Journal of Archaeological Science: Reports 18 (2018) 679–688

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Archaeological spatial analysis and GIS in a small fortification: Ephemeral occupations along the border during the '*Conquest of Desert*' process in Argentinean Pampas (19th Century)☆

Alfredo Maximiano Castillejo[a,*], Facundo Gómez Romero[b], Carlos Landa[c], Camilo Barcia García[d]

[a] *LAQU, UAB Spain, Spain*
[b] *INCUAPA, Departamento de Arqueología, UNCPBA, Argentina*
[c] *Instituto de Arqueología, UBA, CONICET, Argentina*
[d] *Dpto. Prehistoria y Arqueología, UNED, Spain*

ARTICLE INFO

Keywords:
GIS
Ripley K-function
Semivariogram
Empty spaces
Conquest of Desert

ABSTRACT

In the following paper we formulate an interpretation about how the space was managed inside a classic 'Fortín', a sort of small fort, which was located in the Argentinean Pampas during the 1860–1870's period. We review the main features of these sites, like the nature of its structures and buildings or the quick abandonment of military positions due to the advancing process in the frontier. As a case study, *Fortín Otamendi* site is a large area (> 2600 sq. m) divided in several sectors where we had detected and confirmed different scatterings of heterogeneous archaeological remains (e.g. fauna, lithics, metals, glasses…), both in the site and its proximities.

Analytical steps in this research on spatial distributions have been developed from free GIS platform (QGIS) and geostatistical methods. Our aims are to establish an efficient fieldwork, to quantify and characterize spatial distributions, and –according the results obtained–, to solve the problem related with building potential locations, for which we have estimated the probability of a structure location in terms of subareas with significantly low-density distributions of remains.

1. Introduction

The following study belongs to the *Archaeology of Conflict*, field which is defined as the study of cultural patterns, human activities and behaviours associated to conflicts, both in Prehistoric and Historical societies (Freeman and Pollard, 2001; Klausmeier et al., 2006; Scott and McFeater, 2011). This broad definition includes many types of archaeological sites: fortifications, detention facilities, mass graves, monumentality, bunkers and battlefields, among others.

In Pampas region of Argentinean Republic, large areas were occupied by indigenous groups that later were subjugated and conquered militarily by the advance of the 'nation state' involved in an incipient *capitalist world market*. This dynamic built a specific landscape: the invasions of Pampas and Patagonian lands entailed a new geographical organization through new military and civilian settlements. This *invasive dynamic* of indigenous territories by different governments settled in Buenos Aires in the second half of the 19th century established a set of military structures called '*Fuertes*' (military forts) and '*Fortines*' (small military forts or fortlets). During the 1860 to 1870[1] decades, '*Fortines*' like Otamendi site were quite small, round-shaped (diameter size: from 20 to 50 m), and surrounded, first by a ditch and then by a wall or a fence to protect the horses. Commonly, inside the round area there was a wooden watchtower called '*mangrullo*', which was an elevated platform with a straw roof; there also were one or two huts for the troops. On the other hand, these military sites were designed with a specific shape and size, usually circular with one or two rectangular buildings, while the average size was around 3000 sq. m., including the stable that housed the horses (Fig. 1).

Usually, that kind of areas had one cannon, mostly used to warn against enemies or dangers rather than fight the indigenous people. According to their importance, these small settlements housed from 20 to 50 soldiers. Finally, these structures were functional until the reassigned area would be pacified (Walter, 1964). Once the area was pacified, all mobile structures and reusable materials (e.g. wooden fences)

☆ We're grateful to reviewers for their proper comments about main text and pictures. Any mistake belongs to the authors of this paper.

* Corresponding author.

E-mail address: g4amaximiano@gmail.com (A. Maximiano Castillejo).

[1] Between 1878 and 1885 in Pampa and Patagonia territories, a series of military campaigns and actions were carried by the Argentinean Army against diverse Indian peoples. Those campaigns are historiographically known as '*Conquest of Desert*'. Their results were the genocide of several ethnic groups and the complete State control of the territories.

http://dx.doi.org/10.1016/j.jasrep.2017.09.010
Received 13 June 2017; Received in revised form 2 September 2017; Accepted 11 September 2017

Fig. 1. Recreation of ideal *Fortín*. Structural elements like buildings; *margullo* and ditch. Picture from A. Gómez Romero.

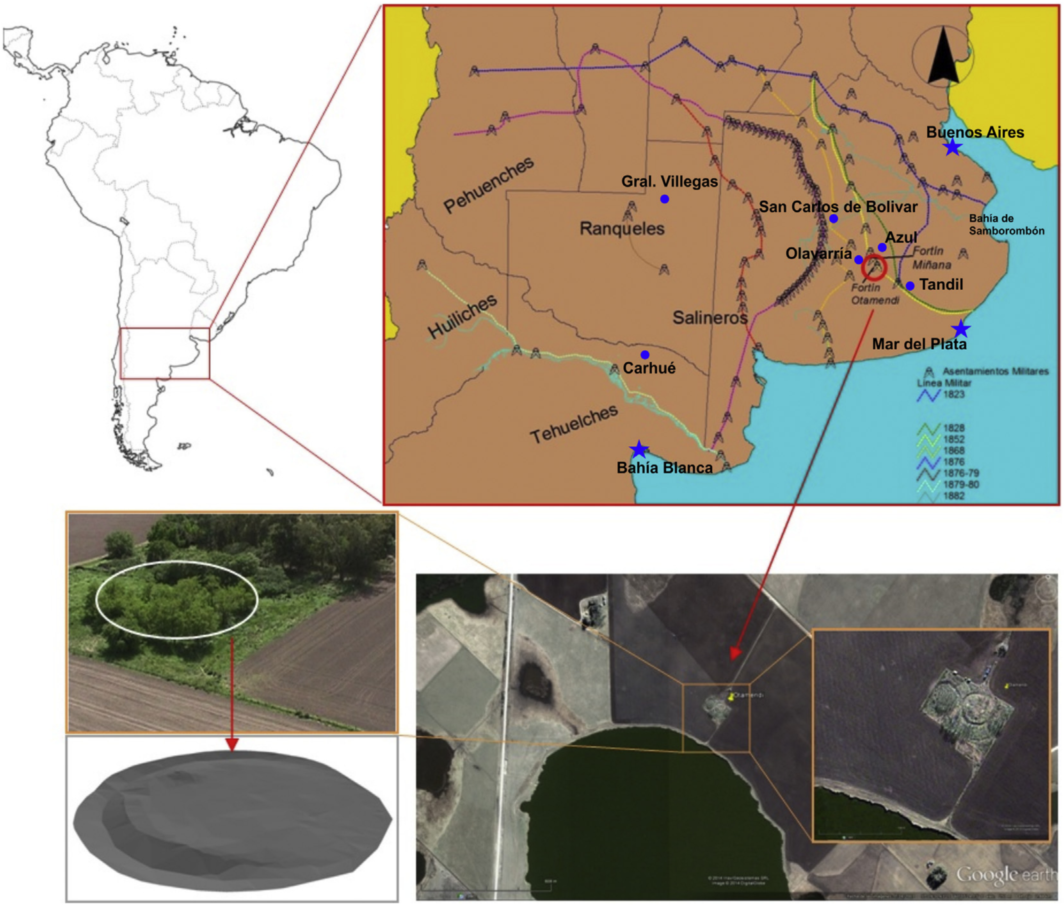


Fig. 2. At the top, location of *Otamendi* site (in red circle) and advancing border line into Indian territories (1823–1882) (Salminci et al., 2009). At the bottom, pictures with aerial details (Google Earth) and 3D surface model of site (white circle on the left). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

were removed to the next location in the advancing border frontline (Ebelot, 1968: 82) (Fig. 2).

The dynamics and conflict of the border spaces constitute a fertile field for the investigation of different disciplines of the Social sciences, such as History, Ethnohistory and Archaeology. Archaeological-historical research carried out in settlements located in the Argentinean southern border against the indigenes has begun to proliferate since the mid-nineties of last century. Military forts and fortlets, located in the present provinces of Buenos Aires, Mendoza, Córdoba and La Pampa, were studied by several researchers (Gómez Romero and Ramos, 1994; Austral and Rocchietti, 1997; Gómez Romero, 1999; Tapia, 1999; Lagiglia, 1991; Leoni et al., 2007; among others). Their productions were interesting contributions that enriched the general and particular knowledge in relation to a chronologically close past, but distant and diffuse in the collective imaginary of Argentine society (Landa, 2011).

The most common material evidences in these kinds of sites are visible topographic changes, a set of concentrated remains in some areas and intentional empty spaces in others (both associated with different social actions). According to that, these sites have a particular post-depositional and taphonomic process: buildings inside the fort had no foundations, and their walls were made of mud (‘*adobe*’), using the earth and sands coming from the excavated ditch. Thus, when that kind of structure is abandoned, it collapses and returns to the sedimentary matrix, leaving no traces behind, the building limits fade and become fuzzy. This formation process makes it very difficult to locate any trace of structures that were extensively documented in written sources and annexed drawings (Thill and Puigdomenech, 2003). This is the main problem not only in *Otamendi* site but also for other small forts excavated by one of us in the 1990's (see Clemente Conte and Gómez Romero, 2008; Gómez Romero, 2005; Pedrotta and Gómez Romero, 1998); then, on archaeological site we can detect spatial distributions of different material remains, but we cannot find any evidence of structure (Gómez Romero, 2007b: 186; Gómez Romero y Maximiano 2011:123)).

In this archaeological context we want to solve a particular spatial problem: to determine the intra-site spatial arrangement of the material evidences associated with specific social practices, linked to the advance of the border frontline and the dynamics of military forts abandon processes in this historical Argentinean period. Therefore, we have used GIS and geostatistics issues in order to:

1. Adjust and improve the fieldwork methodology (see examples in key of digital fieldworks improvements as: Aldenderfer and Craig, 2002; and Barceló et al., 2006a),
2. Characterize the spatial variation of several distributions of remains,
3. Predict building locations according to the dig area and features of these spatial distributions.

In relation with the previous punctuation, we must describe the categories utilized in the analysis of the archaeological record, this are the following:

1) Faunal remains: MNI and MAU analysis, characteristics of the human processes of the bones, like cut marks, fire combustion and termoalterations evidences, etc. Domestic and wild species.
2) Glass: Cylindrical and gin bottles; window glass and other type of recipients.
3) Wares: Tablewares, stonewares, etc.
4) Metal: Different types of aleations; classification of military or non-military artifacts.
5) Lithic: knapping refuse or artifacts, with a microscopic analysis on every edge of each piece.
6) Others: brick fragments; eggshell pieces and unidentified objects (see Gómez Romero, 2007a, b; Gómez Romero and Oliva Benito, 2008, among others).

Using these approaches, we were able to optimize fieldwork introducing spatial frequencies rather than the point data (coordinated data). With this decision, we could dig larger surfaces and faster collect spatial data related with our spatial problem: *where are the limits of structures?* At the same time, we could understand the spatial dynamics of certain variables, and then establish a heuristic discourse about the potential management of space in key of dig areas.

2. Implementing geomatic tools in *Fortín Otamendi* site

In *Fortín Otamendi* site, we consider that geo-computing tools will enable the resolution of such issues as:

i) Finding the significance between the site size and the perception of spatial dynamics depending on excavated volume. In other words, *how much* and in *which way* the excavation should proceed to be able to interpret the site correctly?
ii) *What* kind of social and natural actions could be related with the spatial distribution tendencies of archaeological remains observed inside the site?
iii) *How* the presence of buildings can be detected if they were intentionally demolished and if there were no de facto indicators to locate their possible limits?

Main spatial problems in *Fortín Otamendi* are associated with these three points. If we would be capable to give coherent answers to them, we do not just solve this case study but we also would advance notably in a methodological way (i.e. efficient means of investigating this kind of site) and empirical approaches (i.e. contributing to new perspectives in the enunciation and solution of problems) in Argentinean historical archaeology.

2.1. *The Fortín Otamendi site*

Thill and Puigdomenech (2003:186) referenced a letter from army Colonel Ignacio Rivas to the Argentinean War Ministryin September of 1858, which expressed the need to build a military settlement in the lagoon namely *La Barrancosa*. That military structure was going to be called '*Fortín Barrancosa*' while currently the site is known as '*Fortín Otamendi*' in memory of the officer who died in a battle that occurred nearby.

In May of 1859, the colonel was informed that the ditch structure basic works had been finished and the construction of the stables had started. In September of 1859, Colonel Rivas asked the minister for: "*20 tents for the troops and four for the officers, as the staff slept in the open until completion of the accommodation*" (Thill and Puigdomenech, 2003: 101). According to these references, we have a set of evidences that describe *what* type of site was this one and *how* people lived in it, although this specification does not fall on this particular site but on a kind of fortress-type military structure in general. For example, it is known these settlements were occupied by squadrons of cavalry, and therefore there was an ad-hoc structure built to house the horses (stable) and another one that housed the military force (García Enciso, 1980: 37).

Nowadays, '*Fortín Otamendi*' site is an extensive area (around 2300 sq. m.) surrounded by crop fields. Inside, there are trees and shrubs growing over the surface. The sedimentary matrix is a homogeneous pack of loess –typical sediment on the Great Plains– with the incrustation of some siliceous precipitation – known as '*tosca*' –. In dig areas we found archaeological evidence scattered in this packet, and we link the spatially-allocated remains with the last set of social activities carried out in the site: the dismantling and abandonment of the military place.

2.2. *Fieldwork and data processing for topographical description in Fortín Otamendi site*

We started collecting micro-topographical data of the site – i.e. Total Station survey fieldwork – and then in GIS processing it to elaborate a Digital Elevation Model (DEM). Summary, the data collection strategy was the typical on topographic survey standard procedures. For our level of accuracy – 1,5 cm. error average approx. –, we captured 548 points (x,y,z) and could characterize the whole site surface and its variability. With this support, we were able to define the different (and significant) micro-topographical disturbances, to obtain a digital output that could be used as an analytical spatial base for research activities.

Besides the micro-topographical analysis, we could also detect and quantify some important aspects about site surface:

1. Ditch line or moat, or at least the spatial region where it is best preserved. It should be noted that in the northeast quadrant there is no structural evidence associated with the moat, then we suggest that the most probable cause could be a subsequent back filling of the area motivated by the occupation of a new building (*ranchito*) in this sector, in the first half of the 20th Century.
2. Higher elevations, which could correspond to the accumulation of debris resulting from specifications such as *building structures*, or *intentional concentration* of certain waste.
3. Trend model of changes in micro-topographical relief by slope analysis.

First and second tasks established a display and a measure of different evidences that cannot be observed by naked eye (e.g. small

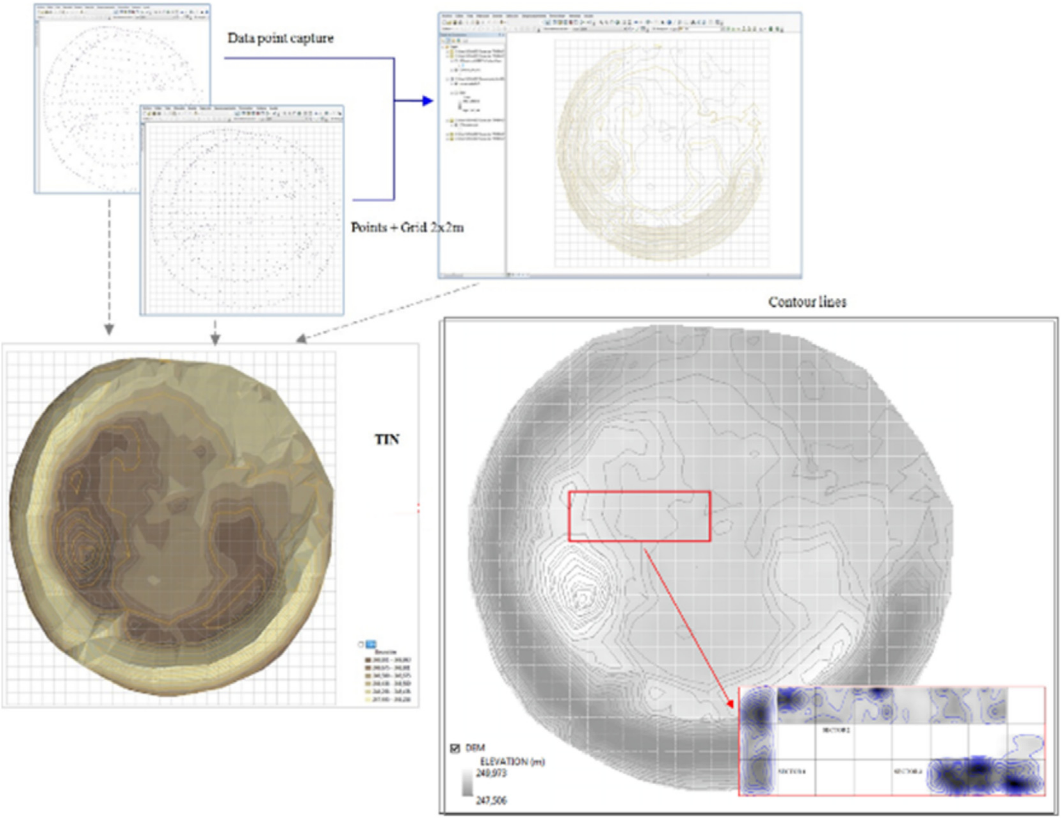


Fig. 3. Spatial data processing steps, from data capture to digital outputs (TIN and DEM). Right-bottom: details of DEM with grid 2 × 2 sq. m. and the excavated area (inside red rectangle) with the total density of archaeological remains (kernel density estimation). Picture oriented to North. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

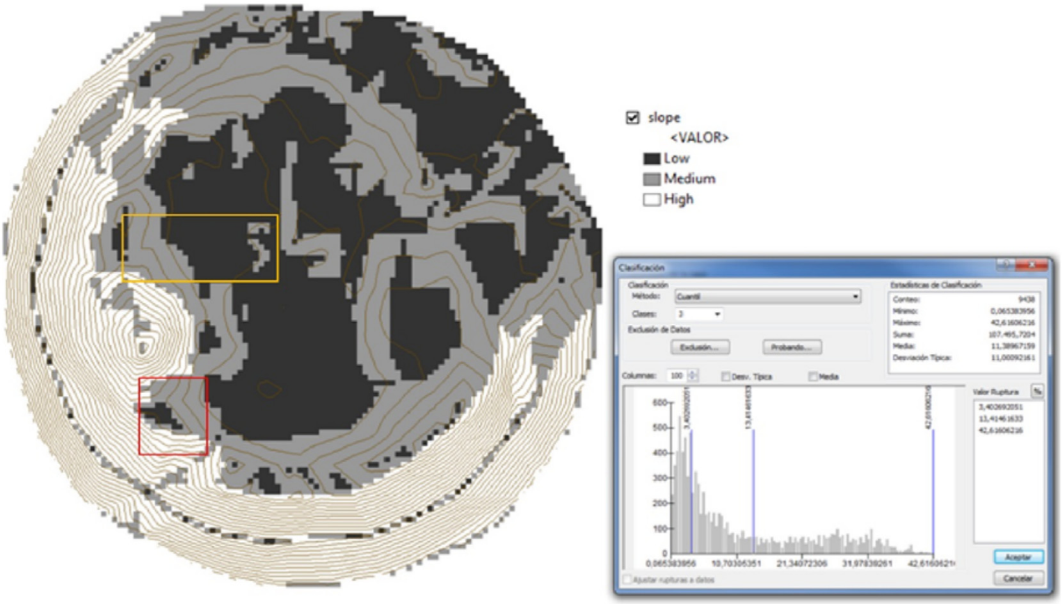
elevations and depressions, and perception of some sectors of the moat) due to a short elevation range (from 247.5to 250 m AMSL), the large area (approx. 2300 sq. m.), and current conditions at the site (growing vegetation).The trend model of micro-topographical changes in relief helped us to determine the presence of sharp slope changes. This way, we made a slope analysis of surface and the results showed us five groups, according to automatic breaking values with Stand. Dev. For a more synthetic spatial resolution, we have reclassified them in three groups with quantile arrangement (see Fig. 3). The result showed darker areas with low slope values: tendency to flatness; while gray areas indicate a moderate slope; the last one corresponds to the ditch encirclement and the elevation on the West, that is: areas with high slope. This approach can reveal if there are some anomalies in function of the rugosity of the surface – i.e. how much abrupt is the change of slope values? – and its potential incidence over artefact spatial distributions in archaeological levels.

At this moment, we are working in an extensive area (a rectangle of 96 sq. m. where 52 of them have been excavated; inside yellow rectangle in Fig. 4) which exhibits low variability in slope, so we can consider the low impact of changes on slope values. However, we must dig in sectors with strong changes in slope (see red rectangle in Fig. 4) because we need to evaluate the possibility of alteration over spatial scatter in areas with elevate rugosity (i.e. high variance in slope through short distances).

3. Analytical results

Here we show the synergies between geomatic resources and spatial analysis to address the archaeological spatial problem in '*Fortín Otamendi*' site. After topographical characterization, we started to work in a GIS platform as a tool for managing several levels of data and information, analysing spatial data, and optimal visualization of results. We must be aware that our hypotheses are limited due to the excavated area is around 2% of total site – test pits and archaeological dig only reaches 56 sq. m. despite total dimension of the site is 2300 sq. m. According to historical conjuncture (i.e. the progression of the frontier and the systematic abandon of forts), we consider that intra-site spatial distributions are largely influenced by the expected abandonment of the site by its inhabitants: military garrison (Maximiano, 2008: 307). In this sense, the spatial distribution hypothesis must be linked with the closure episode of this place (e.g. the garrison might adopted more flexible social practices in space management), and with the first actions happened after the occupants' departure (e.g. social and biological agents rummaging through abandoned remains). Therefore, and at the confluence of all these circumstances, it would be expected a random trend in spatial distribution of archaeological remains around specific places. However, the research of spatial variability must always mind that similar patterns could be generated by different processes, i.e. 'spatial equifinality' (Barceló et al., 2006b:138). Then, the analysis of archaeological variability should be completed with other inputs from descriptions – analytic or inferential – to final interpretation of results in order to be as much accurate as possible. This consideration is essential for archaeological spatial variability due to we only can deal with the observed tiny fraction of the social phenomenon, which might generate a certain degree of confusion in the global interpretation of the observed spatial variability (see Figs. 5–9).

In excavated area of *Otamendi* site, the goals have been the univariate statistical description of data, to parameterize – i.e. to define analytically – spatial distributions of remains and the formulation of a location model to interpret spatial variance. For this purpose –and after a preliminary analysis in every nominal categories and subcategories like *glass*, *faunal*, *metal, crockery*… up to 3035 items for the whole sample –, we have quantified the spatial variation in terms of a global category to detect and characterize the global spatial tendency. The



Clasificación

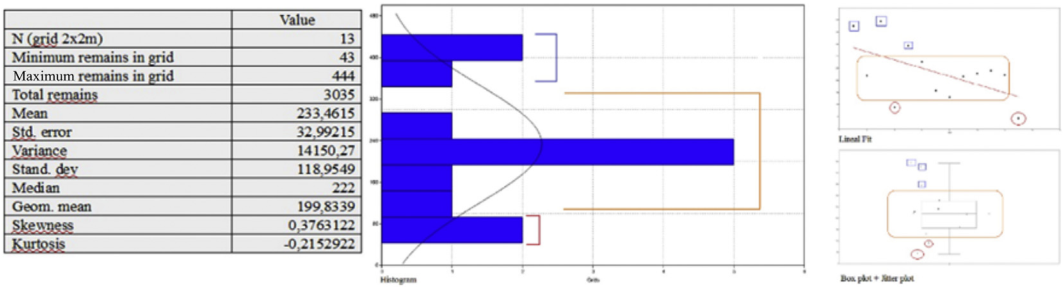
Clasificación
Método: Cuantil
Clases: 3
Exclusión de Datos
Columnas: 100
☐ Desv. Típica
☐ Media

Estadísticas de Clasificación
Conteo: 9438
Mínimo: 0,065383956
Máximo: 42,61606216
Suma: 107.495,7204
Media: 11,38967159
Desviación Típica: 11,00092161

Valor Ruptura
3,402692051
13,41461633
42,61606216

☐ Ajustar rupturas a datos

Fig. 4. Topographic and slope analysis using three groups of value (low, medium and high slope) and its classification applying histogram of distribution with quartile arrangement.



	Value
N (grid 2x2m)	13
Minimum remains in grid	43
Maximum remains in grid	444
Total remains	3035
Mean	233,4615
Std. error	32,99215
Variance	14150,27
Stand. dev	118,9549
Median	222
Geom. mean	199,8339
Skewness	0,3763122
Kurtosis	-0,2152922

Fig. 5. Statistical description of population (left) and histogram (middle);the X-axis displays how many grid quadrates are for each range of items, while Y-axis shows the amount of items in ranges. At the top of right there's a Lineal Fit graphic (Ordinary LS method) where the 2 low-density quadrants are highlighted in red (small red bracket in histogram), then the central part of histogram is indicated by an orange bracket (8 cases, rectangle in LS graphic), and the 3cases for too high values are in blue squares (blue bracket in histogram). At the bottom of right, there are a Box and a Jitter Plot. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

dataset was generated in two formats: we started with coordinated data (x,y,z), but after the firsts fieldwork seasons (sectors 1 and 3) we had decided[2] to use a scalar field: spatial frequency data in sector 2.The results of statistical description were relevant in key of data heterogeneity because we identified some quadrates with outliers, very low remains density (Fig. 4).

Based on that statistical description, our first task was to characterize the statistical spatial patterning for the recovered sample by evaluating the spatial trends of items. A key aspect in the spatial analysis is the extent of the theoretical random pattern, as it implies that any region of the surface has the same probability of containing an item. This spatial behaviour is modelled by the *Poisson theoretical distribution* (Cressie, 1993), stating randomness as the null hypothesis for spatial variability, which is known as CSR (Complete Spatial Randomness).In *Otamendi* site, we decided to explore the spatial tendencies with Ripley's K Function. This statistical test establishes the type, intensity and range of the spatial pattern of a point data distribution (Ripley, 1976, 1981; Venables and Ripley, 1994). In others words, Ripley's K Function is a way to measure statistically significant clustering, spatial uniformity/dispersion, or randomness. Surprisingly, this test is still not broadly used in Archaeology despite all the interesting possibilities that have already been pointed out elsewhere (see Barcia, 2016; Maximiano, 2008; Orton, 2004; Sayer and Wienhold, 2013… among others). The more intuitive and easier to interpret Nearest-Neighbour Analysis (NNA) was not considered a proper option for our data set because an increase in NNA measurements to *n*-th number of neighbours does not easily allow for statistical validation (Conolly and Mark, 2006:165; Sayer and Wienhold, 2013).The main question to solve by this statistical test is the determination of the density of occurrence of two points within a given distance from each other (Diggle, 1983; Ripley, 1977). In other words, it approximately calculates *second order properties* that characterized the number of points found nearby an arbitrary point in the pattern, and describes the spatial structure of these points in terms of spatial clustering, uniformity, randomness… (Pélissier and Goreaud, 2001). Hence, the K-Function of an empirical distribution is compared with three theoretical models, then significant positive or negative deviations from randomness will indicate, respectively, clustering or uniformity of point data at multiples scales regardless of the shape of the area being studied (Conolly and Mark, 2006:166). In essence, if the empirical function is placed above the theoretical aggregation function, the distribution trends towards spatial concentration. In contrast, if the empirical function is placed below the dispersion function, the distribution trends to spreading, and if the empirical function is located between the two theoretical distributions (*an ideal situation is the function* '$f(x)$ = x'), then the distribution of points is spatially random. Its mathematical notation is:

---

[2] We improved fieldwork techniques to optimize the resources, allowing the excavated surface area to be increased without diminishing the quality of further information and progress in resolving the issues raised.

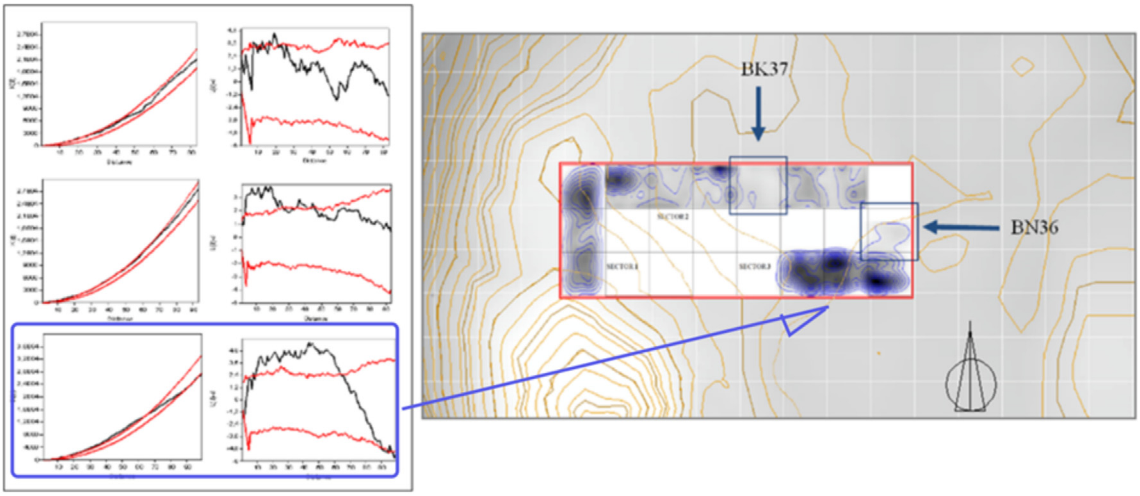


Fig. 6. Left: Ripley's K-function and L transformation (PAST software), left and right columns respectively (sector 1 on top, sector 2 in middle, sector 3 at bottom); there is significant spatial clustering in sector 3, rectangle in blue. Right: DEM, contour layers and spatial density in excavated area of 52 sq. m. You can see the two squares (BK37 and BN36) with low density remains. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

$$\widehat{K}(r) = \widehat{\lambda}^{-1}\sum_{\substack{i=1\\ i\neq j}}^{N}\sum_{j=1} w(s_i,s_j)^{-1}\frac{I(d_{ij}<r)}{N}$$

where N is the number of points per unit area; and λ is the density constant of points, which is calculated dividing N by the area of prospected region in surface units. Then, w is the edge-effect corrector (see Cressie, 1993); I is an indicator with value 1 if distance between two points is less than r or 0 if larger; and d is the distance that separates two locations named s_i and s_j.

The starting point for this test is based on whether a group of points – i.e. archaeological items – are distributed randomly, e.g. following a Poisson distribution with a certain density λ. Thus, the expected number of points within a circle of radius r would be equal to $\lambda\pi r^2$, and deviations from randomness can be calculated with Ripley's K-function (Bailey and Gattrell, 1995; Cressie, 1993; Dixon, 2002; Ripley, 1976, 1981). The expected theoretical value of the K-Function in the case of spatial randomness is equal to πr^2; then $K(r) > \pi r^2$ indicates aggregation; $K(r) < \pi r^2$ indicates uniformity; and $K(r) = \pi r^2$ indicates randomness.

The principal advantage of this test compared with others – like NNA – is the consideration and correction factor of edge effect. The edge effect difficulty usually occurs when it is necessary to count the number of points within a search circle $c(r)$ that intercepts the boundaries of the study area, called A. This search circle has a radius r and is centred at a point located inside A. It has two distinct parts $A + r$ and $A - r$, which respectively mark the regions of the search circle that belong or not to A, falling in or out of it. Usually there is no information about the number of points within $A - (r)$, however if these points are not considered, $c(r)$ would contain fewer points than expected (Brazao Protázio, 2007).The purpose of the edge effect correction factor is to minimize this effect[3]and, in *Otamendi* site, the edge effect is a main component because we are digging in 'small window', just a small sample of the whole site. In this sense, the way we are perceiving distributions is slightly disturbed by how we are performing the fieldwork. Consequently, if we work with a test that does not consider the edge effect (like NNA), the interpretation of spatial patterning would be distorted.

In the results of Ripley's K-function analysis for each excavated sector we can see that distributions tend towards randomness. Although in sector 3 there is a tendency to clustering over short distances, it is not a definite proof as the size and shape of the window we used while digging distorts the characterization of the distribution. However, this sign of aggregation in short distances might indicate something. The results are displayed with both the K-Function and the L-Function, which is a clever transformation of K-Function that enables us to appreciate greater details about the variance established by Ripley's K-Function. Its notation is:

$$\widehat{L}(r) = \sqrt{\frac{\widehat{K}(r)}{\pi}} - r$$

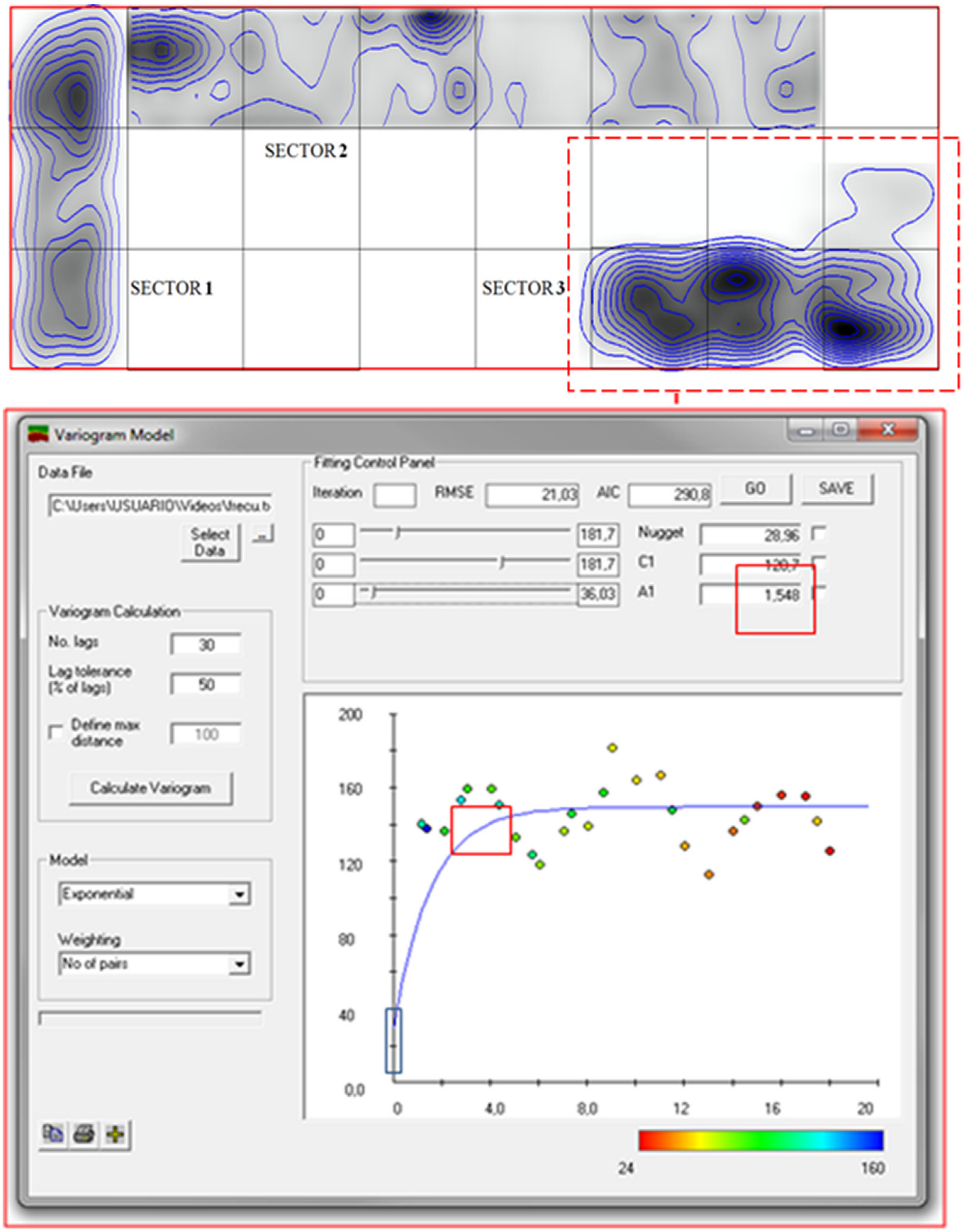
The implications of this analysis leads us to consider the distribution and the potential action that caused it, together with the significance between the size of the site and the perception of spatial dynamics as a function of the excavated area (no > 3% of the whole site). If the statistical test shows spatial randomness as the main tendency in the distribution in every sector, the first thought that raised is taphonomic processes might be the main cause for this lack of spatial structure, then it is plausible that several post-depositional actions could move the remains from their original position towards another. However, we do not believe this could be the only cause of the observed distributions, but we consider the random spatial distribution as an effect caused by some activities related to the waste management, in a particular episode of the end of the life of the fort: the imminent abandonment. Therefore, we do not think that taphonomic dynamics were the cause of the random distribution because the simulation of an intensive taphonomic process would generate a spatial distribution with a clear tendency towards uniformity distribution of remains per sample unit (Maximiano, 2008:319). To strengthen this argument, there are two evidences in spatial distribution: locations with significantly low density of remains have been detected, one in grid BN36 with < 43 items, and grid BK37 with < 84; which entails a significant contrast with relative high frequencies in adjacent squares (around 70–90 items per sq. m.).

This way, Ripley's K-Function is able to show that there is no significant tendency towards clustering or dispersion in the distribution of remains in sectors 1 and 2, as the distributions tend towards randomness. In contrast, there is a tendency towards aggregation in sector 3 for short distances, but it should be mind that in this sector there is an area where spatial frequencies are considerably lower than in other excavated areas. This evidence could indicate a different kind of spatial behaviour in this area and its neighbourhood.

To compare the results of Ripley's K-function, the spatial autocorrelation was calculated for each sector with the semivariogram

---

[3] There are many authors that tackled this issue; see for example Besag (1977), Getis and Franklin (1987), and Dale and Powell (2001), among others.



Data File: C:\Users\USUARIO\Videos\trecu.b

Iteration: | RMSE: 21,03 | AIC: 290,8

0 — 181,7 Nugget: 28,96 ☐
0 — 181,7 C1: 120,7 ☐
0 — 36,03 A1: 1,548 ☐

Variogram Calculation
No. lags: 30
Lag tolerance (% of lags): 50
☐ Define max distance: 100

Model: Exponential
Weighting: No of pairs

Fig. 7. Up: dig area with kernel density and grid (2 × 2 m). Down: Semivariogram models contrasting spatial autocorrelation in sector 3, there is 1.5 m spatial autocorrelation. Generated with Vesper Software.

statistic tool. It was established by analysing how a quantitative property – i.e. intensity – varies according to location, measuring the location for each value of such property that is an independent variable. Intuitively, the spatial autocorrelation is used to determine how the presence of a certain quantity or quality of a property in a specific location makes its presence in neighbouring locations more or less probable. To be more precise, Sokal and Oden (1978) stated spatial autocorrelation tests verify whether the observed value of a variable in a certain location is independent of the values of the same variable in neighbouring locations. This way spatial autocorrelation is linked to the First Law of Geography, expressed as "*everything is related to everything else, but near things are more related than distant things*" (Tobler, 1979).The use of spatial autocorrelation in intra-site archaeology is not broadly widespread, however we still can find some examples in literature are: Hodder and Orton (1976), Carr (1985), Lloyd and Atkinson (2004), Maximiano (2008, 2012, 2013, 2016), Rondelli et al. (2014), among others.

Typical functions in spatial autocorrelation are *Semivariogram* and *Correlogram*; these tools quantify the semi-variance existing in a distribution, measuring the degree of correlation between the values of each variable and the distance between them (Matheron, 1971).The objective of a *semivariogram* is to determine the correlation by quantifying the relationship of a variable extent in a number of points, it can predict the same variable extent points located at known distances, but which have not been sampled using Kriging algorithm (Isaaks and Srivastava, 1989). The *semivariogram* is defined as the arithmetic mean of all the squares of the differences between pairs of experimental values separated by a distance *h*, that is, how variance increases according to several locations (separated by a distance *h*) of a regionalized variable. *Semivariogram* $\gamma(h)$ represents the largest useful thorough geostatistical tool (Armstrong and Carignan, 1997; Weerts and Bierkens, 1993). Its mathematical notation is:

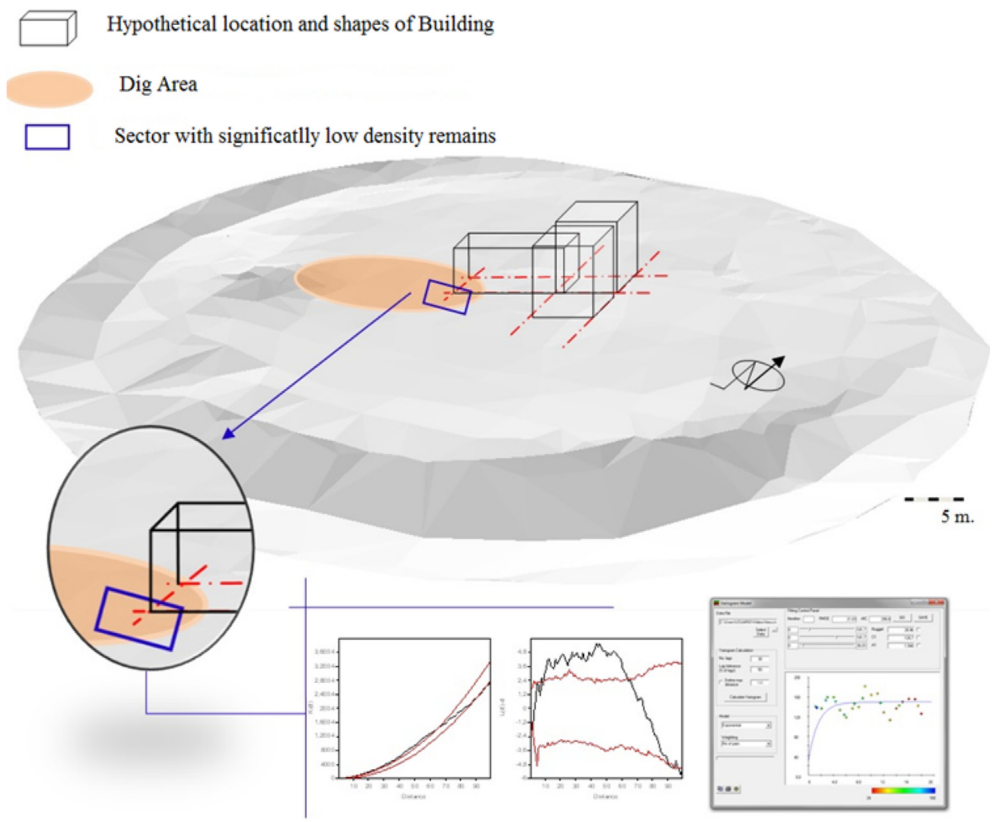


Fig. 8. Spatial hypothesis of potential buildings locations according to analytical results in key of low density remains and no-randomness distribution.

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{f=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2$$

where h is an increasing distance; N is the number of pairs within a distance h; Z is an experimental value; and x_i are the locations where Z value can be measured.

The study of the spatial autocorrelation is closely linked to structural spatial analysis, as both seek to reach a characterization of the potential process that caused the spatial distribution under consideration. As becomes clear, the structure defines the type of *spatial pattern* based on the criterion of distances between locations. Measuring *spatial autocorrelation,* we can estimate the process in terms of spatial variation in intensity or frequency, which makes it possible to describe the nature of the same statistical variation as a ‘surface gradient’ and to

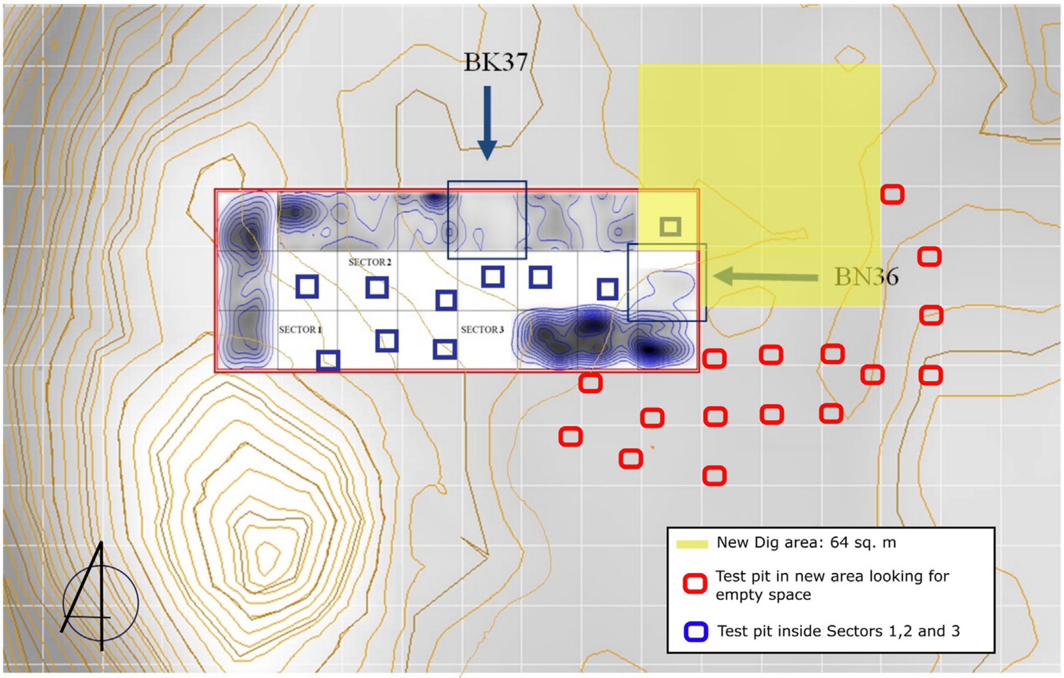


Fig. 9. Schematic representation of new dig area (yellow rectangle = 64 sq. m), and spatial location of new test pits (1 sq. m) inside sectors 1, 2, 3 (blue) and out (red) a total of 26 sq. m. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

establish the limits of it. In *Otamendi* site, the spatial autocorrelation analysis has provided significant results: in sectors 1 and 2 there is no autocorrelation values, while in sector 3 there is a spatial autocorrelation around 1.5 m.

The main spatial implications of these results can be expressed as (and bring us to) two new hypotheses:

i) If we excavate in the neighbourhood of sectors 1 and 2, there would be an equal probability of finding archaeological remains in any location, that is, the surface is *equipotential* in these areas; and
ii) If we excavate in the neighbourhood of sector 3 we would detect a spatial aggregation pattern, with greater probability the more we move to the East.

4. Discussion

Through the topographical characterization of archaeological site (i.e. MDE and slope analysis), its spatial visualization (GIS) and analytical series (Ripley's K-function, autocorrelation and semivariance), the spatial variance in excavated areas of *Fortín Otamendi* has been defined and quantified. In terms of spatial issues, we have detected a singular area in which the frequency of remains and their spatial structure is very different than other sectors: a tendency to spatial aggregation around 1.5 m, and analytical sensitivity to low density of remains ($<$ 35 items per sq. m.).

After the analytical phase, the main question that now arises is whether these statistical differences could be linked with a determinate set of social or taphonomic actions that happened in the past in these locations. Of course, advances in the interpretability of this site requires new perspectives in two main directions: one is the concurrence of geophysical survey (GPR and EM); and the other is the future excavation in certain sectors to establish whether such a low density of remains is significant, if it could be adjusted to any shape (e.g. rectangle or square) and then to associate this spatial trend – low density and non-random pattern – with a differential use of space (i.e. the places where building could be located). At this moment, and after testing alternative fieldworks experiences, we consider the best option is to change the methodology of data collection, leaving behind the coordinate data and to change it only for spatial frequencies. We evaluated this approach in sector 2 which was excavated this way along 24sq. m. in only one fieldwork session, while the others two sectors – 1 and 3 – were still excavated with coordinate data, reaching the extension of 28 sq. m. in three fieldwork sessions. In others words, the efficiency of excavation tasks in sector 2 increased its potential in one third of the time – sector 2 did only 4 sq. m. less than sectors 1 and 3 together!

At the new stage of the project, we are involved only in detecting and characterizing distributions of archaeological remains in terms of their spatial density. This way is more efficient due we can work in larger areas during the same time, with no loss of information according to our spatial problem. But in these circumstances, it will be necessary to replace Ripley's K-function (this statistical test only works with coordinate data) with other tests, which also take edge effect into account. The best choice for frequency spatial data may be Moran's Correlogram (Barceló and Maximiano, 2007).

In terms of archaeological interpretation, we think the spatial randomness (in sectors 1 and 2) is the result of certain causal activities preformed in these locations, and not erroneous analytical measurements based on the partiality dimension of excavated area. Hence, according to our archaeological spatial problem, we consider the spatial pattern of a distribution just as a first indicator but meaningful feature which is closely related with its causality. A qualitative aspect of the entire bonding surface (*equipotential surface*) is there occurrence of a similar density of remains per unit area, tested on different window sizes, except in two locations: the grid BK37 in the middle of sector 2 (no. of items: 84) and the more singular case grid BN36 in sector 3 (no. of items: 43), Southeast corner of excavated area. In this grid, we detected a particular spatial dynamic where artefact density is the lowest and has a non-random tendency. In this situation, low artefact density and spatial aggregation could define a particular spatial dynamic based on the presence of the fuzzy nominal category: "empty space", and we must consider its potential connection with certain social activities.

As mentioned above, due to the condition soft-building practices and site taphonomy, there is no enough valid criterion (e.g. GPR, EM) to recognize the location of existing buildings yet in *Fortín Otamendi* site.

We propose a hypothetical statistical relationship –which must be tested at site– between empty spaces and places with determinate function, for example: the presence of buildings, interiors, transit areas between structures, the parade ground, etc.

5. Final considerations

According to spatial analysis of *Fortín Otamendi* site we have two sets of considerations: one is empirical and the other is essentially theoretical.

Empirically, we aim to evaluate the presence of grids with low density remains and evaluate the hypothesis of empty spaces and its potential correlation with the potential location of determinate structural entities belonging to the 'fortín' (buildings, the parade ground…). For this, we must combine some research strategies: archaeological test pits, and extensive dig surfaces to generate significant and consistent sample for the problem we want to solve.

With all new dataset (over a surface $>$ 80 sq. m), we improvement spatial analysis, and more important issues; we culminate our spatial research applying spatial gradient models. The grading of a particular spatial phenomenon is the expression of how a *regionalized variable* changes depending on the values which take in neighbouring locations (Marr and Hildreth, 1980). This means the gradient determines the spatial continuity in a series of locations that have a similar rate (in our case: low density remains vs high density); it establishes dissimilar regions based on intensity change in the values of the regionalized variable. Therefore, we can use the discontinuities in a spatial pattern by identifying the exchange rate to show the gradient and define the potential limits of buildings. The technique is widely used in image analysis, but also can be applied to archaeological spatial analysis (Maximiano, 2008, 2016) since in both cases they are scalar fields in which the scholar tries to distinguish the outline of an area or to delimit an internally homogeneous area, which is differentiated from the surrounding areas. The algorithm used to increase the gradient is the *first derivative*, but many equivalent methods can be used (Sonka et al., 1993).

In second term, from a *theoretical perspective*, and based on documentary sources and the experience gained through fieldwork, the detection of empty spaces could be linked to a kind of evidences which are undetectable with our current level of information. In this site, the perception and contrast of spatial random dynamics is the reference vector of spatial performance, which is consistent in recognizing that we are excavated a small fraction of the material remains distributions associated with a particular historical moment: dynamics about the conquest of territories represented in a fort-type military structure, site abandonment and the location transfer of the 'fortín' due to the advance of the frontier. Under these circumstances, these dynamics could legitimize the practice of certain activities that would be common in other situations (e.g. waste management in a different way than could be expected to long-term, non-abandoned, active inhabitation). Of course, we are should mind the relationship between the sizes of the analyser main fraction and the total area that could be excavated.

Our expectations are set in advance according to the increase dig area, and through them, we can recognize different spatial dynamics and more important implications: future fieldwork strategies and congruent interpretation about social use of space in terms of its material fraction recovered in *Fortín Otamendi*.

References

Aldenderfer, M., Craig, N., 2002. A GIS-based in-field data recording system for archaeological excavation. In: 13th Annual Workshops in Archaeometry. University of Buffalo, pp. 280–294.

Armstrong, M., Carignan, J., 1997. Géostatistique liné: application au domaine minier. École de Mines de Paris.

Austral, A., Rocchietti, A., 1997. Arqueología de la Frontera en el Pantanillo (provincia de córdoba). el Fuerte Achiras. Primeras Jornadas de Arqueología Histórica y del contacto del centro – Oeste del país. II Seminario de las ruinas de San Francisco, Río Cuarto, pp. 29–36.

Bailey, T.C., Gattrell, A.C., 1995. Interactive Spatial Data Analysis. Longman Scientific and Technical, New York.

Barceló, J.A., Maximiano, A., 2007. Some notes regarding distributional analysis of spatial frequencies. In: Posluschny, A., Lambers, K., Herzog, I. (Eds.), Layers of Perception: Proceedings of the 35th CAA (Berlin, April 2–6, 2007). Vol. 10. Kolloquien zur Vor- und Frühgeschichte, Bonn, pp. 282–287.

Barceló, J.A., Estévez, J., Maximiano, A., 2006a. Real data, virtual excavation: new technologies for archaeological fieldwork at the tops of the world. In: 1st Conference of Archaeology in Tops of the Word, pp. 97–116 Tromsö.

Barceló, J.A., Maximiano, A., Vicente, O., 2006b. La multidimensionalidad del espacio arqueológico: teoría, matemáticas y visualización. In: Grau, I. (Ed.), La aplicación de los SIG en la Arqueología del Paisaje. Universidad de Alicante, Alicante, pp. 132–140.

Barcia, C., 2016. The management of social space in the Upper Palaeolithic: spatial patterns, statistics and open GIS in the Lower Gallery of La Garma (Cantabria, Northern Iberian Peninsula). Int. J. Stud. Res. Archaeol. 1, 205–222.

Besag, J.E., 1977. Commentary to Brian D. Ripley's “Modelling spatial patterns” paper. J. R. Stat. Soc. Ser. B 39 (2), 193–195.

Brazao Protázio, J.M., 2007. Spatial pattern analysis applied to plant ecology. PhD Thesis In: Center for Tropical Marine Ecology. Zentrum für Marine Tropenökologie (ZMT). University of Bremen.

Carr, C., 1985. Introductory remarks on regional analysis. In: Carr, C. (Ed.), For Concordance in Archaeological Analysis. Westport Publishers, St. Louis, pp. 114–127.

Clemente Conte, I., Gómez Romero, F., 2008. Microwear analysis of retouched glass fragments from Fortlet Miñana, Azul, Argentina, 1860–1863. Int. J. Hist. Archaeol. 12, 248–262.

Conolly, J., Mark, L., 2006. Geographical Information Systems in Archaeology. Cambridge University Press, Cambridge.

Cressie, N., 1993. Statistics for Spatial Data. Wiley-Interscience, New York.

Dale, M.R.T., Powell, R.D., 2001. A new method for characterizing point patterns in plant ecology. J. Veg. Sci. 12, 597–608.

Diggle, P.J., 1983. Statistical Analysis of Spatial Point Patterns. Academic Press, London.

Dixon, P.M., 2002. Ripley's *K* function. In: El-Shaaraui, A.H., Piergorsch, W.W. (Eds.), Encyclopedia of Environmetrics. Wiley, New York, pp. 1796–1803.

Ebelot, A., 1968. Frontera Sur. Recuerdos y relatos de la Campaña del Desierto. Kraft, Buenos Aires.

Freeman, P., Pollard, T., 2001. Fields of Conflict: Progress and Prospect in Battlefield Archaeology. BAR International Series 958. Oxford.

García Enciso, I., 1980. Tolderías, fuertes y fortines. EMECÉ, Buenos Aires.

Getis, A., Franklin, J., 1987. Second-order neighborhood analysis of mapped point patterns. Ecology 68 (3), 473–477.

Gómez Romero, F., 1999. Sobre lo arado: el pasado. Arqueología histórica en los alrededores del Fortín Miñana (1860–1869). (Biblos. Azul).

Gómez Romero, F., 2005. The archaeology of the Gaucho vago y malentretenido. Int. J. Hist. Archaeol. 9, 143–164.

Gómez Romero, F., 2007a. Se presume culpable: gauchos, fortines y tecnologías de poder en las pampas argentinas del siglo XIX. (De los cuatro vientos, Buenos Aires).

Gómez Romero, F., 2007b. Sistemas de relaciones sociales en la frontera sur de Buenos Aires: yacimientos Fortín Miñana (1860–1863) y Fortín Otamendi (1858–1869). PhD Thesis. Autonomous University of Barcelona, Department of Prehistory.

Gómez Romero, F., Maximiano, A., 2011. Avances en la aplicación del análisis geoestadístico en arqueología histórica: el ejemplo del Fortín Otamendi (1858–1869). Revista de Arqueología Histórica Argentina e Latino-Americana. 4. pp. 64–85.

Gómez Romero, F., Oliva Benito, A., 2008. Arqueozooología del Fortín Otamendi (1858–1869). En: Continuidad y cambio en Arqueología Histórica. M, Carrara (Compiladora). pp. 633–639 (Rosario).

Gómez Romero, F., Ramos, M., 1994. Miñana Fortlet: Historical Archaeology Research. Historical Archaeology in Latin America. 2. The South Caroline Institute of Archaeology and Anthropology. The University of South Caroline, Columbia, pp. 15–30 Stanley South, publisher.

Hodder, I., Orton, C., 1976. Spatial Analysis in Archaeology. Oxford University Press, Oxford.

Isaaks, E.H., Srivastava, R.M., 1989. An Introduction to Applied Geostatistics. Oxford University Press, Oxford.

Klausmeier, A., Pubrick, L., Schofield, J., 2006. Reflexivity and record: re-mapping conflict archaeology. In: Schofield, J., Klausmeier, A., Purbrick, L. (Eds.), Re-mapping the Field: New Approaches in Conflict Archaeology. Westkreuz-Verlag, Berlin, pp. 5–8.

Lagiglia, H.A., 1991. Arqueología e Historia del Fuerte San Rafael del Diamante. Museo de Historia Natural. Secretaria de Gobierno. Municipalidad de San Rafael, Provincia de Mendoza.

Landa, C., 2011. Fierros Fronterizos. Los materiales de metal como indicadores de identidad y diferenciación social en la Frontera del sur (1776–1885). Editorial Académica Española. (ISBN: 978-3-8454-8502-7. Madrid).

Leoni, J., Tamburini, D., Acedo de Reynoso, T., Scarafia, G., 2007. De balas perdidas y vidrios rotos: distribución espacial de artefactos superficiales en el Fuerte general Paz (1869–1876). Revista de Arqueología Histórica Argentina y Latinoamericana. 1. pp. 29–64 (Buenos Aires).

Lloyd, C.D., Atkinson, P.M., 2004. Archaeology and geostatistics. J. Archaeol. Sci. 31, 151–165.

Marr, D., Hildreth, E., 1980. Theory of edge detection. Proc. R. Soc. London, Ser. B 207, 187–217.

Matheron, G., 1971. La théorie des variables régionalisées et ses applications. Les Cahiers du Centre de Morphologie mathématique de Fontainebleau. Fascicule 5.

Maximiano, A., 2008. Teoría geoestadístcia aplicada al análisis de la variabilidad espacial arqueológica intra-site. PhD Thesis. Department of Prehistory. Autonomous University of Barcelona. https://ddd.uab.cat/pub/tesis/2008/tdx-0523108-145303/amc1de1.pdf.

Maximiano, A., 2012. Geoestadística y arqueología una nueva perspectiva analítico-interpretativa en el análisis espacial intra-site. Analítika: Revista de análisis estadístico. N°. 4. pp. 83–98.

Maximiano, A., 2013. Right Data for Spatial and Temporal Characterization of Archaeological Variability on Intra-site Scale. Geofocus: Revista Internacional de Ciencia y Tecnología de la Información Geográfica. N°. 13_1. pp. 131–153.

Maximiano, A., 2016. Análisis espacial arqueológico: una revisión desde la Geoestadística. In: Mínguez García, M.C., Capdevila Montes, E. (Eds.), Manual de Tecnologías de la Información Geográfica aplicadas a la Arqueología, pp. 203–240.

Orton, C., 2004. Between time and space the geographical dimension of knowledge. Archaeologia e Calcolatori 15, 299–315.

Pedrotta, V., Gómez Romero, F., 1998. Historical Archaeology: an outlook from the Argentinean Pampas. Int. J. Hist. Archaeol. 2, 113–131.

Pélissier, R., Goreaud, F., 2001. A practical approach to the study of spatial structure in simple cases of heterogeneous vegetation. J. Veg. Sci. 12, 99–108.

Ripley, B.D., 1976. The second order analysis of stationary point process. J. Appl. Probab. 13, 255–276.

Ripley, B.D., 1977. Modelling spatial pattern. J. R. Stat. Soc. *B*39, 172–212.

Ripley, B.D., 1981. Spatial Statistics. Wiley, New York.

Rondelli, B., Lancelotti, C., Madella, M., Pecci, A., Balbo, A., Perez, J.R., Inserra, F., Gadekar, C., Ontiveros Cau, M.À., Ajithprasad, P., 2014. Anthropic activity markers and spatial variability: an ethnoarchaeological experiment in a domestic unit of Northern Gujarat (India). J. Archaeol. Sci. 41, 482–492.

Salminci, P., Montanari, E., Landa, C., 2009. La última frontera indígena. Reconstrucción de fortines del siglo XIX en la Pampa Argentina. I Congreso Internacional de Arqueología e Informática Gráfica, Patrimonio e Innovación ARQUEOLÓGICA 2.0. (17 al 20 de junio, Sevilla, España).

Sayer, D., Wienhold, M., 2013. A GIS-investigation of four early Anglo-Saxon cemeteries: Ripley's K-function analysis of spatial groupings amongst graves. Soc. Sci. Comput. Rev. 31, 71–89.

Scott, D., McFeater, A., 2011. The archaeology of historic battlefields: a history and theoretical development in Conflict Archaeology. J. Archaeol. Res. 19, 103–132.

Sokal, R.R., Oden, D.L., 1978. Spatial autocorrelation in biology 1, methodology. Biol. J. Linn. Soc. 10, 199–228.

Sonka, M., Hlavac, V., Boyle, R., 1993. Image, Processing, Analysis and Machine Vision. Chapman & Hall, London.

Tapia, A., 1999. Fortín La Perra. entretelones de la dominación y la supervivencia militar en la pampa central. XII Congreso Nacional de Arqueología Argentina. Universidad Nacional Córdoba, Córdoba.

Thill, J.P., Puigdomenech, J.A., 2003. Guardias, Fuertes y fortines de la frontera sur. Vol. I & II Servicio Histórico del Ejército (SHE), Buenos Aires.

Tobler, W., 1979. Cellular geography. In: Gale, S., Olsson, G. (Eds.), Philosophy in Geography. Reidel, Dordrecht, pp. 379–386.

Venables, W.N., Ripley, B.D., 1994. Modern Applied Statistics with S-Plus. Springer, New York.

Walter, J., 1964. La conquista del desierto. EUDEBA, Buenos Aires.

Weerts, H.J.T., Bierkens, M.F.P., 1993. Geostatistical analysis of overbank deposits of anatomising and meandering fluvial systems; Rhine-Meuse Delta, The Netherlands. Sediment. Geol. 85, 221–232.