Stratigraphic Modelling of Multi-period Sites Using GIS: The Case of Neolithic and Early Bronze Age Knossos

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Abstract

Knossos in the island of Crete, Greece, is a multi-period tell site with a complex depositional and excavation history. Efforts to preserve the Late Bronze Age 'Palace' at the site and make it accessible to the public have necessarily impeded the study of the earlier levels. Indeed, most of the data gathered from these lower levels is fragmentary and, in its current form, resists any coherent overall synthesis. The present paper summarises the results of an attempt to model the depositional record of the Neolithic and Early Bronze Age of Knossos on the basis of the recovered evidence using Geographic Information Systems (GIS). The methodological problems inherent in digital stratigraphic modelling of complex multi-period tell sites are discussed and the ensuing picture assessed. Finally, the analytical value of such reconstructions is explored further, in relation to demographic modelling of multi-phase sites via the concept of packed house volume (PHV).

Key words: Knossos, tell, GIS, stratigraphic modelling, Packed House Volume (PHV)

Introduction to the project

This paper describes an attempted application of GIS to the stratigraphic modelling of multi-period tell sites. The case study is the site of Knossos, which is situated in the north central part of Crete, Greece. It is a multi-period tell site known for the large LBA “Palace” that was excavated by Sir Arthur Evans at the beginning of the 20th century (Evans 1921, 1928). Although the focus of archaeological investigation was placed on the palace itself, evidence for earlier periods dating back to the beginning of the Neolithic was uncovered in many areas. However, the need to preserve the superimposed structures restrained large scale excavation of these early levels and has prevented the coherent diachronic synthesis of the early history of Knossos (Winder 1991, Broodbank 1992, Whitelaw 1992, Evans 1994, Manning 2000, Efstratiou et al. in press).

The idea was that using Geographic Information Systems (GIS), the surviving extent and thickness of the archaeological deposits that underlie the palace would be modelled, on the grounds of the existing stratigraphic and ceramic evidence from various excavated areas (for similar applications see also Richards 1990, Catani et al. this volume). In this sense, a picture of the depositional state for the whole of the tell would be created.

Methodology

In GIS terms, the project is about *Digital Terrain Modelling (DTM)*. The software packages used were ArcView and ArcInfo.

Initially, a DTM of the present surface was produced in order to provide the basis of the analysis. A total area of 600 x 700 m centred on the hill of Knossos was selected, since it provided a visual extent that enabled the comprehension of the surrounding landscape. Contour data (at 1 and 0.5 m interval) and individual spot heights (3,780 in total) were digitised from topographic maps, plans and sections of the palace (Hood and Smyth 1981, Papanis 1982). The interpolation was performed using the *Topogrid* function of ArcInfo (Hutchinson 1988, 1989). The resulting DTM had a resolution of 2 m (figure 1).[1]

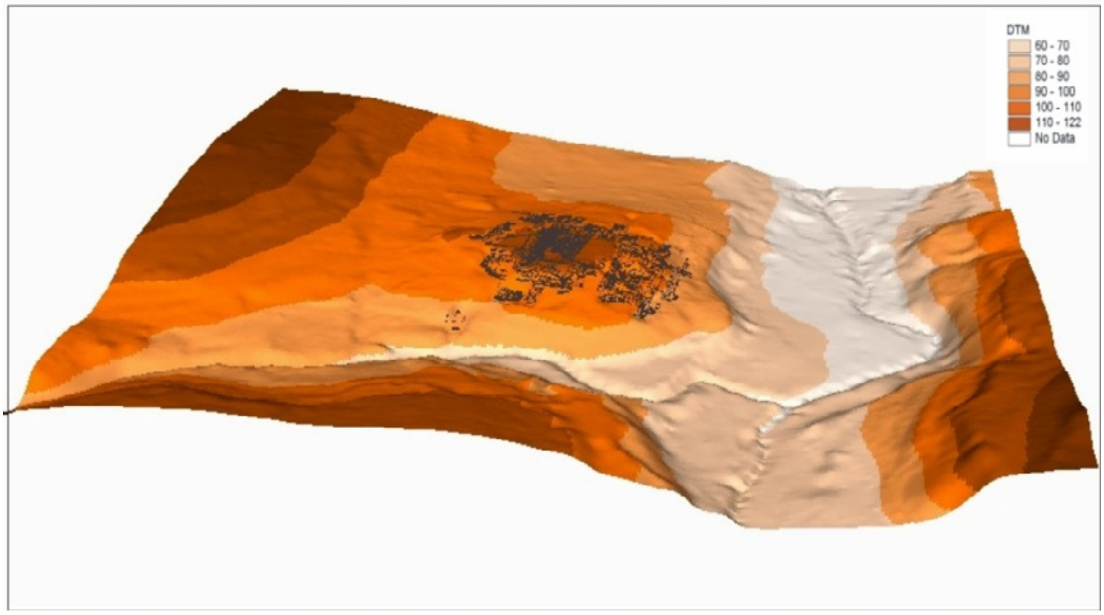


Figure 1 – Present DTM (res. 2m)

Next, a DTM of the pre-excavation tell topography was generated in order to establish the original surface from which early test-pits were dug. In this way, it was possible to use the recorded depths from early trenches, where surface measurements were absent (figure 2).

The depositional episodes modelled in the project were based on the ceramic sequence. Consequently, the resulting surfaces in effect divide the stratigraphy into broad phases that represent a period of use of a particular ceramic ware. Two databases were compiled to be used for the creation of the DTM of each period. The first was in binary form and recorded the presence or not of material of a particular date. The second was numerical and provided the absolute heights of the upper surface of each period. All stratigraphic data were inserted as points (399 in total). Their exact position was taken from record plans, excavation reports and descriptive accounts (see Katsianis 2002:Appendix).

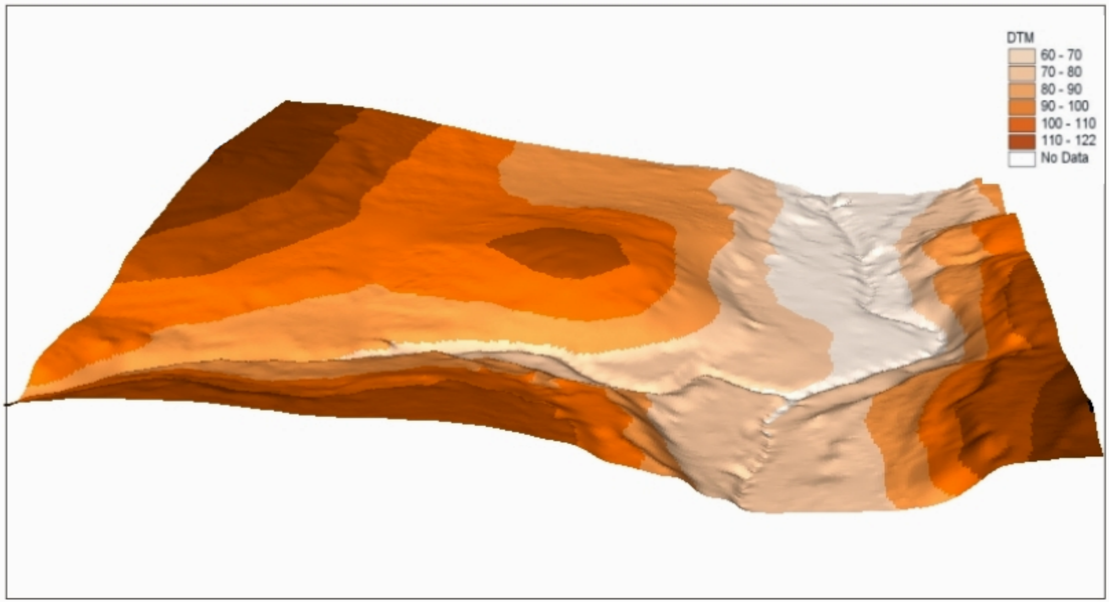
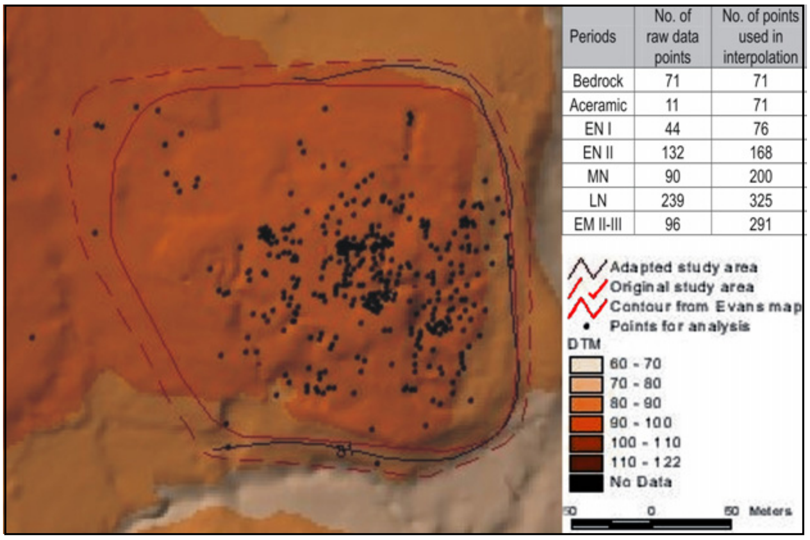


figure 2 - Pre-excavation DTM (res. 2m)

The study area was further localised around the palace, where there was the bulk of the relevant archaeological evidence. The reconstruction of the stratigraphy begun from the bottom upwards, since the bedrock was the only surface that certainly covered the entire area (figure 3).



Periods	No. of raw data points	No. of points used in interpolation
Bedrock	71	71
Aceramic	11	71
EN I	44	76
EN II	132	168
MN	90	200
LN	239	325
EM II-III	96	291

figure 3 – Study area and distribution of points used in the interpolation of the surfaces

Lack of data at the edges prevented point based interpolation procedures (*IDW 12*) to perform well with the creation of the bedrock surface, even when low resolution was employed (30 m!). Only the incorporation of a boundary could constrain the significant *edge effect*. In his excavation accounts from Knossos, J. D. Evans produced a probable contour map of the bedrock, based on its absolute heights and inclination, where exposed (Evans 1971:pl.VI, 1994:fig.1). One of these outer contours was used in order to control the noise from the edge-effect. Its inclusion was enough for Topogrid to interpolate successfully over the whole area at a 5 m resolution and minimise all previous edge effects. The probable introduced error from the inclusion of the contour line was reduced by limiting the study area after the interpolation. Finally, the bedrock DTM was created (figure 3,4).

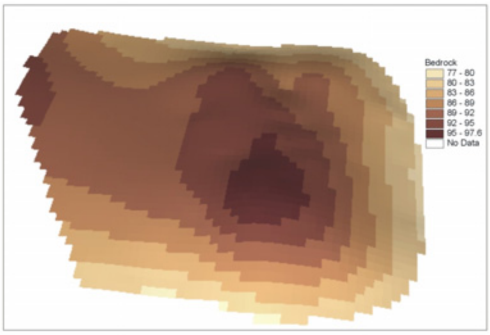


figure 4 – Bedrock DTM (res. 5m)

The rest of the DTMs were more troublesome, because they had to account not only for the depth of the deposit, but also its extent. The binary database provided the areas of presence of the surviving deposits in each period. The points covering this area were then supplemented by the points of the underlying surface that lied outside it. The new point theme was the basis for each interpolation. In effect, each DTM produced, had an increase in height only in the places, where the deposits were present, and kept the previous surface in areas, where it was absent (figure 3 – table).

In this way, six DTMs of resolution of 5m, representing the major phases, were produced (figure 5).

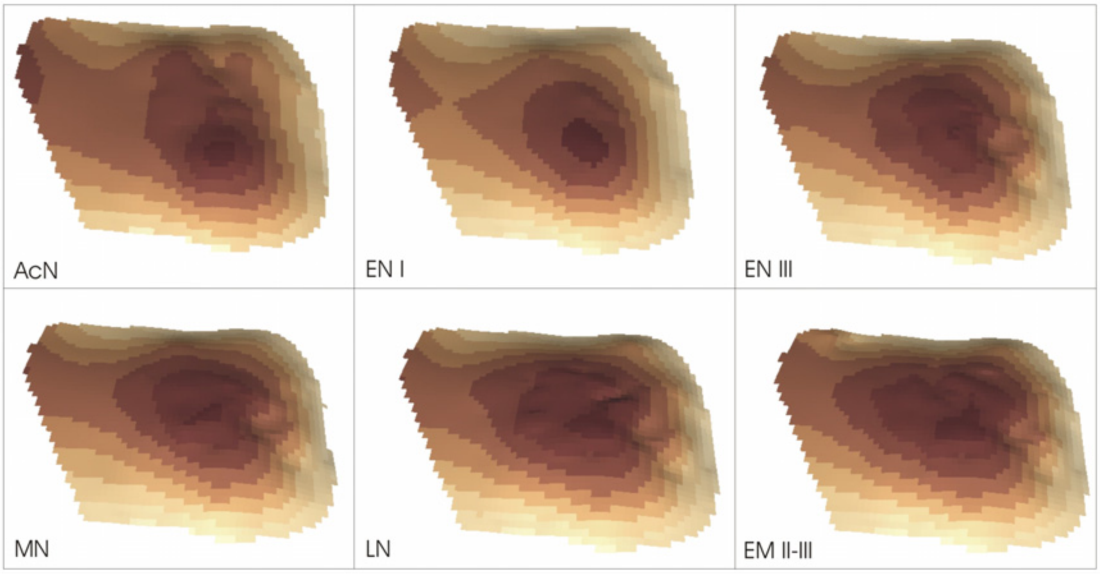


figure 5 - DTM's showing the topography of the surviving deposits in each period (res. 5m)

The assessment of the resulting surfaces in defining the actual shape of the deposits was facilitated by two ways. By extracting profiles from the DTMs (*Profile Extractor 6.0*) the modelled stratigraphic sequence was displayed as sections. These provide insights to the slope of the surviving deposits and the depositional relationships (figure 6).

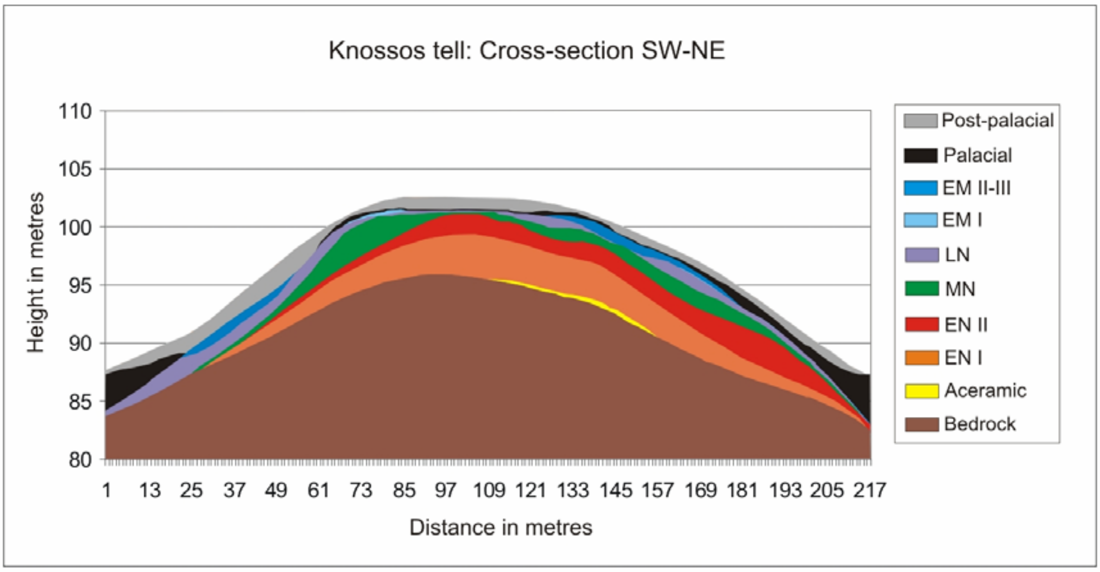


figure 6 - Cross-section of Knossos tell (SW-NE) according to the modelled deposits.

Additionally, six DTMs were produced from the respective surfaces giving a visual and measurable account of both the extent and thickness of the deposits (figure 7). They included measurements of the total area and average depth in every case. From those it was possible to calculate the total surviving volume of each deposit and suggest new estimations of their probable original volume and extent.

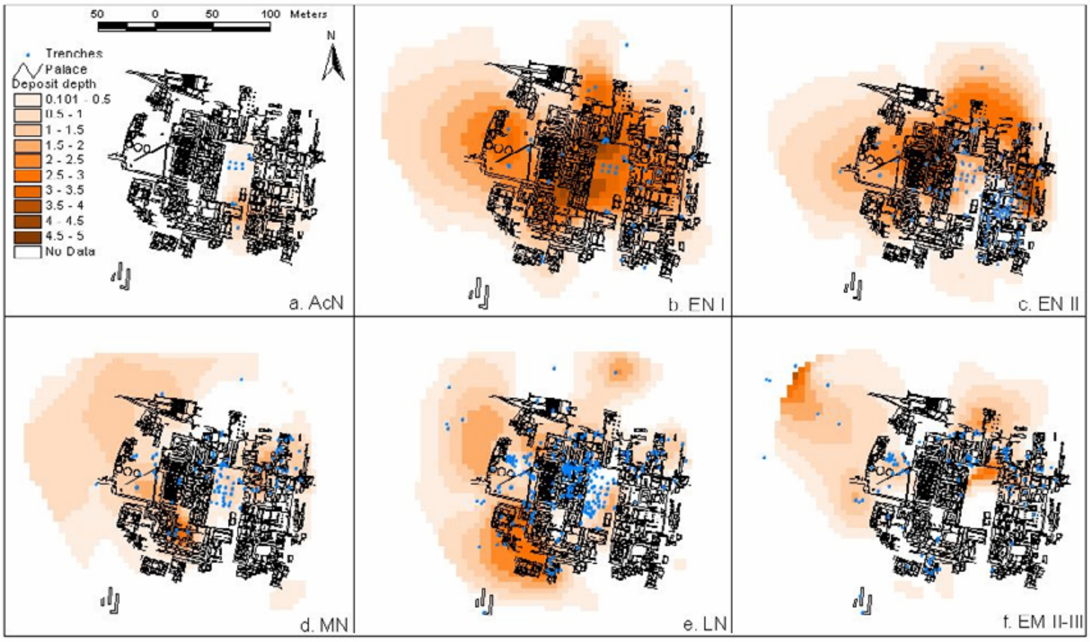


figure 7 - Extent and depth of the surviving deposits in every period according to the interpolation.

Assessment of the results

The archaeological value of such attempts is largely dependent on the accuracy of the result. In the presented application, these surfaces are not precise representations of the deposits. They should be viewed as a rough approximation of the stratigraphy based on the ceramic sequence. Their accuracy is related to two factors: the nature of the primary data and the interpolation performance.

The performed interpolation was based on a set of scarce and irregularly distributed points. In order to cushion the effect from the void areas, the grid resolution had to be confined. The selected scale of 5 m was the highest possible supported by the current dataset. This scale managed to provide a comprehensive account of the shape of each deposit and allowed quantifiable observations of archaeological interest.

The comparison of the surfaces with the primary data reveals that the shape and the depth of the resulting deposits are compatible (figure 7). The main reason for this was the ability of the interpolation procedure to maintain the values of the original data. In addition, the binary data ensured that in most cases the extent of the surviving area was approximated and major truncations were indicated.

However, significant problems that render the results problematic in terms of their archaeological validity were also indicated. By far the biggest methodological fallacy is the edge effect. The extents of the site were impossible to approximate by the interpolation procedure alone, especially to the west of the palace. This suggests that future applications are largely dependent on adequate data around the edges of the study area.

A number of inaccuracies are also present in places where there is lack of data of the earlier periods (not all trenches reached the bedrock). This probably resulted in later periods appearing disproportionally deeper in those areas (i.e. the MN period in the South Propylaeum). This is a problem of the interpolation procedure that is related to the spatial distribution of data.

Another deficiency is the misrepresentation of minor local truncations (i.e. local absence of the deposit). The basic convention of creating one area encompassing all points, that showed the presence of a period, and the resolution employed caused the interpolation to ignore secondary truncations. Binary interpolation procedures could have helped in the better definition of these areas.

On the whole, the accuracy of the surfaces can be considered at least informative of the actual depositional situation. The correlation of the produced surfaces with the archaeological data, helped in the detection of the areas that presented errors. The tracing of the original extents of each deposit was helped by the interpolation, but had to be correlated with the archaeological evidence and is open to interpretation (see Katsianis 2002). Future refinements that will incorporate more local variation are possible, but they are largely dependent on the collection of more data.

Population estimates based on depositional measurements

The modelled deposits were employed in the exploration of issues regarding the diachronic growth pattern of the site. Using a different approach to population estimates advanced by Ammerman et al. (1976), the accumulated deposits of a site can be used as referents of its population, thereby incorporating an idea of occupation intensity as well as extent.

By correlating the total volume of a deposit accumulated over a period with that produced from the collapse of a house, the average number of houses within that period is approximated. This number can then be multiplied by a defined household size and give an approximation of the average population during that same time.

The concept of Packed House Volume (*PHV*) signifies the volume of debris deposited on a site following the collapse of a house. It can be calculated by multiplying the total wall length of a house with its average wall width and its average wall height. In this respect, the quantity of houses standing together at an individual horizon within a period (*N*) can be found by multiplying the total deposit volume (*V*) with the average life expectancy of a house (*T*) and dividing the result by the packed house volume (*H*) and the length of the period (*P*).[2]

$$N = V \bullet T / H \bullet P$$

For the house life expectancy variable (*T*) two values were used, 30 and 40 years, since most pisè house structures are claimed to fall within that range (Ammerman et al. 1976:44, note 7).

The resulting number of houses was then multiplied by the number of residents. This can vary according to the household type. Depending on whether a household is equated with a nuclear or an extended family the calculation used 5 and 9 people respectively. The derived estimates represent the average population any time during that period. In reality, demographic variation should be expected within a period. If an idea of population growth rate can be established, then the population number can be distributed within a period accordingly (table 1).

Phases	Vol. of surviving deposit	House use-life	Length of period	PHV	Quantity of houses	Population number (household of 5)	Population number (household of 9)
	(m^3)	(y)	(y)	(m^3)	(n)	(n)	(n)
AcN	2756	30	500	36	4.6	23	41
EN I	51444	30	1500	48	19.8	99	179
EN II	44652	30	400	60.3	55.5	278	500
MN	24037	30	200	73.5	49	245	441
LN	32266	30	400	84	28.8	144	240
EM II-III	15477	30	800	73.2	8	40	72
AcN	2756	40	500	36	6	31	55
EN I	51444	40	1500	48	28.6	143	257
EN II	44652	40	400	60.3	74	370	665
MN	24037	40	200	73.5	65.4	327	589
LN	32266	40	400	84	38.4	192	346
EM II-III	15477	40	800	73.2	10.6	53	96

table 1 - Population estimates based on Packed House Volume: Use life of houses is set to 30 & 40 years respectively and household composition to 5 & 9 people.

For this paper the surviving deposits' volume was used in the calculation. The resulting figures, therefore, represent the minimum population number according to the used variables during a certain period. Due to the loss of the original deposit volumes (i.e. LN) in later periods and the noted interpolation problems, these figures deviate from the numbers one would actually expect. However, they set a minimum of expectations. Should a reconstruction of the original deposits be made in an interpretative manner, more realistic results can be obtained (for such an example see Katsianis 2002).

Concluding remarks

The above example shows that GIS applications of this kind are not mere predictive models of the archaeological record. They also have analytical value, as they can be used to monitor the processes of the past that might have led to the modelled picture and address complex issues. GIS are essential for this kind of approach, since they provide the only means of bringing together all these fragmentary spatial information in a systematic manner.

The main problems lie in the fact that such modelling attempts and the consequent interpretations are very difficult to verify and their success is largely dependent on the primary data and the capacities of GIS interpolation methods (see also Lock 1994, Robinson and Zubrow 1999, Schneider 2001, Beex this volume). In Knossos, the modelled outcome was an advance in the evaluation of the whole site, but still remains under critical evaluation. Verification and data problems can only be assessed by further excavation, while software performance by more applications and special GIS functions that take into account the problems present in such studies.

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[1] All DTMs are shown with an exaggeration factor of 1.5 for the better comprehension of the modelled landforms.

[2] Ammerman et al. (1976) note four factors that may affect the outcome of the calculation: reuse of material in later phases, erosion of the tell, use of non-durable material and contribution of total volume from other sources (i.e. ceramic, refuse disposal).