in these contexts. As archaeological practitioners of computer graphics we look forward to more accessible software solutions for physically accurate rendering. In addition to 3ds Max improvements, we look forward to greater availability of experimentally-derived luminaire datasets covering the archaeological spectrum. This paper makes considered use of extant software rather than developing new methodologies but we believe that it is only through such careful implementation by archaeologists that technological developments necessary from a cultural heritage perspective may be identified.

Virtual reality is highly dependant on the software and hardware deployed, and on the hand of the archaeologist making use of them. Similarly, limitations in data storage, computation and video display continue to prevent the creation of models to a precision that archaeologists might prefer. This study and many other archaeological reconstructions are in our view only ever revised versions of the drawings created during the excavation, which were a copy of the already altered actual remains, in turn reinterpreted for their publication a few years later. We must never forget that repeated copying and reinterpretation of the archaeological evidence change the image of the past, developing new information but also leaving other data behind.

Even were we able to produce an exact digital replica of the Minoan cemetery at Phourni it is certain that the Minoan burial cult, including the attitude of the living towards death, the perception of afterlife, and the various rituals held for practical or spiritual purposes could never be reconstructed. Our constructed virtual pasts will always have traces of ourselves, being an amalgamation of the modeller’s background and former stimuli, betraying aspects of views, prejudices, preferences and habits. In our view archaeology is all the richer for this.

\* Additional information about the project can be found online: <http://virtualreconstruction-phournicemetery.blogspot.com>

\*\* All the images were produced by Papadopoulos whilst he was a post-graduate at the Archaeological Computing Research Group, School of Humanities, University of Southampton.



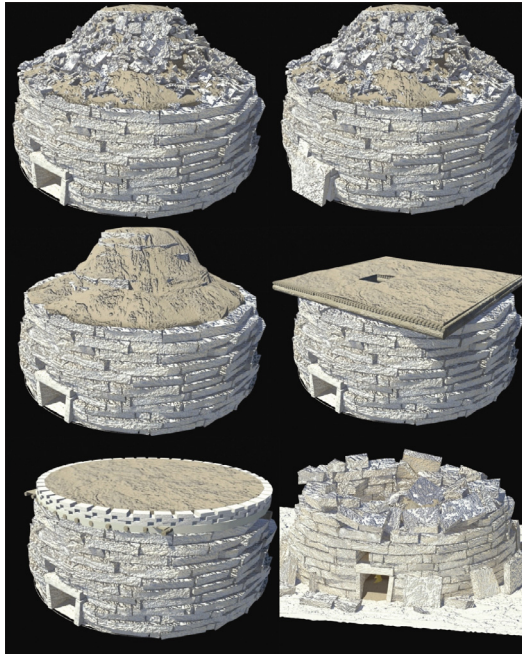
## References

- [APW76] Austin, H. R., Phillips, F. B., Webb, J. D. 1976. "A Method for Calculating Moonlight Illuminance at the Earth's Surface" IN *The Journal of Applied Ecology* Vol. 13, No. 3 p. 741-748 <http://www.jstor.org/stable/2402251>
- [Aut09] Autodesk 2009. *3ds Max*. <http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=5659302>.
- [Bra70] Branigan, K. 1970a. *The Tombs of Messara, A Study of Funerary Architecture and Ritual in Southern Crete, 2800-1700 B.C.* Great Britain: The Garden City Press Limited
- [Bra94] Branigan, K. 1994. "The Corbelling Controversy - Another Contribution" IN *Cretan Studies* 4. p. 65-69
- [Cha02] Chalmers, A. 2002. "Very Realistic Graphics for Visualising Archaeological Site Reconstructions" IN Proceedings of the 18th spring conference on Computer graphics <http://portal.acm.org/citation.cfm?id=584460>
- [CD05] Chalmers, A. & Debattista, K. 2005. "Investigating the Structural Validity of Virtual Reconstructions of Prehistoric Maltese Temples" IN Mudge, M. Ryan, N. Scopigno, R. *The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST)* <http://www.cs.bris.ac.uk/Publications/Papers/2000420.pdf>
- [DC01] Devlin, K. & Chalmers, A. 2001. "Realistic Visualisation of the Pompeii Frescoes" IN Proceedings of the 1st international conference on Computer graphics, virtual reality and visualisation <http://portal.acm.org/citation.cfm?id=513867.513878>
- [DCB02] Devlin, K., Chalmers, A., Brown, D. 2002. "Predictive Lighting and Perception in Archaeological Representations" IN *UNESCO World Heritage in the Digital Age 30th Anniversary Digital Congress* [http://doc.gold.ac.uk/~mas01kd/publications/unesco\\_paper.pdf](http://doc.gold.ac.uk/~mas01kd/publications/unesco_paper.pdf)
- [Esr09] Environmental Systems Research Institute 2009. *ESRI*. <http://www.esri.com/>
- [Goo01] Goodison, L. 2001. "From Tholos Tomb to Throne Room: Perceptions of the Sun in Minoan Ritual" IN Laffineur, R. & Hägg, R. (eds.) *Aegaeum 22 POTNIA. Deities and Religion in the Aegean Bronze Age*. Proceedings of the 8<sup>th</sup> International Aegean Conference [http://www2.ulg.ac.be/archgrec/IMG/aegeum/aegeum22\(pdf\)/11%20GOODISON.pdf](http://www2.ulg.ac.be/archgrec/IMG/aegeum/aegeum22(pdf)/11%20GOODISON.pdf)
- [Goo04] Goodison, L. 2004. "From Tholos Tomb to Throne Room: Some Considerations of dawn light and directionality in Minoan Buildings" IN Cadogan, G. et al. (eds.) *Palace, City, State: Proceedings of the Conference in Herakleion in November 2000*, 12, British School at Athens Studies. p. 339-350
- [Har74] Harrison, N. J. 1974. *The Handbook of Electro-Optics*. RCA Commercial Engineering
- [Hoo60] Hood, S. 1960. "Tholos Tombs of the Aegean" IN *Antiquity* 34 p. 166-176
- [JDS\*01] Jensen, W. H. et al. 2001. "A Physically-Based Night Sky Model" IN *Proceedings of Siggraph, 12-17 August 2001*. Los Angeles <http://graphics.ucsd.edu/~henrik/papers/nightsky/>
- [JPS\*00] Jensen, W. H. et al. 2000. "Night Rendering" IN *University of Utah Technical Report (UUCS-00-016)*. Computer Science Department: University of Utah <http://graphics.ucsd.edu/~henrik/papers/night/>
- [Juv04] Juvanec, B. 2004. *The Stone: What Can Be Done in Dry Stone Walling System*. Online Resource <http://www.stoneshelter.org/stone/>
- [LD06] Levy, R. & Dawson, P. 2006. "Reconstructing a Thule Whalebone House Using 3D Imaging" IN *IEEE MultiMedia*, vol. 13, no. 2, pp. 78-83
- [Mag94] Maggidis, C. 1994. *Burial Building 19 at Archanes: A Study of Prepalatial and Early Protopalatial Funerary Architecture and Ritual*. Unpublished PhD Dissertation. University of Pennsylvania
- [Men09] Mental Images 2009. *Mental Ray*. <http://www.mentalimages.com/index.php>
- [Pap05] Papadatos, Y. 2005. *Tholos Tomb Gamma: A Prepalatial Tholos Tomb at Phourni, Archanes*. Philadelphia: INSTAP Academic Press
- [RC03] Roussos, I. Chalmers, A. 2003. "High Fidelity Lighting of Knossos" IN Arnold, D., Chalmers, A. Niccolucci, F. (eds) *4th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage (VAST)* p. 47-56 <http://www.eg.org/EG/DL/WS/VAST/VAST03/195-202.pdf>. abstract.pdf;internal&action=paperabstract.action
- [Rou03] Roussos, I. 2003a. *Image Based Flame Lighting* Unpublished PhD Dissertation. University of Bristol
- [SCM04] Sundstedt, V. Chalmers, A. Martinez, P. 2004 "High fidelity reconstruction of the ancient Egyptian temple of Kalabsha" IN Proceedings of the 3rd international conference on Computer graphics, virtual reality, visualisation and interaction in Africa <http://portal.acm.org/citation.cfm?id=1029970>
- [Val88] Vallianos, C. 1988. "Prologos" IN Syrmakezis, K. (ed.) *Ta Mhtata ths Krrhths. Dierevnish ths Statikhhs Leitourgias tous me Sygxrones Methodous*. Voro: Mouseio Krrthikhhs Ethnologias. p. 9-13
- [War07] Warren, P. 2007. *The Roofing of Early Minoan Round Tombs: The Evidence of Lebena Tomb II (Gerokampos) and of Cretan Mitata* IN Betancourt, P. et al. (eds.) *Krinoi kai*

Limenes. Studies in Honor of Loseph and Maria Shaw. Pennsylvania: INSTAP Academic Press p. 9-16.

[War73] Warren, P. 1973. "The Mitata of Nidha and Early Minoan Tholos Tombs" IN AAA 6 p. 449-456

[Zan07] Zányi, E. 2007. "High Dynamic Range Display of Authentically Illuminated Byzantine Art from Cyprus" IN Arnold, D. Niccolucci, F. Chalmers, A. (eds.) *The 8th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST 2007)*

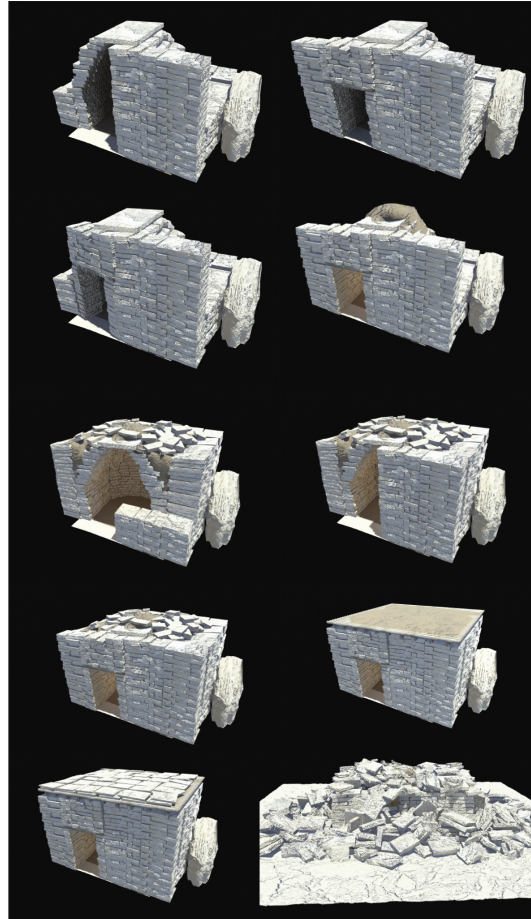


**Figure 12:** Structural models for Tholos Tomb:

**A.** Earth and stones act as a counterweight for the forces exerted by the vaulted roof **B.** Entrance and window closed with slabs **C.** Only earth is used as a counterweight for the forces exerted by the vaulted roof **D.** Rectangular roof with a small opening facilitating air ventilation, light and human movement. **E.** Reconstruction based on the parallels from Lemba Lakkous. The entire earth structure of the roof is held in place with layers of stones set in mud around the edge of the wall head **F.** Destruction of Tholos Tomb C using Reactor.



**Figure 14:** Second phase of Tholos Tomb C when a ray of light directly enters the tomb (30th April at 7:00 2007)



**Figure 13:** Structural models for Burial Building 19:

**A.** Reconstruction based on the published handmade drawing by Christophilis Maggidis [Mag94] **B.** A rubble wall was constructed in the whole west side to facilitate the positioning of a wooden lintel and create the illusion of a regular house tomb **C.** A rubble wall was constructed to facilitate the positioning of a wooden lintel by bridging the gap between the west and the north side **D.** A vaulted or semi-vaulted structure cannot be stable and hold its own weight, if earth or stones have not been put on it to provide constant pressure and act as a counterweight **E.** Reconstruction, which presents the only way of construction of a vaulted roof in order to be stable. The exterior is rectangular, the interior forms a semi-vault and the gap between the two is filled up with a great amount of earth and stones. The west wall does not exceed the 1 metre **F.** The west wall reaches the maximum height of the structure (2.5 metres) **G.** The whole west wall reaches the maximum height of the structure (2.5 metres) and facilitates the positioning of a wooden lintel **H.** The whole building was made up of stones and the roof was constructed with wooden beams and pressed earth **I.** The whole building was made up of stones and the roof was constructed with wooden beams and schist slabs **J.** Destruction of Burial Building 19 using Reactor.