Characterising lighting ambiances through the study of lamps in Kommos City (Crete) during the Bronze Age (3200-1100 B.C.)

Bastien Rueff, Phd student in Aegean protohistory, University Paris 1 Panthéon-Sorbonne. ArScAn Laboratory (UMR 7041).

Introduction

Occurrences of Cretan lamps multiplied during the Bronze Age, especially from the Middle Minoan period (for the chronology, see fig.1). Their frequent discovery in residential context suggests that these items were used in daily life. Yet, most of the studies that were conducted about them followed a descriptive approach that does not allow to show the way they were used in buildings.

Prepalatial period	EM I	Early Minoan I	3200 – 2750/2500
	EM II	Early Minoan II	2750/2500 - 2300
	EM III	Early Minoan III	2300 – 2100
	MM I A	Middle Minoan I A	2100 – 1900
Protopalatial period	MM I B	Middle Minoan I B	1900 – 1800
	MM II	Middle Minoan II	1800 – 1700
Neopalatial period	MM III	Middle Minoan III	1700 – 1600
	LM I A	Late Minoan I A	1600 – 1500
	LM IB	Late Minoan I A	1500 – 1450
Postpalatial period	LM II	Late Minoan II	1450 – 1400
	LM III	Late Minoan III	1400 – 1100

Fig.1: *Chrono-cultural context. Map of Eastern Mediterranea (http://www.histgeo.ac-aix-marseille.fr/webphp/pays.php?num_pay=236&lang=fr). Map of Crete (http://reflectim.fr/tag/carte-de-crete-grece/)*

At the end of the XIXth and at the beginning of the XXth centuries, pioneers of Aegean archaeology had, however, expressed some concerns about the functioning and the function of Cretan lamps from Bronze Age. This willingness to go beyond purely typological descriptions of artefacts translates into a global approach going from fat residues and use-wear traces observation (Persson, 1942) to lamp analysis in their archaeological context. In tombs and sanctuaries, light coming from the lamps is either given a symbolic meaning (Demargne, 1932; Evans, 1930; Evans, 1935) or a utilitarian function (Evans 1906; Xanthoudides, 1924). In residential buildings, authors believe that preserved openings, as well as rooms' function and surface area justify the presence of lamps, as we can see for instance with G building in Gournia (Boyd Hawes, 1908), the palace of Knossos (Evans, 1930; Evans, 1931), the palace of Malia (Chapouthier, Demargne

1942; Pelon 1970), the Zb house (Deshayes, Dessenne, 1959) and the "House of the Beach" of Malia (Van Effenterre, Van Effenterre, 1976). This exhaustive approach lacks an experimental program that would document the technology of lamps, similar to what is done during the same period for tooling (Procopiou, 2010). Moreover, none of these works proposes a real overview.

Since the 1970s, the way lamps were published in excavation reports radically evolved. Documentation has been considerably renewed by numerous diggings (Archanes, Haghia Photia, Mochlos, Petras, Vassiliki, Monastiraki, Khania, Galatas, Vrokastro, etc.; Treuil, et al., 2008). Lamps are gathered and classified into typo-chronologies, but their lighting function is no longer treated.

These typo-chronologies are based on morphological criteria: material, foot, spoot, handle, body, rim, clay and decors. After the old classification of Palaikastro (Bosanquet, Dawkins, 1923), we can cite several other classifications: Phaistos (Mercando, 1974-1975), Mochlos (Evershed, et al., 1997), Knossos (MacGillivray, 1998) and the more generic one for stone lamps (Warren, 1969). We can also add the recent typo-chronologies of the district Mu of Malia (Poursat, 2013) and of the House X of Kommos (Rutter, 2013).

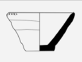
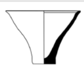
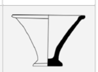
Type	DATATION	SIZE (cm)	ILL.
Conical cup type C	LM I A	Height : 5 Width : 5	
Conical cup type D	LM I B	Height : 6 Width : 5	
One-handled footed cup	LM III A	Height : 8 Width : 6	No ill.
Flat-based deep Kalathos	LM III A	Height : 10 Width : 8	
Footed deep kalathos	LM III A	Height : 10,6 Width 7,8	
Pedestal-footed bowl	LM III A	Height : 15 Width : 10,8	

Fig.2: *Bowls reused as lamps in Kommos during LM period (after Rutter, 2013)*

Unfortunately, the functional aspect of lamps cannot be approached only with morphological criteria. Besides, these criteria may be misleading when identifying the items. Indeed, except for Kommos (fig.2) and Mochlos, none of these classifying systems takes into account the numerous conical cups, kalathoï, kylix, footed cups and pedestal-footed bowls that have been proven to have been reused as lamps, despite their lack of spout, thanks to the burning traces observed on their rim (Barnard, Brogan, 2003; Gillis, 1990; Hood, 1964), especially during the LM III (Hallager, 2011).

Beyond its utility to identify lamps, this parameter is essential because, in some cases, the lack of spout may indicate the use of solid fuels, allowing the wick to maintain itself, as Douglas (2001) and Thalmann (2012) suggest for Near East areas during the IIIrd millenium B.C.

Research in the 2000s is characterized by a new interest in buildings' lighting in Eastern Mediterranean. Regarding lamps, this interest is expressed by numerical reconstitutions based on experimental programs aiming at recording light. These experimental programs are effectively focused on lighting technological choices (from the wick to the fuel), such as what has been done for the sites of Troy in Minor Asia (Bronze Age) (Kurzmann, 2005), of Tel Kedesh in North Galilee (Persian period) (Elrasheedy, Schindler, 2015) or, more generally, in Ancient Greece (Vth-IVth centuries B.C.) (Amouretti, 1986). However, they are also interested in light properties, whose photometric data are recorded thanks to several measurement tools, in order to render numerical models. This method, for instance, permitted to examine the activities that could be performed under the lamps' flames in andron (rooms dedicated to banquets) in Greece during IVth and IIIrd centuries B.C. (Moullou, et al., 2012a).

In this perspective, virtual reality, able to exploit the physical data of the experimentation, opens the door to promising lines of research. By giving substance to a building's lighting, it contributes to understanding the lived space and sensorial perceptions of its inhabitants (Paliou, Wheatley, Earl, 2011). Initiated by Kate Devlin and Alan Chalmers (2001), 3D opens a wide exploratory field on space functionality, linked to light areas. This innovative approach offers the advantage of finding applications in every chrono-cultural context, from Cretan and Anatolian Neolithic houses (Cox, 2015; Papadopoulos, Hamilakis, Kyparissi-Apostolika, 2015), to Cypriot Byzantine church (Happa, et al., 2009), through palaces and domestic units in Cretan Bronze Ange (Papadopoulos, Earl, 2013; Papadopoulos, Sakellarakis, 2013; Roussos, Chalmers, 2003), Athenian Parthenon in Classic Greece (Debevec, et al., 2015) or Egyptian temple of Kalabsha in the Ist Century B.C. (Chalmers, Martinez, Sundstedt, 2004).

Following this functional approach, this article aims at proposing an analytical method to study Cretan lamps from the Bronze Age, using Kommos city as a case study. This site was chosen for three reasons: first of all, for the diversity of archaeological contexts that can be found there, allowing to evaluate the conditions in which lamps were used, according to their location (domestic units, civic and administrative buildings, boathouse, etc.). Secondly, because this site was occupied for a thousand years, it allows us to observe an evolution in the lighting trends. Finally, as Cretan lamps of all shapes can be found on this site, comparisons with other sites and suggestions concerning the functioning of so far unknown lamps can be undertaken.

Our approach aims at evaluating whether a spatial analysis allows us to understand how lamps are distributed in different archaeological contexts. Our goal is also to propose an experimental protocol that can be used to characterize light ambiances. We hope this approach can apply to other chrono-cultural areas.

I. Lamps and lighting in Kommos: towards a spatial analysis

I.1. Kommos, a Cretan Bronze Age city

Located in the southern part of Crete (fig.1), the Kommos site was built on the side of a hill. After a sparse occupation during Late Neolithic and Early Minoan periods, the extensive installation happened during MM I B (Shaw, 2006). At this period, there were two areas: one at the top of the hill (Hilltop Area, HA) and one halfway to the top (Central Hillside Area, CHA). An earthquake destroyed these buildings at the end of MM (they were later rebuilt, at the beginning of the LM) (Shaw, 2006). Meanwhile, during MM II, a building named AA was built down the hill, in a zone called Southern Area (SA). This edifice's function is not known, though some religious sherds were found there (Shaw, Shaw, 2006). It was destroyed at the end of MM II and replaced by a building named T during MM III. T building was made of cut stones, had a court in its centre and hosted civic and administrative activities. Besides, six large juxtaposed galleries, serving as boathouses, composed the southern part of T building. As early as the Neopalatial period, Kommos could have served as a harbour for the neighbour cities of Phaistos and Haghia Triada (ibid., 2006). After the building's destruction at the end of LM I followed a period of hiatus. Then, during LM III A2, a new monumental unit was built, composed of edifices N and P. They seem to have assumed the same function as T building had. The whole site was abandoned at the end of the LM III B. It was not reoccupied before the end of the 11th century B.C. (Shaw, 2006).

I.2. Lamps in Kommos lighting device

Thanks to a bibliographical study, we have been able to list 81 already published lamps, among which however 10 could also be braziers. With the help of simple statistical treatments and of a GIS, we investigated what factors could explain lamps' distribution in buildings, according to other artificial light sources that were discovered on the site (i.e. 28 hearts and kilns). The analysis is based on vestiges found in situ, in order to

make sure that lamps were used at least one time in the room they were found in.
The next step of this approach will be to include openings (doors, windows, lightwells, etc.). Besides, this work will soon be reinforced by a direct analysis of archaeological finds, with a focus on use-wear traces which are essential indicators of combustion process.

Protopalatial period
22 lamps dated from protopalatial period were identified in Kommos. All of them are in clay. Pedestal lamps are more numerous than low lamps (respectively 13 and 9). Nevertheless, six items qualified of pedestal lamps could actually be braziers. Pedestal lamps have two spouts and, usually, two tenons (Shaw, Shaw, 1992). Low lamps can have one straight spout and one rounded vertical handle but can also be simple bowls (ibid., 1992).
The totality of the protopalatial sample comes from CHA (East building, North building, east of the Round building) and SA (AA building, construction fill, pit's fill under T building). Lamps are not present in HA. As far as we know, there is no other artificial light sources during this period. Furthermore, none of the lamps was found in situ, making impossible an analysis of the lighting device.

Neopalatial period
During neopalatial period, lamps are present in all the areas of the site (fig.3). 35 were recognised. All of them are in clay. Low lamps with one spout and one rounded vertical handle as well as bowls reused as lamps became more numerous than pedestal lamps which have almost disappeared. Between MM III and LM I A, we assist to the gradual appearance of hearts in buildings (Shaw, 1990). According to us, these hearts may have replaced pedestal lamps as fix artificial light sources.
Among lamps, 18 were discovered in situ, 1 comes from the upper floor and 16 are in secondary position but do not comes from a upper floor.

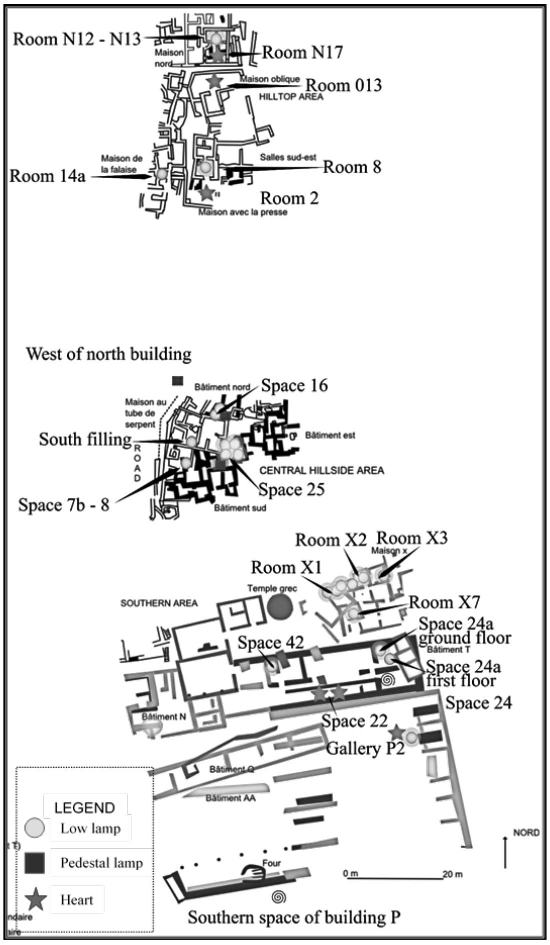


Fig.3: *Lamps' distribution during neopalatial period (after Shaw, 2006)*

These lamps are present in HA (House with the Press and Southern Cliffside), in CHA –with a hiatus during LM I (East building, North building, west of the North building, South building), then in SA (T and P buildings, House X). In P building, a single case of low lamp was found but it could be a Cypriot importation whose style allowed excavators to date it from Late Cycladic II (= LM I B) (Shaw, 2006). The monumental character of the building it has been found in suggests that lamps may be indicators of social position of inhabitants.
The use of QGIS software allowed us to evaluate, firstly, whether a correlation between the nature of light sources and room's size was

existing. Then, it helped us to examine whether a correlation between nature of light sources and activities was existing as well.

According to this analysis, lamps are preferentially found in rooms whose surface ranges from 1 to 10 square meters (rooms X1, X2, X3 and X7 of the House X, room 8 of the House with the Press, space 25 of the East building, room 42 of T building, room 7b-8 of the South building). Only two cases of low lamps are present in the very large rooms 24a of T building (34 square meters) and gallery P2 of P building (212 square meters). The important surface of this gallery seems on its own to explain the need in light sources. This hypothesis is reinforced by the fact that the lamp was found at the back of the room which was certainly darker than the entrance.

The review of the function of the room reveals that lamps mainly lit storage rooms (rooms X1, X2, X7 of the House X, space 25 of the East building, spaces 24a and 42 of T building). The recurrence of soot deposits on these lamps allows us to think that they were not only stored in these rooms, but also used. In some cases, it seems that lamps lit specific activities such as craft productions. This is the case for room 8 of the House with the Press where jewellery was manufactured and for room 7b-8 of the South building for which no particular activities were identified but whose furnitures could reveal some weaving (Shaw, 2006). The lamp discovered in room X3 of the House X could likewise have lit cooking activities that took place there.

Burning structures are numerous in rooms with surfaces between 20 and 80 square meters (room 2 of the House with the Press, space 24a of T building, room 013 of the Oblique house, space 22 of T building). One heart was nevertheless found in space X3 of the House X whose surface is of only 7 square meters and another heart was found in the very large gallery P2 (212 square meters). The analysis of all these rooms' function suggests that burning structures were used in kitchen as cooking/heating/lighting fixtures (room 2 of the House with the Press, space X3 of the House X, space 22 of T building) but that they also served to light circulation spaces (court 013 of the Oblique house) and rooms whose surface must have required a high need in light (gallery P2 of P building).

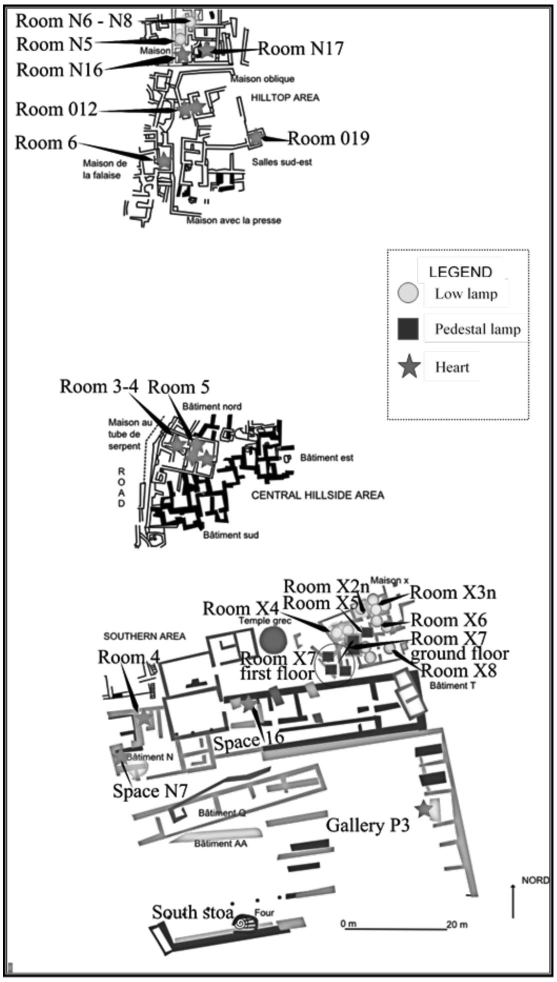


Fig. 4: *Lamps' localisation in Kommos during postpalatial period (after Shaw, 2006)*

Postpalatial period

22 lamps were recognised for postpalatial period (fig.4). Except one case in stone (S663), all of them are in clay. Theses lamps are almost all conical cups, kalathoï, footed cups and pedestal-footed bowls reused as lamps (Rutter, 2013). They were mainly found in the House X that provides therefore a homogeneous assembly from LM II-LM III A2. Three of these lamps

were also found in the House of the Snake Tube and the North house.
Burning structures are very numerous during LM III. They were found in HA (Oblique house, Southern Cliffside, south-east rooms of the North house –where a LM III B brazier was discovered as well), in CHA (House of the Snake Tube –a LM III A2 brazier was also found there), then in SA (T, P and N buildings).
According to the review of spatial distribution, lamps are still found in small rooms with surfaces that range between 1 and 5 square meters on the one side, 10 and 20 square meters on the other side (rooms X4[1] and space X7 of the House X, rooms N5 and N6-N8 of the North house). They seem to have lit domestic activities such as meals (rooms X4 of the House X), sleeping (room N5 of the North house) and intern circulation (corridors N6-N8 of the North house). Concerning the room X7, the current state of research does not allow to specify whether the light of lamps had a symbolic meaning, despite the presumed function of "sanctuary" of this room.
Burning structures are located in rooms of varied sizes, ranging between 10 and 20 square meters on the one side, 80 and 160 square meters on the other side (rooms 012 and 019 of the Oblique house, rooms 3-4 and 5 of the House of the Snake Tube, rooms N16 and N17 of the North house, room 6 of the Southern Cliffside, room 4 of N building, south stoa and gallery P3 of P building, space 16 of T building). In HA, these rooms are dedicated to food preparation. It is also the case in CHA and SA, except for rooms 3-4 and 5 of the House of the Snake Tube and for gallery P3 of P building. In general, hearts seem to have lit large rooms that were sometimes located in the centre of buildings (for instance the room 5 of the House with the Snake Tube where three hearts were discovered). We can assume these fixtures were used as fix sources in order to relay low lamps located in the periphery.
To conclude this part, it seems that simple statistic and cartographic analysis can contribute to understanding the distribution of lamps in buildings. A careful consideration should, in the future, allow us to see whether lamps are indicators of the social position of inhabitants and how they can inform us about modalities of occupation of a building (space functions, rhythm of activities, attendances of places, etc.). It will be necessary to take into account openings. Meanwhile, we propose below an experimental program aiming at evaluating the light ambiances that could occur in Crete during Bronze Age.

II. An experimental program to characterize light ambiances

II.1. Protocol

This experimental program focused on two main issues: "the making of light" on the one side, practical aspects of lamps manipulation on the other side. About "the making of light", we tried to find out whether Minoan and Mycenaean people were able to make some light ambiances choices. In order to do so, we systematically registered illuminance's and flames colours' values[2] coming from various experimental luminaires, fuels and wicks. A photometric cell including a luxmeter and a thermocolorimeter was used to measure these values. These measures were systematically taken 15cm away from the flame, in a fully dark room.
A second step consisted in observing practical aspects related to lamps manipulation, in order to develop a better understanding of the way they were used. First, we attempted to characterize luminaires' mobility and the gesture involved in their transportation. Then, we estimated burning length of different fuels and wicks by using replicas of lamps that were found on sites.

1 In this room, « the combination of door and window was clearly intended to maximize the use of light coming from the light-well » (Shaw, Shaw, 2012: 8).

2 Illuminance is defined by the quotient of luminous flux received on a plane area; it is read in lux. Flame colour is the warmth of a colour, measured in kelvin (Ezrati, 2002)

Eventually, we examined whether spouts are necessary for the wick to maintain itself. This parameter is indeed very important in the light of recent data attesting the occasional use of spoutless vases as lamps (e.g. in Kommos).

II.2. Experimental material

Fig. 5: *Experimental lamps. From left to right: highly polished clay hand lamp (one of the two items manufactured following M66/110-24 in Heraklion Museum) ; Belgium blue stone lamp (foreground) and Villebois bayadère stone lamp (background); pedestal clay lamp*

Lamps

Five experimental lamps were manufactured (fig.5). Two of them are low lamps made of calcareous stone, following a typical shape of MM-LM I, which is characterized by a wick cutting and a handle, according to Peter Warren's typo-chronology[3] (1969). These two lamps are 3cm high, 13cm long and 10cm wide. Their body can hold 0.03L. One of them is made of a light grey Villebois bayadère stone. Its shininess is low, despite having been polished. The second one is made of a Belgium blue stone, and is blue-grey with white spots. Though having been as polished as the first one, its brightness is more pronounced, due to its darker colour. We wondered whether lamps' shininess had an impact on the light produced.

The three other lamps were made of clay and designed following lamps discovered in Malia site (fig.5). Two of them are hand lamps. Their only difference is their polish (one being not polished at all), in order to establish whether shininess influences the light a lamp produces. They both were manufactured following the type 2a lamp from Jean-Claude Poursat's typology (2013) – more precisely the one recorded as M 66/110-24 in Heraklion museum. This type is characterized by a circular body, a straight spout, an annular low foot, a rounded vertical handle, a potter's wheel manufacturing, a coarse red polished fabric clay. It is 7.2 cm high and has a 9.4 cm diameter. We paid a great attention to reproducing the same proportions than the original archaeological items, since shape and function of Minoan lamps are closely linked. For instance, body's capacity determine fuel's quantity, and therefore the burning duration. Our experimental replicas are 6.8cm high and have a diameter of 9cm. They have a capacity of 0.25L. These dimensions are close to the original ones.

The third one is a pedestal lamp designed after a model belonging to type 9c of Jean-Claude Poursat's typology (2013) (M67/53 conserved in Heraklion museum). This type is defined by a high foot, a concave body, made of a coarse, red and polished clay. It has two vertical tenons and two wick-cuttings[4]. The archaeological model is 31cm high and has a diameter of 26.4cm. The experimental one is only 19.5m high, but is large enough for a comparison to be made with low lamps. Its diameter however is quite similar to

3 The lack of handle on our experimental lamps is not a problem for manipulating the items: an external protuberance on the rim is wide enough for the lamp to be held between two fingers, or by its bottom.

4 Since the budget dedicated to experimentations was not sufficient enough, the experimental model does not have tenons and has only one wickcutting. However, as we will explain later in this article, wickcutting is not a necessary condition for the wick to be maintained. Furthermore, the lamp can be transported directly held by the body.

the original one, as it is 25cm wide.

Fuels

Fuels have been gathered from the study of available resources in Aegean world. There are two categories: vegetable oils on the one hand, animals' fats and beeswax on the other hand.

Vegetable oils:

The first vegetable oil we tested is olive oil. There is evidence of its production at a domestic scale as early as EM (Blitzer, 1993). Linear B documentation mentions small quantities from LM III, which could be interpreted as a use as fuels (Rougemont, 2008). It is for instance the case in Mari (Syria), where the palace distributed olive oil to inhabitants in order them to fill their lamps, whose capacity went from 0.17 to 0.3L (ibid, 2008). As a comparison, Françoise Rougemont (2011) reminds us that lamps from district Mu of Malia could contain between 0.05L and 0.3L.

Besides, we also used the oils extracted from the following vegetables as fuels: sesame, almond, moringa, poppy, scots pine, cypress, hemp, flax, castor, safflower, rape, sunflower and nut. The use of this products is attested by archaeobotany in Egypt during Bronze Age (Lucas, Harris, 1962; Brewer, Redford, Redford, 1994) as well as in Linear B texts from Late Bronze Age III (Melena, 1975; Melena, 1983). The experimental oils are organic. For our next studies, products made from traditional techniques should be used in order to evaluate the impacts of energetic properties of oils on light.

Animals' fats and beeswax:

We used as experimental fuels the following products: lard, beef fat, lamb fat, pork fat and beef marrow bones. These products were collected in butcher shops. They are attested by archaeozoology in Crete (Trantalidou, 1990). There are evidences of their specific use as fuels in epigraphical documentation, for instance in Nippur during Late Bronze Age (Mesopotamia), where a half-qû[5] of lard is mentioned among fats that serverd as fuels (Lion, 2006).

Moreover, we used beeswax as experimental fuel, since this resource was used in Crete during Bronze Age according to residue analysis that were conducted on MM III – LM IB lamps discovered on Mochlos site (Evershed, et al., 1997). Residue analysis likewise detected beeswax in two perforated sherds from Neolithic sites of Limenaria (Thasos) and Dikili Tash (Eastern Macedonia and Thrace) (Decavallas, 2011). Burning traces are observed on these sherds. That indicates that they may have been used as lamps. Nevertheless, concerning Dikili Tash, soot deposits could also be explained by the fire that destructed houses (ibid., 2011).

Wicks

Flax, papyrus and hemp have been used as experimental wicks. These vegetables were used as wicks in Classical Greece and Roman Empire according to Pausanias (Description de la Grèce, livre 1, L'Attique, 26, 6) and Pline the Elder (HN, XXVIII, 11, 47). We used different manufacturing techniques to determine whether material or manufacture is the most importants modulation parameter of light. We bought coils of flax and hemp, which means they were spinned beforehand. We then transformed them into wicks thanks to drawstring and braiding techniques. On the opposite, we harvested papyrus ourselves, before manually retting and spinning them (fig.6).

5 Around a half liter.

ht

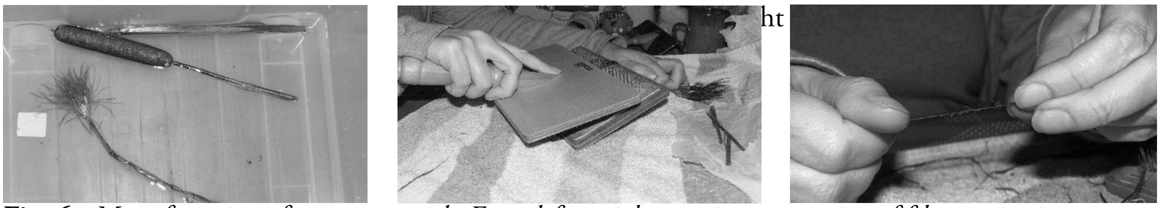


Fig. 6 : *Manufacturing of a papyrus wick. From left to right : retting, separation of fibers, spinning*

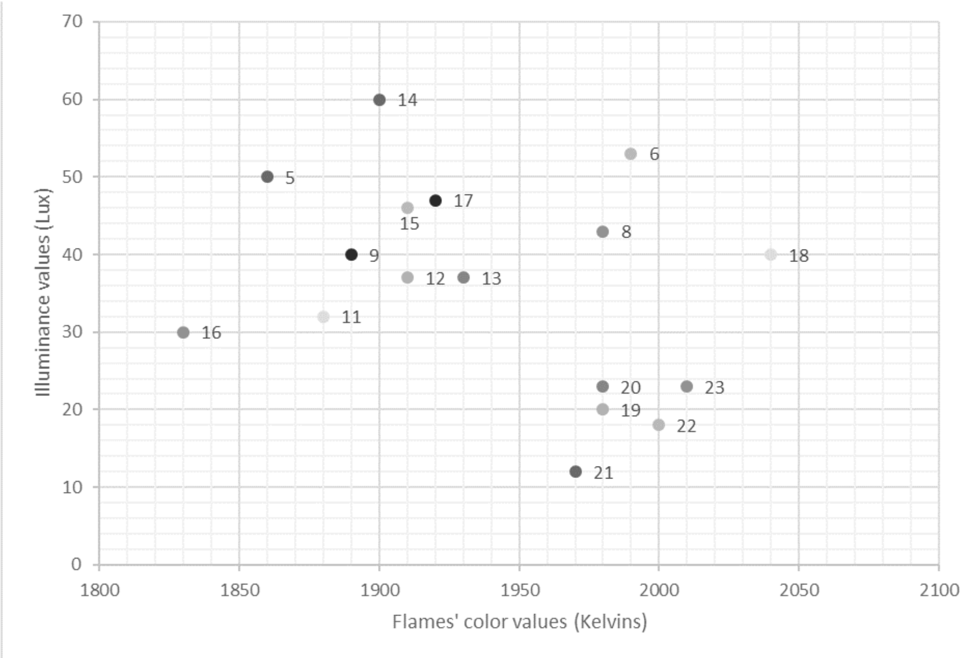
II.3. Results

Flames colour temperature and light measurements

Lamps' role:
As this series of test aimed at specifying the role lamps play in light and flames colour, only the lamps we used have varied. We used stone and clay lamps, more or less polished, and of different colours, in order to determine how important a lamp's brilliance is in reflected light. Olive oil and drawstring-made flax wicks were used for all of the tests.
This experiment shows that lamp model plays a that brilliance influences illuminance, and that polish does not (fig.7). Belgium blue stone lamp produces a higher illuminance than the other lamps. This can be explained by its brilliance, due to its dark blue colour. As its polish is similar to the Villebois bayadère stone lamp, we can deduce that polish is less important than brilliance to reflect light. This is confirmed by the experiments on clay lamps: the illuminance was similar, whether the lamp was polished or not. This finding allows us to think that Minoans and Mycenaeans were able to directly modulate illumination by choosing their lamps' material.

	Lamps	Illuminance (lux)	Flames' color (kelvins
TEST 1	Unpolished clay	30	1960
TEST 2	Polished clay	28	1940
TEST 3	Villebois bayadère stone	30	1940
TEST 4	Belgium blue stone	40	1970

Fig.7: *Measurments for lamp tests*



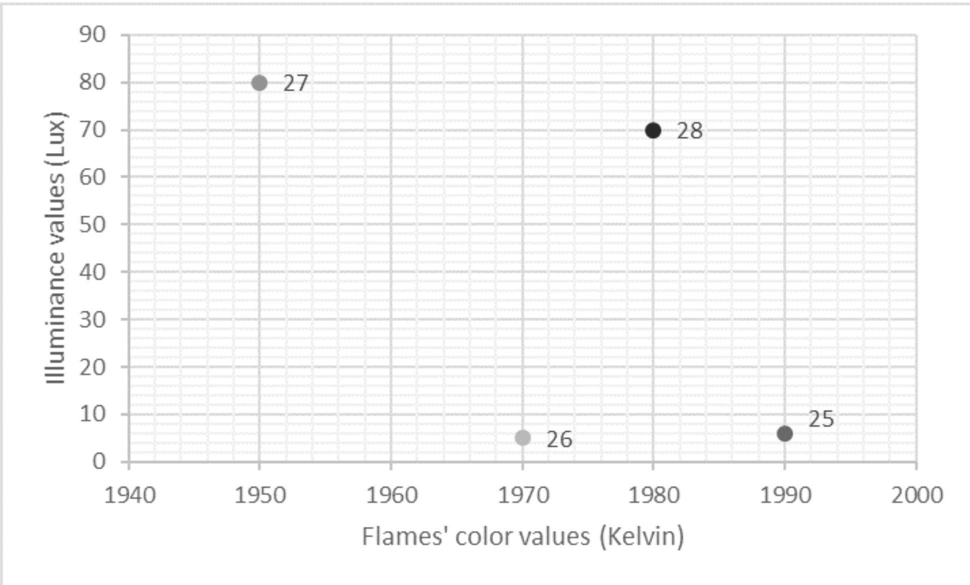
	Fuels	Illuminance (lux)	Flames’ color (kelvi
Vegetable oils			
TEST 5	Flax oil	50	1860
TEST 6	Castor oil	53	1990
TEST 7	Cypress oil	No data	No data
TEST 8	Moringa oil	43	1980
TEST 9	Almond oil	40	1890
TEST 10	Scots pine oil	No data	No data
TEST 11	Poppy oil	32	1880
TEST 12	Safflower oil	37	1910
TEST 13	Sesame oil	37	1930
TEST 14	Rape oil	60	1900
TEST 15	Sunflower oil	46	1910
TEST 16	Nut oil	30	1830
TEST 17	Hemp oil	47	1920

Animal fats and beeswax			
TEST 18	Lard	40	2040
TEST 19	Bef fat	20	1980
TEST 20	Pork fat	23	1980
TEST 21	Lamb fat	12	1970
TEST 22	Beef marrow bone	18	2000
TEST 23	Beeswax	23	2010

Fig.8: Measurments for fuel tests

We must however precise and keep in mind that differences in illuminance are negligible without any measurement tools.

Animal fats and beeswax			
TEST 18	Lard	40	2040
TEST 19	Bef fat	20	1980
TEST 20	Pork fat	23	1980
TEST 21	Lamb fat	12	1970
TEST 22	Beef marrow bone	18	2000
TEST 23	Beeswax	23	2010



	Material	Number of wicks	Manufacturing technique	Illuminance (lux)	Flames' c (kelvin
TEST 25	Papyrus	1	Spinning	6	1990
TEST 26	Flax	1	Braiding	5	1970
TEST 27	Hemp	1	Drawstring	80	1950
TEST 28	Flax	2	Drawstring	70	1980

Fig.9: *Measurments for wick tests*

Fuels' role:
In this series of tests, variable is the fuel. We tested separately vegetable oils and animal fats in order to examine whether differences in the light produced could be perceived between them. We only used the Villebois bayadère stone lamp and drawstring-made flax wicks. Values for olive oil have already been stated in test 3.
Our experiment first shows that a wide range of vegetable oils and animal fats functioned as fuels. Measures for cypress and scots pine oils are not relevant, as they were actually essential oils.
Among the two main categories of fuels (vegetable and animal), a slight difference in illuminance was observed. Vegetable oils seem to provide a higher illuminance than animal fats (respectively an average of 43.2 and 22.6 lux) (fig.8). This difference however cannot be perceived by human eyes.

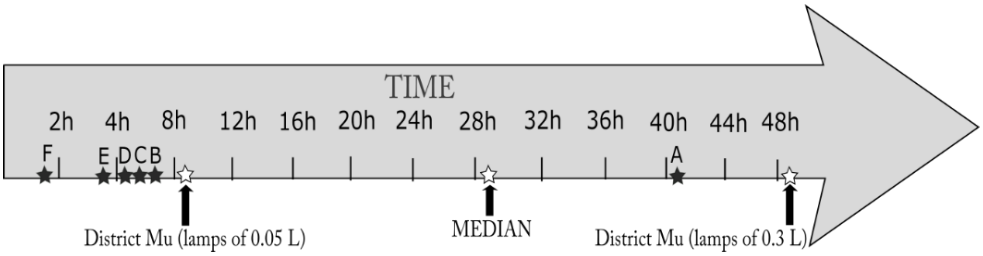
A variation in flames colour also appears between these two categories. Beeswax and animal fats seem to produce a colder flames colour than vegetable oils (respectively an average of 1997 kelvins and 1910 kelvins) (fig.8). This difference cannot be easily perceived by human eyes, but we can assume this has an incidence in terms of luminance, which is the radiance of light emitted from a surface in a given direction. In other words, the whiter and the brighter a wall, the more significant the difference.

Wicks' role:
In this series of tests, only the wick's material, number and manufacturing technique have varied. We systematically used olive oil and the Villebois bayadère stone lamp. Values for a single drawstring-made flax wick have already been stated in test 3 (fig.7).
All the tested materials worked. Papyrus emits a significantly lower illuminance than hemp and flax. However we find that a wick's width is more of a discriminatory factor than its material's nature (fig.9).. Similar observations were made in other experimental programs in Eastern Mediterranean (Elrasheedy, Schindler, 2015; Moullou, et al., 2012b).
In our experiment, hemp wick was thus wider than flax and papyrus wicks. Width offers more material to burn and a higher value. We find that braiding technique, which produces narrower wicks than drawstring-made ones, provides a significantly smaller illuminance value. Test 28 shows us material's width and manufacturing technique can be logically counterbalanced can the adding of several other wicks.
In the light of tests 25-26 and 27, whose values are highly different, we can affirm that wicks' manufacturing technique is the main factor for light intensity modulation.

From lamp mobility to involved gesture
Archaeological data show a differential distribution of lamps according to their height in Kommos. It can be assumed that pedestal lamps were used in a fixed way, whereas low lamps were transported. We tried to define precise lamps' mobility criteria, which has implications in the gesture involved in lighting. Our experiment reveals that a lamp can easily be moved around if it is not too cumbersome (size and height), if its rim is turned inward and/or its body is deep, and if a single hand is required to hold it. Such findings could be used in other chrono-cultural areas in order to document the way lamps were used.
These criteria are defined as follow:
- Concerning size and height, the lower a lamp, the easier its transportation.
- Concerning rim's orientation and body's depth, open-shaped and shallow bodies make overflow easier. This is also true for solid fuels, since they melt under flames' heat. Overflow can be a cause of domestic accidents, since the person holding the lamp can be burned by the hot fuel.
- Concerning the number of hands needed to manipulate the lamp[6]: this criteria depends on the number of gripping means, and sometimes of size and height. A lamp with more than one handle was likely to have rarely been moved. Simultaneous use of two hands seems indeed to be an obstacle for transportation. Nevertheless, the lack of gridding means does not prevent to move the lamp around if it is possible to hold it by its base or body.

Burning length and flames' maintenance
Contrary to Marie-Claire Amouretti's observations (1986), our experimentations contribute to show that burning length does not depends on the wick's size but on lamps' capacity, fuel's nature and number of wicks (fig.10).
Concerning lamps' capacity, tests A and B of this experiment show that in a 0.25 L bowl, the burning lasts 41 hours and 58 minutes, whereas in a 0.03 L bowl it lasts 6 hours and 15 minutes. Based on maximum and minimum district Mu

6 This criteria will have to be proven by a ethnoarchaeological approach



A	Unpolished lamp, olive oil,one drawstring-made flax wick of 12 cm length	0,25 L	41h58
B	Belgium blue stone lamp, liquid pork fat, one drawstring-made flax wick of 9 cm length	0,03 L	6h15
C	Belgium blue stone lamp, olive oil, one drawstring-made flax wick of 11 cm length	0,03 L	5h40
D	Villebois bayadère stone lamp, beeswax, one drawstring-made flax wick of 12 cm length	0,03 L	4h10
E	Villebois bayadère stone lamp, pork fat, two drawstring-made flax wicks of 9 cm length each	0,03 L	3h50
F	Belgium blue stone lamp, beeswax, two drawstring-made flax wicks of 9 cm length each	0,03 L	1h39

Lamps of 0.05 L from Malia	**Lamps of 0.3 L from Malia**
0,05 x 2518/0,25 = 503.6 minutes = 8.4 hours	0,3 x 2518/0,25 = 3021.6 minutes = 50.6 hour:
MEDIAN : 29.5 hours	

Fig. 10: *Burning time with experimental lamps, fuels and wicks and calcul of median burning time in district Mu of Malia lamps*

of Malia lamps' capacity (respectively 0.05 and 0.3 L) (Rougemont, 2011), we could evaluate a burning length of between 8 hours and 40 minutes and 50 hours and 6 minutes for these lamps. It means that the median length is of 29 hours and 50 minutes in this district (fig. 10).

Fuel's nature is the second factor influencing burning length. Tests C and D show that in two lamps of a same capacity, liquid pork fat disappears less quickly than olive oil and, more significantly, than beeswax (respectively 6h15, 5h40 and 4h10). The noticeable difference between beeswax on the one hand and animal fats and olive oil on the other hand can be explained by the fact that these two last fuels easily impregnate the wick whereas beeswax solidify around it.

Finally, the third burning length factor is the number of wicks, as it can be seen in tests 4 and 6. The fact the ratio is not exactly of one on two can be explained by the burning hazards, especially the wick's maintenance required.

This maintenance consists in adjusting more or less frequently the wick to bring it closer to the fuel. Depending on the fuel chosen, the frequency of this operation varies. Liquid animal fats and vegetable oils are absorbed in a concentric and regular way. It is rarely - if not never - necessary to bring the wick closer to the fuel since vegetable oils and liquid animal fats make easier the wicks' capillarity. On the opposite, solid fuels such as beeswax and lard melt under flames' heat from one side of the lamp inward. When the liquid part is absorbed, the flame extends on the wick until reaching the solid part. In some cases, it can burn the wick before the fuel completely disappears, so that it becomes necessary to slightly move the wick closer to the remaining fuel. This operation can occur every ten minutes, sometimes less, requiring a real attention that is a full part of daily Cretan Bronze Age activities. From this point of view, beeswax and lard are less advantaging than vegetable oils and liquid animal fats.

Spout's utility and burning traces

The experimentation seems to show that the presence of a spout in not indispensable for the wick to be maintained, especially with solid fuels. However, maintenance is more frequently required without any spout since the wick tends to sag. In the case of liquid fuels for instance, the wick can rely on the rim but with close-shaped bowls it will be necessary to often adjust it in order for it not to fall and drown into the fuel.

This technological precision leads us to wonder whether a lamp is always made out of an object. In the future, more emphasis should be on Vassiliki Peskov's ethnographical point of view (1992, p.90), reminding us that, in the middle of XXth century, in the Taiga, a single "wood chip was serving as candle".

Conclusion

This article aims to introduce a techno-functional approach in order to study Cretan Bronze Age lamps, Kommos city being the main case study to achieve this purpose. The use of statistical and cartographic treatments seems to be a promising method to examine the place of lamps in buildings' lighting devices. In this perspective, it is important to map out all the lighting fixtures. Of course, some improvements are possible. In the future, it will be, for instance, indispensable to take into account house openings.

The experimental program we have been presenting contributes to characterizing lighting ambiances. First, by measuring light properties with the use of several lamps, fuels and wicks identified among archaeological data. Secondly by focusing on the practical aspects of lamps manipulation.

In the future, the goal of this work, core of my ongoing Phd thesis topic, will be to determine which activities were lit by lamps, at what moments of the day and, whether it is possible to detect spaces functionality through the study of light areas.

This methodology has been proven accurate to the study of Cretan Bronze Age lamps. Therefore, we look forward for it to be applied to other chrono-cultural areas.

BIBLIOGRAPHY:

AMOURETTI M.-Cl., *Le pain et l'huile dans la méditerranée : de l'araire au moulin,* Paris, Les Belles Lettres, 1986

BARNARD K.A., BROGAN T.M. (eds.), *Mochlos IB. Period III. Neopalatial Settlement on the Coast : The Artisan's Quarter and the Farmhouse at Chalinomouri. The Neopalatial Pottery,* Philadelphie, INSTAP Academic Press, 2003

BLITZER H., « Olive cultivation and oil production in minoan Crete », dans AMOURETTI M.-C., BRUN J.-P. (eds.), *La production de vin et d'huile en Méditerranée. Actes du symposium international organisé par le centre Camille Jullian (Université de Provençe –C.N.R.S.) et le Centre archéologique du Var (Aix-en-Provençe et Toulon, 20 -22 novembre 1991),* Paris, De Boccard, 1993, 55-64

BOSANQUET R.C., DAWKINS R.M., *The Unpublished objects from the Palaikastro excavations, 1902-1906,* Londres, Macmillan, 1923

BOYD HAWES H., *et al., Gournia, Vassiliki and other prehistoric sites on the isthmus of Hierapetra, Crete, Excavations of the wells-Houston-Cramp Expeditions, 1901, 1903, 1904,* Philadelphie, The American Exploration Society, free museum of science and art, 1908

BREWER J., REDFORD D.B., REDFORD S., *Domestic plants and animals. The Egyptian origins,* Warminster, Aris and Philipps, 1994

CHALMERS A., MARTINEZ P., SUNDSTEDT V., « High Fidelity Reconstruction of the Ancient Egyptian Temple of Kalabsha », *dans AFRIGRAPH. Proceedings of the 3rd International Conference on Computer Graphics, Virtual Reality, Visualization and interaction in Africa,* New-York, ACM, 2004, 107 – 113

CHAPOUTHIER F., DEMARGNE P., *Fouilles exécutées à Mallia : troisième rapport. Exploration du palais, bordures orientale et septentrionale (1927, 1928, 1931, 1932),* Paris, Librairie orientaliste Paul Geuthner, 1942

DEBEVEC P., et al., « Digitizing the Parthenon : Estimating Surface Reflectance under Measured Natural Illumination », dans STANCO F., BATTIATO S., GALLO G. (eds.), *Digital Imaging for Cultural Heritage Preservation,* Boca Raton, CRC Press, 2006, 159 – 213

DEMARGNE J., « Culte funéraire et foyer domestique dans la Crète minoenne » dans BCH, vol.56, 1932, 60-82, [en ligne], visible sur <www.persee.fr>, (consulté le 15/12/2015)

DEMARGNE J., « Culte funéraire et foyer domestique dans la Crète minoenne » dans BCH, vol.56, 1932, 60-82, [en ligne], visible sur <www.persee.fr>, (consulté le 15/12/2015)

DESHAYES J., DESSENNE A., F*ouilles exécutées à Mallia. Exploration des maisons et quartiers d'habitation (1948-1954). Deuxième fascicule,* Paris, Librairie orientaliste Paul Geuthner, 1959

DEVLIN K., CHALMERS A., « Realistic Visualization of the Pompeii Frescoes », dans SPENCER N. (ed.), *Proceedings of the 1st International Conference on Computer Graphics, Virtual Reality, and Visualization : Camps Bay, Cape Town, South Africa (5-7 novembre 2001),* New-York, Association for Computing Machinery, 2001, 101-123

DOUGLAS D.A., *The development and demise of the Early Bronze Age IV, Near Eastern Oil-Lamp,* thèse soutenue à la Commonwealth Open University, 2001

ELRASHEEDY A., SCHINDLER D., « Illuminating the Past : Exploring the Function of Ancient Lamps », dans *Near Eastern Archaeology,* vol.78, Issue 1, mars 2015, 36-42

EVANS A., *The Prehistoric Tombs of Knossos,* Londres, B. Quaritch, 1906

EVANS A., *The Palace of Minos: a comparative account of the successive stages of the early Cretan civilization as illustrated by the discoveries at Knossos,vol.III,* Londres, MacMillan, 1930

EVANS A., *The Palace of Minos: a comparative account of the successive stages of the early Cretan civilization as illustrated by the discoveries at Knossos,*Vol. IV, Part.2, Londres, MacMillan, 1935

EVERSHED R., *et al.,* « Fuel for Thought ? Beeswax in Lamps and Conical Cups from Late Minoan Crete », dans *Antiquity*, vol.71, n°274, 1997, 979-985

EZRATI J.-J. 2002, *Théorie, technique et technologie de l'éclairage muséographique,* Paris

GILLIS C., *Minoan conical cups. Form, function and significance,* Göteborg, Paul Aströms Förlag, 1990

HALLAGER B.P., « Some light on LM III Hand Lamps », dans ANDREADAKI-VLAZAKI M., PAPADOPOULOU E. (eds.), *Proceedings of the 10th Cretological Congress (Chania, 1-8 October 2006),* Chania, Literary Society « Chryssostomos », 2011, 71-80

HOOD M.S.F., « Inscribed Cup from a Late Minoan IB Deposit at Knossos », dans *Kadmos,* 3, 1964, 111-113

KURZMANN P., « Zwei vielflammige Öllampen aus Troia », dans *Studia Troica,* vol.15, Tübingen, Eberhard-Karls Univerität, 2005, 177-182

LION Br., « Les suidés dans la documentation textuelle du Bronze Recent », dans MICHEL C., LION Br. (eds.), *De la domestication au tabou : le cas des suidés au Proche-Orient ancien,* Paris, De Boccard, 2006, 103-114

LUCAS A., HARRIS J.R., *Ancient Egyptian Materials and Industries,* Londres, E. Arnold, 1962

MELENA J.L., « La Produccion de plantas aromaticas en Cnoso », dans *Estudios Clasicos,* 78, 1975, 180-183, [en ligne], visible sur <interclassic.um.es>, (consulté le 28/11/2015)

MELENA J.L., « Olive Oil and Other Sorts of Oil in the Mycenaean Tablets », dans *Minos: Revista de filologia egea,* 18/1-2, s.l., 1983, 89-123, [en ligne], visible sur <gredos.usual.es>, (consulté le 28/11/2015)

MERCANDO L., « Lampade, lucerne, braccieri di Festos », dans *Annuario della Scuola archeologica di Atene e delle missioni italiene in Oriente,* volumes 52-53, nouvelle série 36-37, Rome, L'Erma de Bretschneider, 1978, 15-167

MOULLOU D., et al., « Lighting in Antiquity », dans KOSTIC M. (ed.), *5th Balkan Light International Conference, Belgrade 5-6 octobre 2012,* Belgrade, 2012a, 236-244

MOULLOU D., et al., « Methods and Tools for the Study of Artificial Illumination in Antiquity » dans ZACHARIS N. (ed.), *Proceedings of 2nd Archaeological Research and New Technologies Conference, 21-23 October 2010,* Kalamata, 2012b, p. 107-114

PALIOU E., WHEATLEY D., EARL G., « Three-dimensional visibility analysisof architectural spaces : iconography and visibility of the wall paintings of Xeste 3 (Late Bronze Age Akrotiri)», dans *Journal of Archaeological Science,* vol. 38, 2011, 375-386

PAPADOPOULOS C., EARL G., « Formal Three-dimensional Computational Analyses of Archaeological Spaces », dans PALIOU E., LIEBERWIRTH U., POLLA S. (eds.), *Spatial analysis in Past Built Spaces – Workshops (Berlin, 1-2 april 2010),* Berlin, Topoi, 2013, 135 - 165

PAPADOPOULOS C., SAKELLARAKIS Y., « Virtual Windows to the Past : Reconstructing the “Ceramics Workshop” at Zominthos, Crete », dans MELERO J., CANO P., REVELLES J., (eds.), *CAA 2010 : Fusion of Cultures. Proceedings of the 38th Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Granada, Spain, April 2010,* Oxford, Archaeopress, 2013, 47-54

PAPADOPOULOS C., HAMILAKIS Y., KYPARISSI-APOSTOLIKA N., « Light in a Neolithic dwelling: Building 1 at Kourtroulou Magoula », dans *Antiquity*, vol. 89, Issue 347, 2015, 1034 – 1050

PAUSANIAS, *Description de la Grèce, Livre 1. L'attique (26,6),* Paris, F. Maspero, 1962

PELON O., *Fouilles exécutées à Mallia. Exploration des maisons et quartiers d'habitation (1963-1966). Troisième fascicule,* Paris, Librairie orientaliste Paul Geuthner, 1970

PERSSON, *New tombs at Dendra near Midea,* Lund, C.W.K. Gleerup, 1942

PESKOV V., *Ermites dans la Taïga,* Arles, Actes Sud, 1992

PHOTOU V., « Éléments d'analyse architecturale et la question des fonctions de trois bâtiments- « villas » : la Royal Villa, le « Mégaron » de Nirou et le « Mégaron » de Sklavokambos », dans HÄGG R. (ed.), *The Function of the « Minoan Villa ». Proceedings of the Eight International Symposium at the Swedish Institute at Athens, 6-8 june 1992,* ActaAth-4° 46, Stockholm, 33-50

PLINE L'ANCIEN, *Histoire Naturelle, XXVIII, 11, 47,* texte établi, traduit et commenté par J. André, Paris, Les Belles Lettres, 1972

POURSAT J.-Cl., *Fouilles exécutées à Malia. Le Quartier Mu V. Vie quotidienne et techniques au Minoen Moyen II,* Athènes, EFA, 2013

PROCOPIOU H., « L'archéologie de la continuité : la perception du monde rural en Protohistoire égéenne », dans ARCHAMBAULT DE BEAUNE S. (ed.), *Écrire le passé. La fabrique de la préhistoire et de l'histoire à travers les siècles,* Paris, CNRS éditions, 2010, 149-161

ROUSSOS I., CHALMERS A., « Hidh Fidelity Lighting of Knossos », dans ARNOLD D., CHALMERS A., NICCOLUCCI F. (ed.), *VAST 2003 : The 4th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage,* Aire-la-Ville, Eurographics Association, 2003, 195-202

ROUGEMONT F., « Some Thoughts on Knossos Oil Records compared to Mari Oil Records », dans *Bulletin of the Institute of Classical Studies,* n° 51, Londres, Université de Londres, 2008, 185-186

ROUGEMONT F., « Oil at Nuzi and in the Linear B Records. A First Step Towards a Comparative Study », dans DIETRICH M., LORETZ O. (eds.), *Ugarit-Forschungen. Interationales Jahrbuch für die Altertumskunde Syrien-Palästinas,* n° 43, Munster, Ugarit Verlag, 2011, 345-410

RUTTER, « What Happened to the Lights ? Changes in the Usage of Ceramic Lamps at Neopalatial and Early Postpalatial Kommos», dans GRAZIADIO G., et al. (eds.), *Φιλική Συναυλία. Studies in Mediterranean Archaeology for Mario Benzi,* Oxford, Archaeopress, 2013, 31-38

SHAW M.C., « Late Minoan hearts and ovens at Kommos, Crete », dans DARCQUE P., TREUIL R. (eds.), *L'habitat égéen préhistorique. Actes de la Table Ronde internationale organisée par le Centre de la Recherche Scientifique, l'Université de Paris 1 et l'École française d'Athènes (Athènes, 23-25 juin 1987),* Athènes, EFA, 1990, 231-254

SHAW J., SHAW M. (eds.), *Kommos III. The Late Bronze Age Pottery,* Princeton, Princeton University Press, 1992

SHAW J., SHAW M.C. (eds.), *Kommos V. The monumental Minoan Buildings at Kommos,* Oxford, Princeton University Press, 2006

SHAW J.W., SHAW M.C. (eds.), *House X at Kommos : a Minoan mansion near the sea. Part. 1 : architecture, stratigraphy, and selected finds,* Philadelphie, INSTAP Academic Press, 2012

THALMANN J.-P., « Ex Oriente lux. L'invention de la lampe au Proche-Orient », dans GIRAUD J., GERNEZ G. (eds.), *Aux marges de l'archéologie. Hommages à Serge Cleuziou,* Paris, Diffusion de Boccard, 2012, 175-185

TRANTALIDOU K., « Animals and Human Diet in the Prehistoric Aegean », dans HARDY D.A. (ed.), *Thera and the Aegean World III, volume two, earth sciences. Proceedins of the third international congress, Santorini, Greece, 3-9 september 1989,* Londres, The Thera Foundation, 1990, 392-403

WARREN P., *Minoan stone vases,* Cambridge, University Press, 1969

XANTHOUDIDÈS S., *The vaulted tombs of Mesara, with a new introduction and additional bibliography of Keith Branigan,* Westmead, Farnborough: Gregg international publishers, 1971