# Testing Spatial Patterns and Hypotheses at Minoan Palaikastro, Crete

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## Abstract

A set of spatial and statistical analyses has been conducted on material from the site of Palaikastro on Crete with the principal aim of synthesizing a methodology for effectively questioning an archaeological intra-site dataset by means of Geographical Information Systems (GIS) and statistics. The present study is part of this set of analyses. In earlier studies, the artifactual and architectural data were displayed and described visually using GIS. Additionally, artifactual data were statistically described using univariate and bivariate graphs. The aim of the present study is to test the significance of the spatial associations, hypothesized in former studies, according to these visual and statistical descriptions. The hypotheses concern the spatial associations between architectural features and artifact groups as well as the associations between two artifact groups. Kolmogorov-Smirnov and Chi-squared tests are used for the significance testing. GIS is utilized to query the data.

## 1 Introduction

Revealing patterns within archaeological datasets and describing associations between different data groups are crucial to archaeological research. Statistical methods provide archaeologists with ways of quantifying archaeological patterns and associations. The results obtained, however, may be misleading if the implications attached to each statistical technique are not properly realized and considered. Therefore, archaeologists should gain sound understanding of statistical methods and sufficient experience prior to implementing these methods. Exemplary applications of statistical methods are of significant value to archaeological research as each application could serve as a means of getting more acquainted with the notoriously "tricky" techniques of statistics and gaining relevant experience on applications. The present study takes the Bronze Age site at Palaikastro, Crete, as a case study and offers a synthesis of a comprehensive and exemplary intra-site methodology by utilizing statistical methods and GIS, in order to question the functional organization across the site.

Palaikastro is the name of the modern village located on the eastern tip of Crete. The inhabitants of the island during the Bronze Age are called "Minoans," named after the legendary King Minos, known to us through Greek mythology. According to current evidence, the Minoan settlement near Palaikastro (on the Roussolakkos plain) began in the Early Bronze Age and continued uninterrupted until Late Minoan IIIC, around 1200 BC (MacGillivray and Driessen 1990:395). The eminence of the city during the Bronze Age is evident from the city plan, which is one of the best preserved, largest, and well-planned examples in Minoan architecture (MacGillivray et al. 1984:129). A first series of excavations took place on the site between 1902 and 1906, work then resumed in 1962-1963, and yet again between 1986-1996 (MacGillivray and Driessen 1990:396). Some additional tests were done in 2003.

Within the area excavated between 1986-1996, which is the subject of the present study, seven "buildings" were identified and numbered from one to seven (e.g., Building 1, Building 6, etc.), as shown in Figure 1. It should be noted that "Building 6" and "Block M" refer to different parts of the site. The area, located on the south side of the alleyway 5/6, on the north side of the main street and west side of the street shared with Block β, is referred to as "Block M." "Building 6" has been used to specifically denote the structures located in the southeast of Block M (Driessen 2006:pers. comm.).

In earlier studies, architectural and artifactual remains were described and explored visually, using GIS (Haciguzeller 2006c), and statistically (Haciguzeller 2006b). As a result, various discussions were opened that relate to the significance of associations between:

- Specific part(s) of the site and spatial distribution of a particular group of artifacts: e.g., is there a significant spatial association between Buildings 4 and 5, and "ritual artifacts" (those artifacts interpreted as being associated with ritual activity)?
- Spatial distributions of two different groups of artifacts: e.g., is there a significant spatial association between stone vases and "banqueting vases" (vases interpreted as being associated with drinking, eating, and pouring)?

The present study utilizes two statistical methods—Kolmogorov-Smirnov and Chi-square tests—to test hypotheses regarding these associations. A significance level of 0.05 is used for both of the tests.

## 2 Methodology

GIS software MapInfo Professional 7.5 is used for this study. The area in question is divided into square grids with 3-m, 4-m, and 5-m sides. These grids are spatially attributed to the buildings excavated so that the artifacts located within those grids are also attributed to specific buildings.

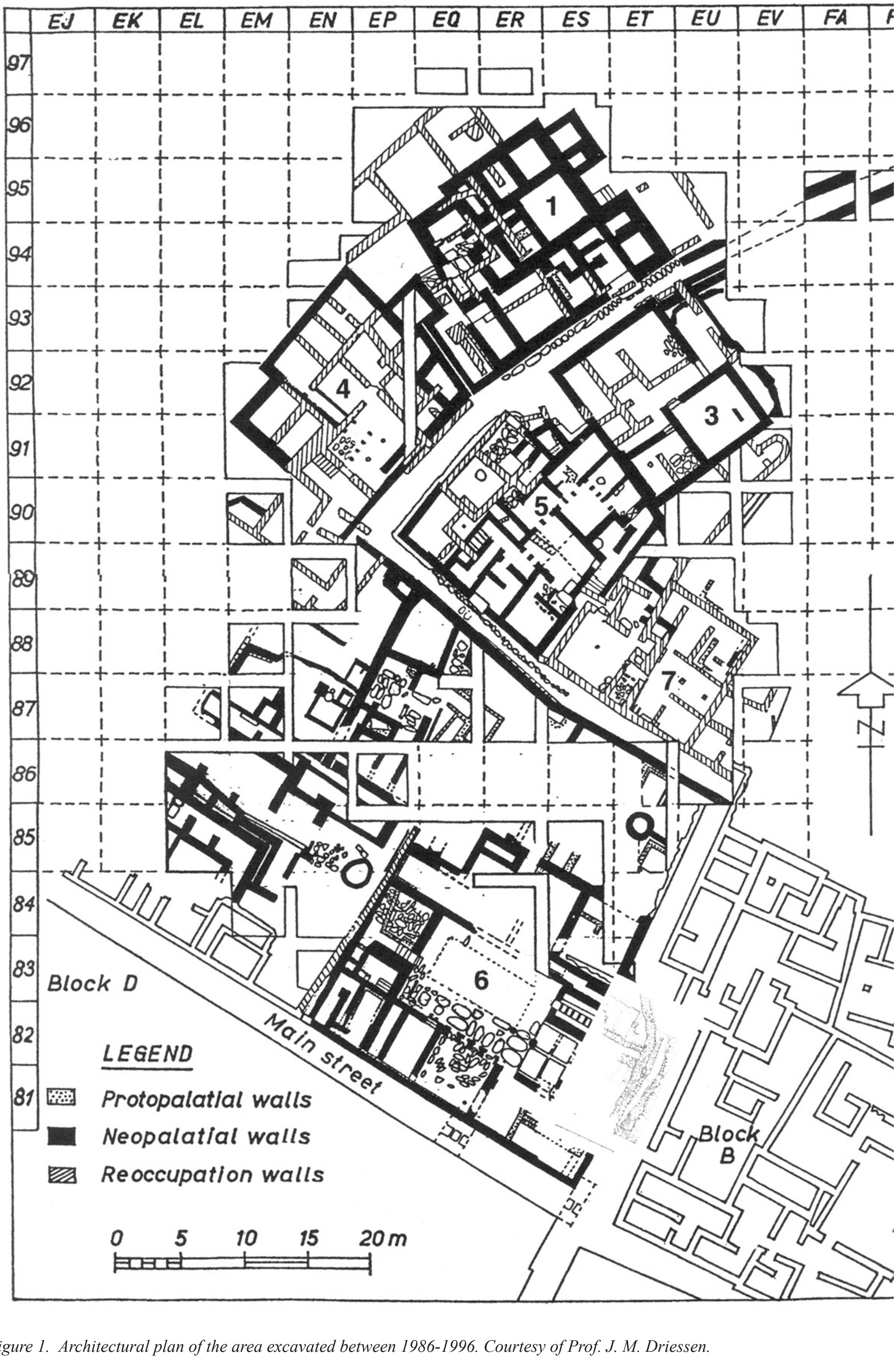


*Figure 1. Architectural plan of the area excavated between 1986-1996. Courtesy of Prof. J. M. Driessen.*

To test the spatial associations between the distribution of a particular group of artifacts and a certain part of the site, the Kolmogorov-Smirnov test is used. This test is appropriate for comparing two sets of observations measured at the ordinal scale, which have an inherent ordering and ranking between the observation categories (Fletcher and Lock 2005:2), and to test whether the distributions found in these observations are significantly different from each other at a specific significance level (see also Shennan 1997:55-61).

The densities of a specific artifact group (e.g., ritual artifacts) in each 3-m-by-3-m grid are categorized as "absent," "present," "sparse," etc. The density categories (ranges) are created according to the "Natural Break" method MapInfo provides for ranged thematic mapping where the range breaks are determined according to an algorithm that uses the average of each range to distribute the data more evenly across the ranges (MapInfo 2006). The number of grids that belong to each category at two different areas of the site (e.g., Buildings 4 and 5, and rest of the site) are counted. The tabulated numbers formed two sets of observations for two areas, appropriate for using the Kolmogorov-Smirnov test. The maximum observed difference between cumulative proportions of number of grids in each category is compared with the minimum calculated difference. If the former exceeds the latter, this means that there is a difference between the two areas of the site in their distribution of grid numbers in each density category, which may be interpreted archaeologically. Minimum difference is calculated as follows:

$$1.36\sqrt{\frac{n1+n2}{n1n2}} \quad (1)$$

where "n1" is the number of grids in the first area, and "n2" is the number of grids in the second area. The number 1.36 is the theoretically derived multiplication factor appropriate to the 0.05 significance level (see Shennan 1997:55-61).

For testing the spatial association between distributions of two different artifact groups, the Chi-squared test is used. This test is based on the absence/presence of the members of groups in each grid, which are either 5-m-by-5-m, 4-m-by-4-m, or 3-m-by-3-m in size. A two-by-two contingency table is created to tabulate the number of grids that fit in one of the four possible cases (in a specific grid, artifact types A and B are both absent; type A is present, type B is absent, etc.). The measured observations in the contingency table are compared with the expected observations, which would be detected if there was no spatial association between the spatial distribution of the two artifact groups. For measuring the degree of association, two coefficients are used: $ø^2$ (phi-squared) and Yule's Q (see also Hodder 1976:201-203; Shennan 1997:104-118).

## 3 Data Analyses

One of the questions raised in former studies was whether there was a spatial association between the area covered by Buildings 4 and 5, and the distribution of ritual artifacts. Maps of the artifact densities across the area illustrated that the grids associated with these buildings included a high number of ritual artifacts (Haciguzeller 2006c).

A count of ritual artifacts in each 3-m-by-3-m grid is used to categorize these grids as "absent," "present," and "dense," which respectively refers to whether a grid has no ritual artifacts, only one ritual artifact, or more than one (Figure 2). The calculations are based on the counts of grids in each category as tabulated in Table 1. According to the Kolmogorov-Smirnov test, the association of ritual artifacts with Buildings 4 and 5 is not significant since $D_{\text{maximum observed}} = 0.167$ is smaller than $D_{\text{minimum required}} = 0.196$.

*Table 1. Kolmogorov-Smirnov test for testing spatial association of ritual artifacts with Buildings 4 and 5.*

| Density of Ritual Artifacts | Bld 4 and 5 | Proportions | Cumulative Proportion | Other Buildings | Proportions | Cumulative Proportion | Dif. Cum. Proportions |
|---|---|---|---|---|---|---|---|
| Absent | 39 | 0.650 | 0.650 | 201 | 0.817 | 0.817 | **0.167** |
| Present | 13 | 0.217 | 0.867 | 31 | 0.126 | 0.943 | 0.076 |
| Dense | 8 | 0.133 | 1.000 | 14 | 0.057 | 1.000 | 0.000 |
| Total | 60 | 1.000 | | 246 | 1.000 | | |

Another question raised previously was whether a certain part of the site, including Block M and Building 6, was associated with banqueting during ritual gatherings or other communal activity in the Neopalatial Period (c. 1700-1450 BC). The question was formulated for three reasons. First, during the Neopalatial Period, Block M displays a very different architectural type and history when compared to the buildings at the north and the town blocks to the south and east (MacGillivray et al. 1992:125). The monumental features, such as the paved entrance to Building 6 and its main hall opening out on a columnar court, are unparalleled at Palaikastro (MacGillivray et al. 1998:233) and might have been used during the communal gatherings in the area. Second, in former studies, mapping with GIS illustrated that the density of Neopalatial banqueting vases in Block M and Building 6 was high (Haciguzeller 2006a; 2006c). Third, the statistical description of artifact attributes by means of bivariate graphs illustrated that Block M and Building 6 included many drinking vases and banqueting vases, respectively (Haciguzeller 2006b).

The same methodology is used to address another question. This time, five categories are created for the counts of the ritual artifacts in each 3-m-by-3-m grid as "absent,"


*Figure 2. Ranged mapping of the artifact counts.*

*Table 2. Calculations of Kolmogorov-Smirnov test for testing spatial association of banqueting vases with Block M.*

| Density of banqueting vases | Block M | Proportions | Cumulative Proportion | Other Buildings | Proportions | Cumulative Proportion | Dif. Cum. Proportions |
|---|---|---|---|---|---|---|---|
| Absent | 39.000 | 0.443 | 0.443 | 55.000 | 0.333 | 0.333 | **0.110** |
| Sparse | 22.000 | 0.250 | 0.693 | 56.000 | 0.339 | 0.673 | 0.020 |
| Dense | 18.000 | 0.205 | 0.898 | 46.000 | 0.279 | 0.952 | -0.054 |
| Very Dense | 9.000 | 0.102 | 1.000 | 8.000 | 0.048 | 1.000 | 0.000 |
| Densest | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 |
| Total | 88.000 | 1.000 | | 165.000 | 1.000 | | |

*Table 3. Calculations of Kolmogorov-Smirnov test for testing spatial association of banqueting vases with Building 6.*

| Density of banqueting vases | Bld 6 | Proportions | Cumulative Proportion | Other Buildings | Proportions | Cumulative Proportion | Dif. Cum. Proportions |
|---|---|---|---|---|---|---|---|
| Absent | 18.000 | 0.340 | 0.340 | 55.000 | 0.333 | 0.333 | 0.006 |
| Sparse | 21.000 | 0.396 | 0.736 | 56.000 | 0.339 | 0.673 | 0.063 |
| Dense | 8.000 | 0.151 | 0.887 | 46.000 | 0.279 | 0.952 | **-0.065** |
| Very Dense | 5.000 | 0.094 | 0.981 | 8.000 | 0.048 | 1.000 | -0.019 |
| Densest | 1.000 | 0.019 | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 |
| Total | 53.000 | 1.000 | | 165.000 | 1.000 | | |

"sparse," "dense," "very dense," and "densest" (Table 2 and Table 3). According to the significance test, spatial distribution of banqueting vases is associated neither with Building 6 nor with Block M. For Building 6, the absolute value of $D_{\text{maximum observed}} = -0.065$ is smaller than $D_{\text{minimum required}} = 0.215$. For Block M $D_{\text{maximum observed}} = 0.110$ is smaller than $D_{\text{minimum required}} = 0.180$ as well.

Another question raised in former studies was whether there was a spatial association between stone vases and banqueting vases, and/or stone vases and ritual artifacts. When these artifacts were plotted together as point distributions, there seemed to be clustering of the points. If such associations were tested and found significant, the functionality of stone vases in Minoan Crete could be better understood (Haciguzeller 2006a; 2006c).

As an example, Tables 4-6 tabulate the calculations of the Chi-squared test, using 5-m-by-5-m grids, for quantifying the spatial association between stone vases and banqueting vases. If there was no association the Chi-squared value would be 3.84 according to the table of percentage points of the Chi-squared distribution (see Shennan 1997:407). The calculated Chi-squared value is 8.89, which is higher than the expected value. Therefore, we can say that for a degree of freedom = 1 and 0.05 significance level, there is a spatial association between stone vases and banqueting vases.

When all of the results for the Chi-squared test are considered, the association between stone vases and banqueting vases is confusing: there is almost no association when 3-m-by-3-m quadrates are utilized. On the other hand, Yule's Q values for 4-m-by-4-m and 5-m-by-5-m grids, however, are very high, pointing to strong spatial association. Concerning the stone vases and ritual artifacts, the results obtained with 3-m-by-3-m and 5-m-by-5-m grids show almost the same degree of association. However, when the data are tested with 4-m-by-4-m grids, there is no spatial association.

*Table 4. 2-by-2 contingency table for tabulating the counts of grids to be used in Chi-squared test.*

| | Banqueting Vase | | | |
|---|---|---|---|---|
| | | Present | Absent | Total |
| Stone Vase | Present | 77 | 6 | 83 |
| | Absent | 23 | 9 | 32 |
| | Total | 100 | 15 | 115 |

*Table 5. 2-by-2 contingency table for tabulating the expected number of grids.*

| | Banqueting Vase | | | |
|---|---|---|---|---|
| | | Present | Absent | Total |
| Stone Vase | Present | 72.2 | 10.8 | 83.0 |
| | Absent | 27.8 | 42 | 32.0 |
| | Total | 100.0 | 15.0 | 115.0 |

*Table 6. Calculation of the chi-squared value.*

| Category | Observed (Oi) | Expected (Ei) | Oi-Ei | $(Oi-Ei)^2$ | $(Oi-Ei)^2/Ei$ |
|---|---|---|---|---|---|
| Present (SV), Present (BV) | 77 | 72.17 | 4.83 | 23.29 | 0.32 |
| Present (SV), Absent (BV) | 6 | 10.83 | -4.83 | 23.29 | 2.15 |
| Absent (SV), Present (BV) | 23 | 27.83 | -4.83 | 23.29 | 0.84 |
| Absent (SV), Absent (BV) | 9 | 4.17 | 4.83 | 23.29 | 5.58 |
| | | | | | $X^2cal = 8.89$ |

## 4 Conclusions

The statistical results of this study are as follows:

- At a 0.05 significance level, and using 3-m-by-3-m grids, there is no spatial association between Buildings 4 and 5 and the distribution of ritual artifacts.
- At a 0.05 significance level, and using 3-m-by-3-m grids, there is no spatial association between Block M and Building 6 and the banqueting vases.
- At a 0.05 significance level, the degrees of spatial associations between stone vases and "banqueting vases," and stone vases and ritual artifacts are very much influenced by the grid size. The results are varied and inconsistent.

When the statistical results are interpreted archaeologically, it is possible to say that Buildings 4 and 5 are more related to the ritual activity than the rest of the area analyzed. The difference between the density of ritual artifacts in these buildings and rest of the area is high, although it is not high enough to accept that there is a significant difference. Block M and Building 6 do not seem to be related to banqueting. When 3-m-by-3-m grids are used for the Chi-squared test, there is no association between stone vases and banqueting vases. An area of 9 m², however, is too small for a communal activity like banqueting. This might be the reason that these two artifact groups do not show clustering when 3-m-by-3-m grids are used. The results obtained by means of 4-m-by-4-m and 5-m-by-5-m grids are more reliable, and do point to a strong spatial association. Thus, it can be suggested that stone vases were probably used for banqueting in Palaikastro, although it is hard to say something about their use for ritual activity.

At this point, two issues should be highlighted. First, statistics are merely a tool for archaeology. The results of statistical analyses should be considered by archaeologists with a skeptical attitude to avoid misleading interpretations. Second, whatever the methodology used, accuracy and objectivity of data collected on-site is of utmost importance to archaeological research. "Problematic data" will create "problematic interpretations" and neither GIS nor statistics can create miracles to rectify the spatial or conceptual flaws in an archaeological dataset.

Using a set of spatial and statistical analyses at Palaikastro, a methodology for effectively questioning an archaeological intra-site data set has been synthesized. The study revealed that accurate and "archaeologically unbiased" data collection could lead to fruitful interpretations of functionality concerning different parts of an archaeological site. Inferences on functionality at the intra-site level can contribute to several discussions in archaeology concerning issues such as social stratification, ritual practice, and daily life (on possible relationships between social stratification and banqueting activity in Minoan society, see, e.g., Moody 1987:239-240, and for Mycenaean society, Bendall 2004). With sufficient awareness and knowledge of statistical techniques as well as a complete and accurate GIS database of an archaeological site, the methodology presented here can be used to open new perspectives in archaeological research.

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