

A Methodological Approach for Intra–Site Analysis of Prehistoric Settlements

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The method presented here has been applied to two case studies: Almyros2 and Perdika1 which are located in the region of Thessaly in Greece. It has been assumed that both these settlements belong to Middle Neolithic period. This study aims to propose a combined methodological approach in order to examine if such sites were conceived following a determined spatial organization. Four different technologies have been implemented, including geophysical prospection, space syntax, 3D modeling, and 3D visibility analysis. The promising results obtained from the combination of such technologies, hopefully, will encourage specialists to adopt, compare, and develop integrated methodologies more often, especially when excavations are limited.

Keywords:

Space Syntax, 3D visibility analysis, geophysical prospection, intra-site analysis, prehistoric archaeology, Thessaly

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1. INTRODUCTION

Thessaly is located in central Greece looking over the Aegean Sea to the East. It consists mainly of plains and low hills, surrounded by mountains (Chasia, Kamvounia, Olympus, Pindus, Ossa and Pelion) and, at its central area, it is crossed by the Pineios River. Excavation finds at Theopetra cave suggest a human occupation in the area since the Middle Palaeolithic period (~130,000 years ago) [Kyparissi-Apostolika 2003]. Early excavations were focused at the Neolithic sites of Sesklo and Dimini, located close to Volos [Τσοῦντρας 1908, Theocharis 1973]. Since the first discoveries, numerous

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other sites have been identified and the exploration of the area is still ongoing [Krahtopoulou, 2019]. However, most theories about Neolithic settlements in Thessaly, in particular about the layout of the settlements and the house architecture, are based on the fragmentary record of archaeological excavations, most of which have not managed to bring to light whole settlements. There are more than 400 known Neolithic sites in Thessaly and most settlements were developed on low tells, typically called magoules [Alexakis et al., 2011] (fig. 1). A number of habitation sites are also manifested on extended flat areas. Many of them were inhabited continuously or with some phase interruption for several periods, and some of them continued even during the BA denoting a preference in the prolonged occupation at the same location, despite the necessary reorganization of the settlements. These were generally composed of rectangular buildings of different size and orientation. Many of them were surrounded by a system of enclosures (walls and/or ditches). Even though the function of the enclosures has not been clearly defined, a number of theories have been proposed: protection of the settlement, demarcation between the inside (the settlement and the community) and the outside (the external world) [Demoule and Perlès, 1993; Parkinson and Duffy, 2007].

This paper uses the results of the IGEAN project - Innovative Geophysical Approaches for the study of Early Agricultural villages of Neolithic Thessaly, which focused on the understanding of the inter- and intra-site spatial patterns of numerous magoules, by means of a comparative study between archaeological and geophysical data (<https://igean.ims.forth.gr/>). The project, consisting of a multidisciplinary research team, managed to map extensively a high number (21) of Neolithic sites through a manifold geophysical approach, combining different geophysical instruments and techniques, along with the use of aerial photography and satellite remote sensing in tandem with surface collection of diagnostic material [Kalayci et al., 2017; Sarris, 2013]. Measurements acquired by single sensor and multisensory magnetometry, multi frequency Electromagnetic Induction (EMI), and Ground Penetrating Radar (GPR) were combined to enrich the interpretation of the results and provide an accurate image of the underlying structures' relics. Aerial photography, photogrammetry, and remote sensing have been also employed as a support tool to create a high-resolution digital elevation model (DEM) having a spatial resolution of about 10 cm and enhance the interpretation of the archaeo-environment surrounding the magoules. The method was most appropriate as all magoules have a low elevation and are located in relatively flat cultivated areas with absence of trees. The aerial images and the produced DEMs captured sufficient area around the magoules (even if they are not centered within the DEM) to carry out the analyses. The combination of all these techniques has provided a well-defined image about the spatial distribution of the structures within the Neolithic settlements. Through the course of the project, a number of architectural features (rectangular structures, burnt or un-burnt foundations, enclosure walls, multiple ditches, and other minor anomalies) were identified, illuminating the probable evolution of these settlements during different occupation phases. Among the sites inspected, four of them (Almyros2, Perdikal, Rizomilos2, and Almyriotiki) that presented a clear image of their layout have been selected to be further investigated through space syntax and 3D visibility analysis. The combination of these two instruments might be helpful for trying to further examine the internal organization of the sites. In this paper, the results derived from the application of this workflow to the sites of Almyros2 and Perdikal will be presented. The two settlements have been chosen for their rich layout characteristics as perceived from the

interpretation of the geophysical results. In addition, the two sites are supposed to belong to the same chronological period, according to the diagnostic material found in situ.

The space syntax analysis (consisting of axial map, convex map, and the measurements derived from them) reveals areas of the settlements that were more or less integrated and connected with other spaces. Through the application of the method of Hillier and Hanson [Hillier and Hanson, 1984] quantitative analyses can be produced based on the number of convex spaces and axial lines through their connection and comparison. Some important measurements that can be derived from this method are connectivity, integration, choice, and step depth. The calculations derive from the neighborhood size of each node in a graph "by neighborhood we mean the nodes that are linked to each node within a certain graph distance that might either be topological, metric or angular. For axial and convex analysis we use a topological distance that is calculated from each node to define the radius within which different measures are calculated" [Al_Sayed et al., 2014, p.15]. As Chapman [Chapman, 1990] underlined, it is fundamental to combine and compare the alpha (convex and axial spatial analysis) and gamma (access/permeability) analysis with other measures as well, but even the other measures can independently contribute to a more in-depth interpretation, above all considering control over space. On the other hand, Brown [Brown, 1990], commenting on Chapman's research, underlined the uncertainty of a direct interpretation of the results from axial and convex analyses. He suggested to consider the obtained measures in a larger context without generalizations. Still, he recognized the importance of "depth" as it can indicate spaces with larger accessibility and thus with more contacts and movements. Following a similar line of approach, Cutting [Cutting, 2003] demonstrated that this tool is useful when no assumptions are made and when the rest of information about boundaries, openings, and passages are available. With respect to the access analysis, she suggested to employ it as a "tool to think with" rather than a quantitative instrument of examination. There are even more studies that manifest the contribution of space syntax in archaeology, such as the study of the symbolical aspect of Maya architecture [Homann-Vorgin, 2005], the analysis of the social and political power reflected in the architecture of the fourteenth-fifteenth century community of Arroyo Hondo Pueblo in New Mexico [Shapiro, 2005], the examination of hypothetical restrict access and circulation in the last phase of the Late Bronze Age Pylos palace in Greece [Thaler, 2005], to the investigation of the role of the different inhabitants of Cretan Hellenistic houses and their relation with the rest of the community [Westgate, 2007], and the evaluation of the socio-economic activity of Pompeii [Van Nes, 2014]. The particular approaches have been increasingly used in archaeology for addressing topics related to the social interaction of the inhabitants and their negotiation with the built environment [Fisher, 2009; Harrison, 2021; Osborne, 2012].

The analysis of visibility in archaeology has been widely implemented since the 80's, above all in landscape studies. During the years, several approaches succeed each other, as isovist method [Clark, 2007], visibility graph [Turner et al., 2001], viewshade analysis [Fisher et al., 1997; Loots et al., 1999; Ruggles et al., 1993; Wheatley, 1995], and texture viewshade [Earl, 2005; Paliou, 2018; Paliou et al., 2011; Paliou, E., 2007], in order to achieve a higher degree of reliability and to obtain as much information as possible. The last few years, one more step ahead was made through the possibility to calculate lines of sight together with obstruction points, and to analyze visibility directly within a 3D model (usually a 3D DEM, digital elevation model) through GIS tools (3D visibility analysis) [Landeschi et al.,

2016; Manzetti, 2016]. In this research, the 3D visibility analysis is used to obtain the frequency of visibility map of the settlements that suggests which areas were the most visible and which ones were the most hidden to the sight. By means of a color scale applied to the sites, several degrees of visibility are shown on the map.

The concept of space organization and its implications in social interactions of the inhabitants in prehistoric times is very much discussed. The results of the above analysis could not directly address the social implications of the Neolithic societies, but they can offer another angle of information regarding the social dimensions of it based on the spatial analysis results. As Efstratiou explains, since social phenomena are not measurable and straightforward, a place where social relationships happened can be empirically detected, for instance noticing the spatial distribution of objects and the changing in the construction of houses [Efstratiou, 2017]. Efstratiou accepts and understands the need of using an empiric and quantitative approach, but at the same time he claims the importance of adopting the dialectics if we want to deeply understand all the facets of prehistoric (and not only) societies.

This paper presents a methodological approach to obtain quantitative data that can contribute to our study of the use of social space in Neolithic settlements.



Figure 1. Area of Thessaly (Greece) with the magoules studied under the IGEAN project. The two case studies, Almyros 2 and Perdika 1 are located to the south and central area of east Thessaly.

2. METHODOLOGY

The methodological approach of this research is based on the integration of different disciplines and instruments. The investigation of the spatial organization of the Neolithic sites of Thessaly contemplates the reconstruction of the structural remains of the settlements themselves (structures, encircling walls, ditches, open-air spaces).

2.1 3D reconstruction

The reconstruction of the height of Neolithic constructions or walls has been a challenging task since there are no fully preserved structures dated to that age. Despite this, it is possible to attempt some reconstructions based on the sporadic remains, the architectural proportions, similar well-preserved historical structures or even contemporary constructions using the same materials. From the geophysical surveys, we know that many of the structures of the Neolithic tells of Thessaly were of rectangular or squared shape and they were made of mud-bricks and, in few cases, with stone foundations. Unfortunately, despite the considerable amount of discovered archaeological remains, there is no evidence of their possible height. However, there is few useful information available: in Dimini, the average thickness of the walls of the houses is 0.60 m, the thickness of the surrounding walls is between 0.60 and 1.40 m and have been estimated to be 2.90 m in height [Wace and Thompson, 1912]. Recently, a 3D reconstruction of a Neolithic dwelling at Koutroulou magoula in Thessaly has been attempted: based on the measurements of the fallen mud-bricks, its height was hypothesized to be about 3 m [Papadopoulos et al., 2015]. Based on the above evidence and the dimensions suggested by the geophysical survey, and as a working hypothesis for the goals of the particular research, a height between 4 and 5 meters has been contemplated for the centre and between 2 and 3 meters for the side walls. The surrounding walls of the settlements were considered to be about 3 meters high, and the identified ditches were reconstructed with a depth of about 3 meters. Accordingly, 3D models of four Neolithic settlements (Almyros2, Perdikal, Rizomilos, Almyriotiki) have been realized. Here, only the analyses carried out on the sites of Almyros2 and Perdikal will be presented as case studies. The geophysical features that corresponded to structural remains were traced through ArcMap and their attributes (dimensions, area, alignment, etc.) were estimated before importing the vector outlines of them in 3D Studio Max, which was used to construct the 3D models of the structures. The DEM of the settlements and their surroundings have been constructed using photogrammetry processing of the RPAS (Remotely Piloted Aircraft System) aerial images. The contours extracted from the DEMs were imported into 3D Studio Max.

2.2 3D visibility analysis

The 3D reconstruction of the sites of Almyros2 and Perdikal have been used to perform the 3D visibility analysis, therefore to verify if there are key areas more or less visible within the settlements. The 3D models have been converted into a multipatch and imported into ArcScene together with a grid of observer points, normally distributed at distances of 10 meters from each other and 1.60 meters above the ground level, to simulate the average height of a person. The visibility tool was selected to obtain the map of frequency of visibility, which shows the different level of visibility of the whole area of the 3D model, through various colors. The resulting map is a raster file accompanied by the legend of the color scale: each color specifies the number of observer points that have visual

access to the corresponding-colored area in the raster. Simplifying, for this study, a color scale that goes from blue to red has been set: the bluish colors indicate the most visible areas, while the reddish colors indicate the less visible (hidden) areas.

2.3 Space Syntax analysis

For proceeding with the intra-site spatial network analysis of the settlements and the creation of convex and axial maps, the digital outline of the geophysical structural remains were imported as a .dxf file into DepthmapX, an open-source software developed by Alasdair Turner and Tasos Varoudis from the Space Syntax Laboratory at the University College of London (downloadable at <https://github.com/SpaceGroupUCL/depthmapX/releases>). The convex maps of the sites of Almyros2 and Perdikal have been created following the rule “the fattest, the fewest” and respecting the principle for which a space can be defined convex when the segment, which is connecting two points within it, is fully contained inside the convex space. Axial maps have been realized as well, according to the rule “the longest, the fewest”. Each convex space and each axial line were produced manually. The software offers the possibility to automatically create them, but since the available plans of the geophysical features do not clearly mark their boundaries, the result would have not been accurate. Moreover, drawing each polygon and line is already a first instrument of interpretation, forcing the executor to focus on the several spaces between the structures and trying to understand already their shape, size, and function. Once the convex spaces are outlined, they must be manually linked before performing the analyses, which in our case were connectivity, integration, step depth, and choice. The connectivity “measures the number of immediate neighbors that are directly connected to a space” [Al_Sayed et al., 2014, p. 15], suggesting which area, or axe, of the settlement has a high or low degree of connection with other spaces. In this way, it can contribute to identify which part of the settlement might be more easily reachable by its “neighborhoods”. The integration “shows how deep or shallow a space is in relation to all other spaces” [Al_Sayed et al. 2014, p.15], suggestive of the density of people in a certain area, which can be also used as an index of social interaction. The definition of integration given by the handbook of space syntax is clear enough: the most integrated spaces might be those areas usually reserved to public activities where large groups of people participate. The step depth can be measured in the convex map and “tells you how far away an element is from all the other elements” [Al_Sayed et al., 2014, p. 15], indicating the level of segregation of an area and the difficulty, or ease, to reach it. The choice can instead be applied to the axial analysis, which “measures movement flows through spaces” [Al_Sayed et al., 2014, p. 15], proposing the preferable pathways within a settlement.

The analyses of the axial and convex maps produce several outputs. As soon as the analyses are performed, we obtain an image with the convex spaces and the axial lines represented by several colors, which specify the level of connectivity, integration, step depth, and choice (different colored maps for each measurement). Moreover, an attribute summary of the descriptive statistics describing the central tendency and variability of for each measurement were produced. This provided a quantitative measure of the particular variables.

The results obtained from the 3D visibility analysis and space syntax methodology were examined together. The evaluation of the level of visibility of a specific area and its spatial network attributes can lead to similar conclusions but they can also present different characteristics that offer the

occasion to rethink, develop, and enhance initial interpretations. The amalgamation of the aforementioned analyses can strengthen the hypotheses about the spatial organization of Neolithic settlements in Thessaly, if applied to a large sample of sites.

3. CASE STUDIES AND RESULTS

3.1 Almyros2

The magoula of Almyros2 is located 2 km south of the modern town of Almyros and surface finds witness an occupation dated between the Early Neolithic to the Middle Neolithic (6500-5300 BCE). The site arises above the plain by 5 to 7 meters. Circular traces that delimit the settlement are quite visible in orthophotos of the National Cadastral. The area was investigated by Vertical Magnetic Gradient measurements (6.60 hectares), Electromagnetic Induction (2.39 hectares), and Ground Penetrating Radar (GPR) techniques (0.37 hectares). The most interesting results have been obtained through the magnetic survey, while the GPR and the resistivity survey did not provide any significant data. As the orthophoto suggested, the geophysical survey confirmed the presence of a settlement surrounded by ditches and an internal enclosing wall (Fig. 2).

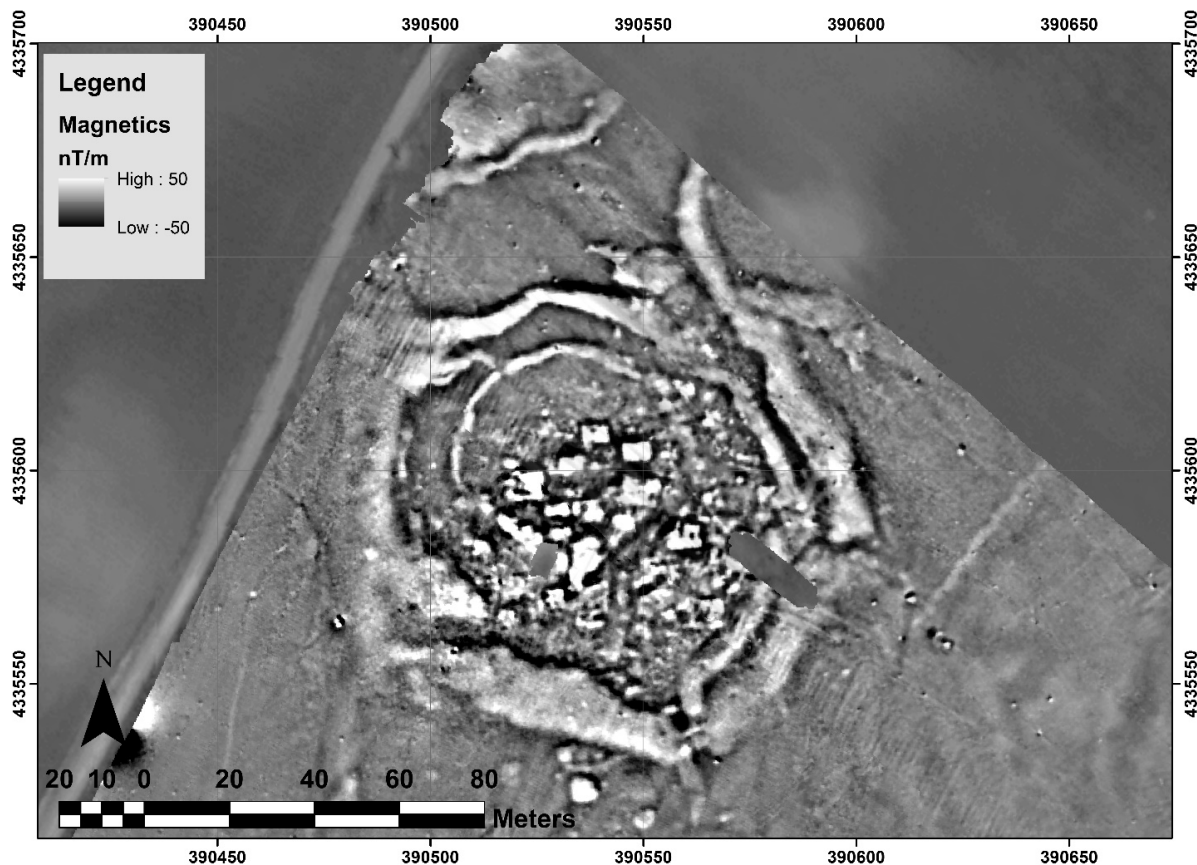


Figure 2. Results of the magnetic gradiometry survey in the area of Almyros2 magoula.

Magnetic fields are vector quantities characterized by both strength and direction. The strength of a magnetic field is measured in units of Tesla (T), equivalent to one Weber (measurement unit for magnetic flux) per square meter. The measurements of the Earth's magnetic field are often quoted in units of nanotesla (nT). Magnetic gradients, as those shown in Fig. 2 are variation of magnetic field along a certain direction and are measured in nanotesla per meter (nT/m).

Through the ditches and the wall there are passages that can be interpreted as openings to access the internal area of the settlement. At least 20 structures have been identified: the largest ones have a surface of 63 m² and the smallest ones of 15 m². Most of the structures are within the encircling wall, whereas a few structures spread outside, towards the southern entrance, suggesting a spread of the occupation during a later expansion of the village. The magnetic measurements revealed that the structures were made of daub and were burnt, it is not clear if intentionally or unintentionally. In the northern part of the enclosed area, there is a large space without any evidence of structural remains.

The convex map of Almyros2 has been drawn within the area delimited by the ditches and here the connectivity and the integration values are presented (Fig. 3).

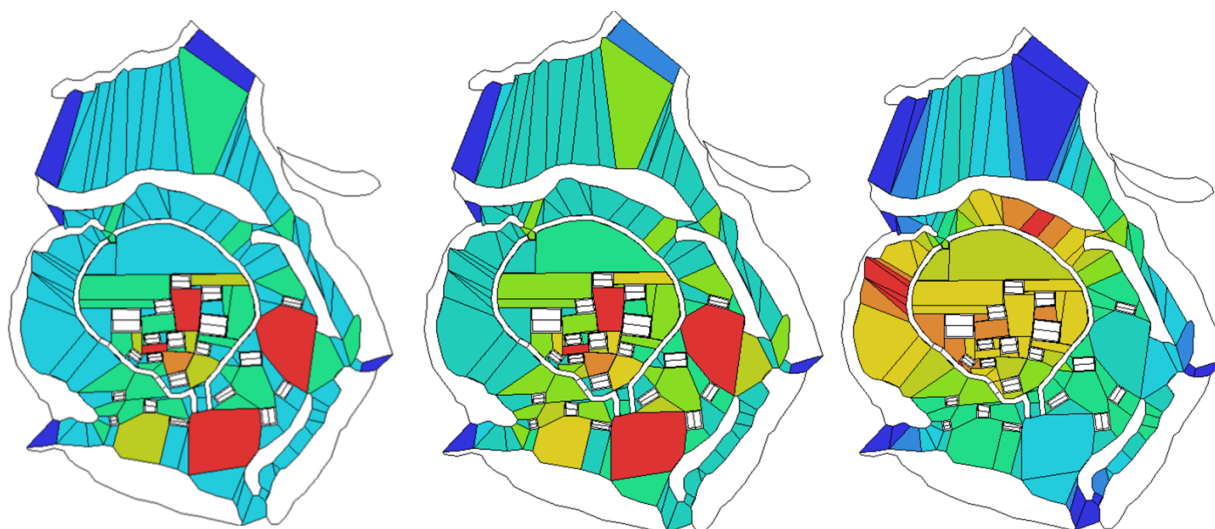


Figure 3. Convex map of Almyros2 with Connectivity values (left), Integration values (middle) and step depth values measured from the entries to the settlement (right).

The bluish color on the maps marks the lower values and the reddish color marks the highest values. By the two maps, it becomes obvious that the level of connectivity and integration of Almyros2 are similar. Both maps testify that the northern area of the settlement is the less connected and integrated. Within the walls, the most integrated and connected areas are located at the centre of four-five dwellings, suggesting a kind of a common yard area. The space located at the north of the households, within the walls, results to be less integrated and connected. The large space that is right outside the presumed southern entrance of the walls, located in the middle of the external dwellings, is highly connected and integrated. This might denote the easiness to move between the two areas occupied by the settlement. Another highly connected and integrated space is outside the walls but

on the east side, still among the houses. Both aforementioned areas are in front of passages through the external ditches. The range of connectivity values for all the convex spaces is 1-6 with an average of 2.36. Similarly, integration values range from 0.21 to 2.97, with an average of 1.36. Since the average values are closer to the minimum values rather than to the maximum values, it can be concluded that the settlement has a low level of connectivity and integration, which implies a larger number of spaces with low connection and integration values. In a similar way, taking into account the various entries to the settlement (the openings through the ditches and the surrounding wall), as they were clearly suggested by the geophysical data, the step depth measurement from all the entrances has been considered (Fig. 2 right). The area of the settlement located within the surrounding wall seems quite segregated in terms of potential contacts with the external territory, since step depth takes values between 8 and 12 (indicated by the blue color). In other words, outsiders that try to reach the core of the village do not have any direct access to it, but instead they have to pass through several spaces before arriving there.

The axial map has been drawn based on the convex spaces. Connectivity, integration, and choice have been considered (Fig. 4). The color scale goes from blue (low values) to red (high values).

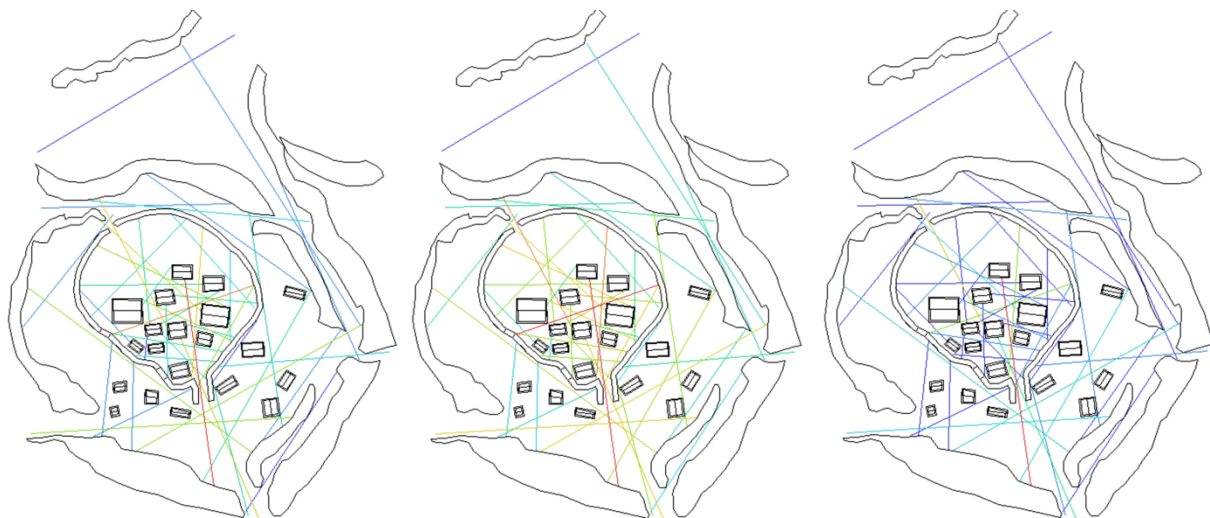


Figure 4. Axial map of Almyros2 with Connectivity values (left), Integration values (middle) and Choice values (right).

The axis most connected, integrated and with the highest possibility of choice is the one passing through the south entrances, crossing with an N-S orientation almost half of the extent of the village. The second axis most connected and integrated is almost perpendicular to the aforementioned, having an orientation SW-NE, and crossing the central part of the village. The second axis that can be frequently chosen is the axis that passes through the NW entry of the surrounding wall, with an orientation NW-SE, reaching the central area of the village. The latter is also quite well integrated and connected. In general, the two perpendicular axes that cross the village within the surrounding wall are the most integrated. Descriptive statistics for the axial connectivity (range 1-18 and average 7.11), integration (range 0.70-5.39 and average 3.13) and choice (range 0-104 and average 15.28), indicate a

low level of connectivity with a sufficient degree of integration (good distribution of axes with low and high values), but a very scarce number of possibilities of movements through the settlement (many axes have a low value for the choice measurement). Within the centre of the site, even if many axes are populating the area, only three of them demonstrate a high value of choice. The area within the surrounding wall is directly connected with the outside zone but confined in the area within the ditches. Three main axes are clearly defined: one passing through the south entry of the walls, one passing through the NW entry of the wall and one crossing perpendicularly the first one, in the middle of the settlement. The northern part of the settlement that consists of a lower number of dwellings is indeed the less integrated, connected and "chosen" area according to the convex and axial maps. The above suggests a certain design plan for the organization of the space that allowed diverse levels of contacts among the areas of the settlement, restricting however the degrees of freedom of movement within the core of the community.

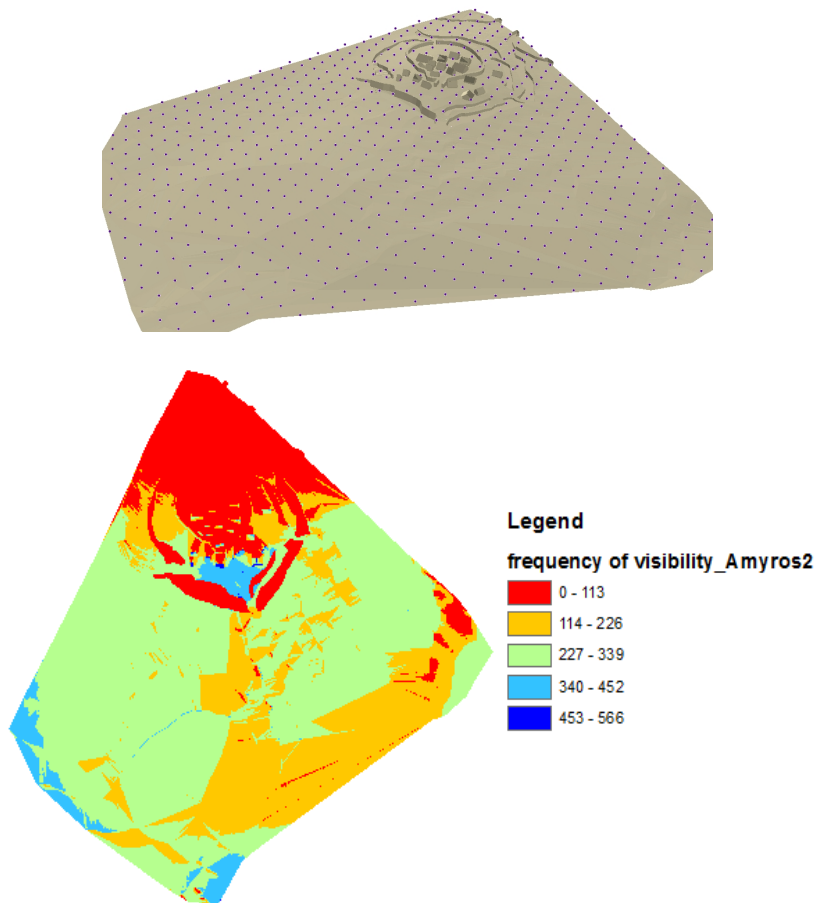


Figure 5. Grid of observer points in the area of Almyros2 (top) and frequency of visibility map (bottom). The number in the color scale indicates the number of points that have visual access to the corresponding area on the map: reddish colors corresponding to less visible areas and bluish colors corresponding to highly visible areas.

For the 3D visibility analysis, a grid of 703 observer points, at regular 10 m intervals, has been realized based on the DEM (Fig. 5). The resulting map of frequency of visibility indicates that the part of the village located within the surrounding walls is well protected from the external observers: only a small range of 0-15 observer points has visual access to that area (red color on the map). Similar weak visibility exists for the northern area of the settlement, in contrast to the southern part of it which is mainly surrounded by relative wide ditches.

Taking into account both the results derived from the space syntax analysis and those from the 3D visibility analysis, it can be suggested that the northern part of the settlement, which displays an absence of dwellings and the presence of a possible "plaza", is the area being less connected and less visible. In contrast, the southern part of the settlement seems to be well connected to the central area and more open towards the external territory, verifying the southern opening to be the main entrance to the settlement. From the spatial organization point of view, the layout of the site suggests a relative control over the movement within the settlement and a weak degree of interaction among the inhabitants.

3.2 Perdikal

Perdikal, also called "Dautza", consists of a settlement next to a river, located at the western part of the Almyros plain, in the district of Magnesia, in the central-eastern part of Thessaly, and just a few kilometers from the coastline, which during the Neolithic period was a few hundred meters inland (Alexakis *et al.* 2011).

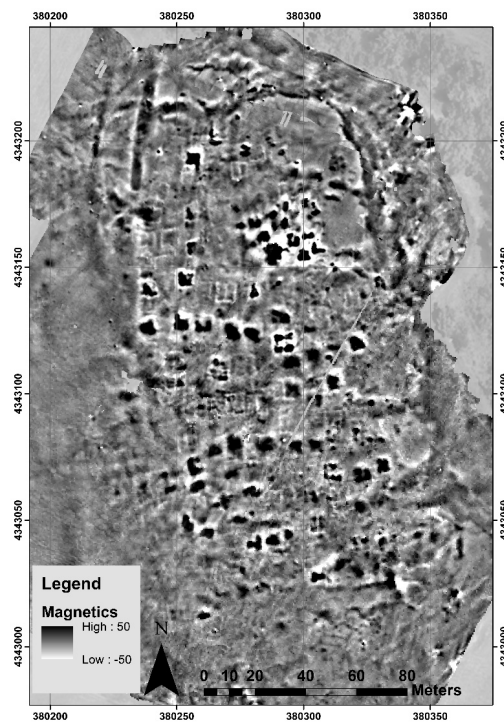


Figure 6. Results of the magnetic gradiometry survey in the area of Perdika1 magoula.

The diagnostic material identified on the surface allowed us to date the life span of the settlement from the Early Neolithic to the Middle Bronze Age. High resolution satellite images within a 1 km radius around Perdikal identified paleochannels and other hydrological features that seem to be associated with the settlement. The area was investigated through magnetic (5.19 hectares), electromagnetic (2.32 hectares), and GPR (0.44 hectares) techniques. The results obtained by the magnetic survey revealed more than 50 rectangular structures and ditches, also confirmed by means of electromagnetic induction measurements, which spread over a total area of about 230m x 140m (Fig. 6). The geophysical results are so clear that it is possible to identify different types of constructions and they might suggest different occupation phases. At the summit of the *magoula*, close to the riverbed, there are traces of a group of about 13 burnt structures confined by a small enclosure wall. This core may represent the initial occupation phase of the settlement, which was later expanded with the construction of more mud-brick (high magnetic readings) structures expanding to the area to the south of the *magoula*. The average size of the structures is about 31 m² and all seem to expand within a rectangular elongated region to the south of the *magoula*.

In this study, we limited our analysis to the supposed second phase of the settlement, consisting of about 50 burnt daub structures both inside the tell and the surrounding flat settlement, assuming as a working hypothesis their coexistence in the particular period. The four structures that are located towards the NE, outside the surrounding ditches and close to the riverbanks, have not been considered in the drawing of the concave spaces, as it is difficult to define their function and to identify their convex spaces (Fig. 7).

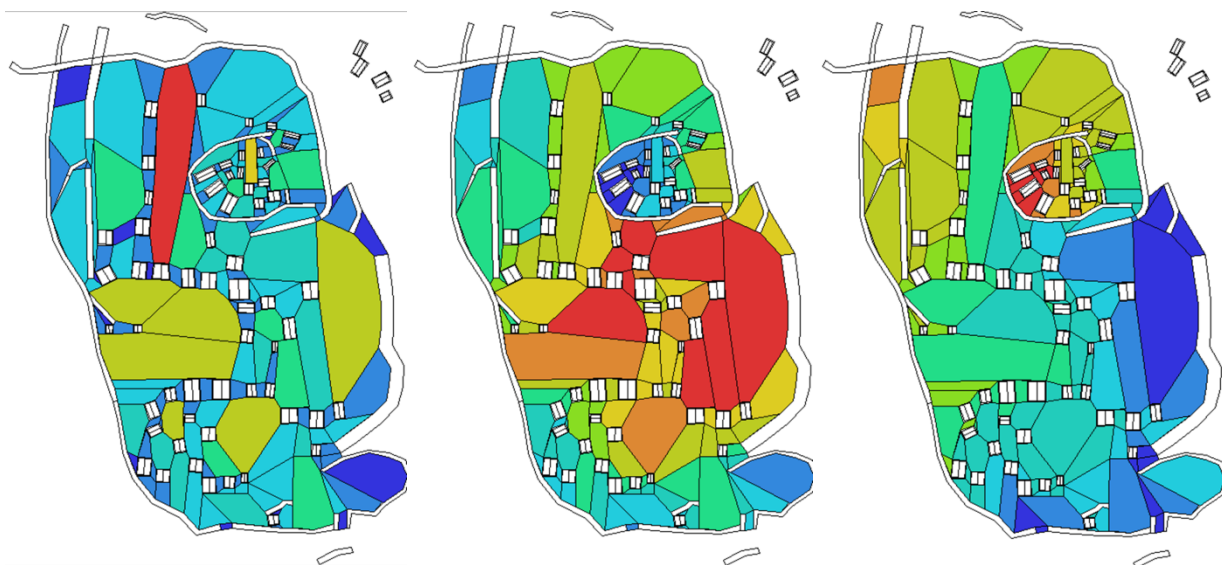


Figure 7. Convex map of Perdika1 – Phase 2 with Connectivity values (left), Integration values (middle) and step depth values measured from the entries to the settlement (right).

Descriptive statistics of connectivity (range of 1-9 with an average of 2.78) and integration (range of 0.39-0.92 with an average of 0.64) indicate a very low degree of connectivity and a medium degree of integration. The most connected space is located approximately at the central north part of the

settlement, with a N-S orientation, surrounded by spaces that have the lowest values of connectivity. The most integrated spaces are located in the central area of the site, in proximity to the eastern entrance through the ditches. Compared to the flat settlement, the core cluster at the top of the tell, which is surrounded by walls, remains a less integrated area. With the exception of the areas that are close to the east and southern entrances of the settlement, the rest regions of it remain in relative isolation and difficult to access, which is indicated by the step depth, which reaches a maximum value of 13.

Similarly, the measurements of connectivity (range of 2-17 with an average of 7.77), integration (range of 1.16-5.14 with an average of 3.33) and choice (range of 0-113 with an average of 19.29) from the axial map testify that the settlement is low connected but quite integrated (Fig. 8).

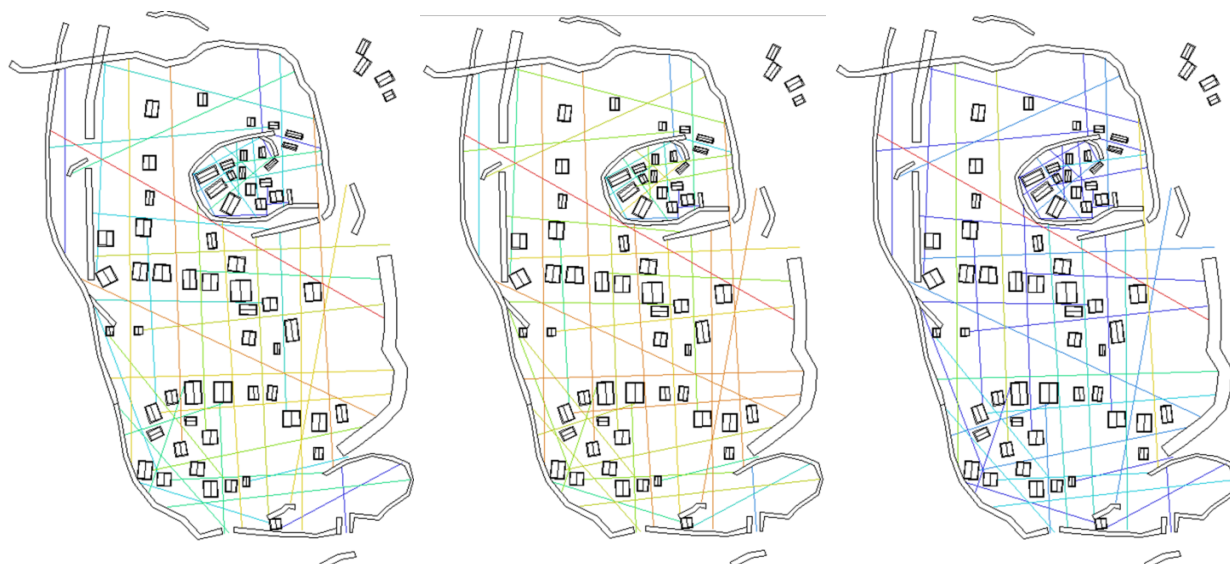


Figure 8. Axial map of Perdika1 – Phase 2 with Connectivity values (left), Integration values (middle) and Choice values (right).

The most integrated axis is also the most connected and preferred and it crosses the northern part of the village with orientation SE-NW. The least connected and integrated areas are located at the peripheral zones of the flat settlement towards the south, west, and north. Connectivity and integration values resulting from both the convex and axial maps confirm that the eastern entrance of the settlement, which is also overlooking towards the river, constitute the main access point with the external territory, while the southern entrances (as they are suggested from smaller breaks through the ditches) appear to be more isolated. This suggests that the eastern entrance, which may be considered the main one, is directly connected through the most integrated, connected, and chosen axis to the most connected space. It is indeed the particular entrance that provides access to the river that extends to the east of the settlement. The eastern and the southern parts of the settlement are less isolated and the movements throughout the site are not direct but instead they hinder a limited degree of freedom. This may be related also to the distribution of the structures, which seem to be clustered in different sections of the site forming small, but still discrete,

neighborhoods. Extended over a smooth, higher elevation ridge, the flat settlement, together with the top of the *magoula*, remain relatively invisible to the exterior (Fig. 9). The 3D visibility analysis confirms also that the central eastern part of the village, in close proximity to the eastern entrance, is more exposed to visual contacts from the exterior. We can also notice that the most connected space is the most hidden from the outside visual exposure.

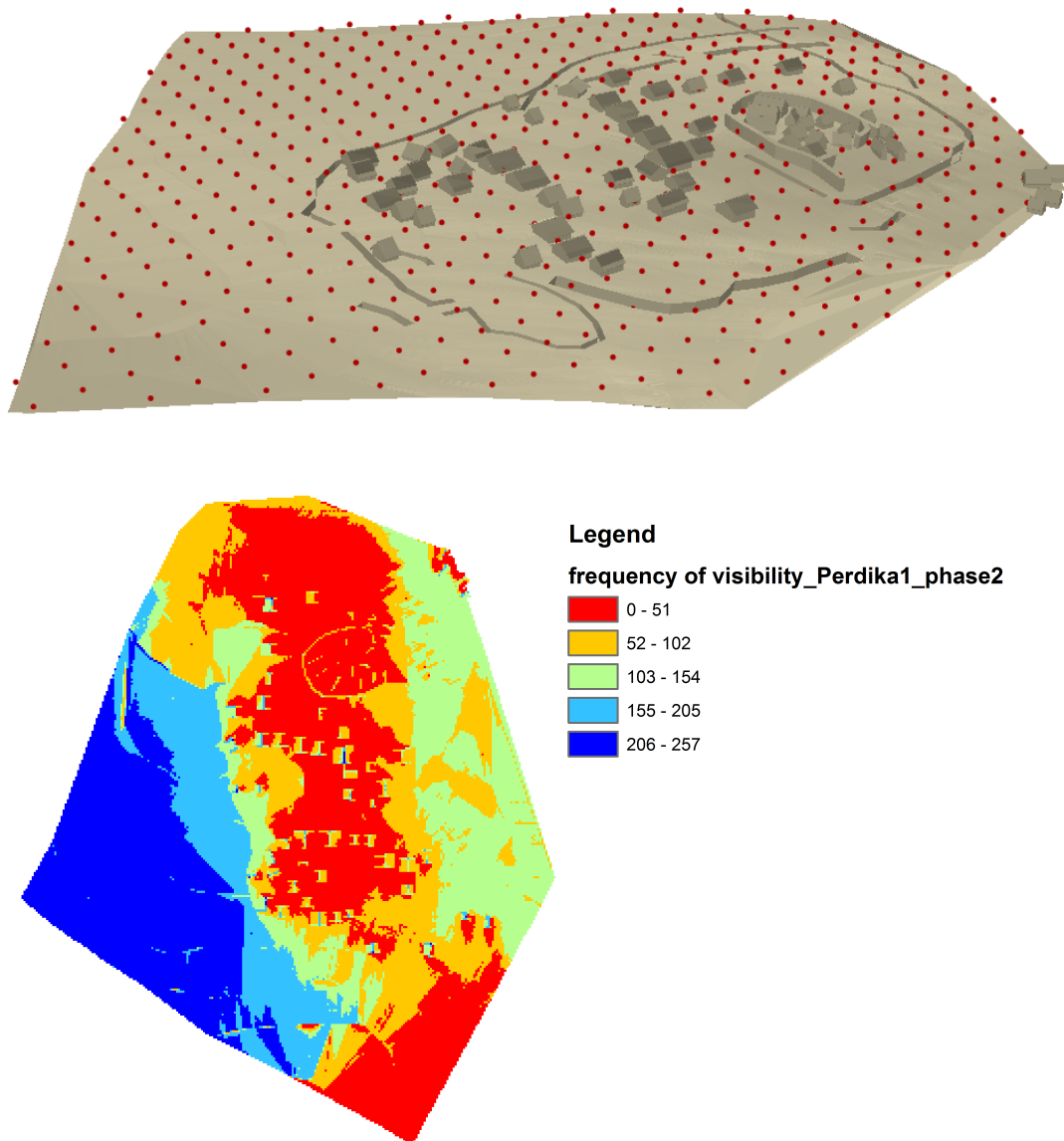


Figure 9. Grid of observer points in the area of Perdika1 – Phase 2 (top) and frequency of visibility map (bottom).

4. DISCUSSION AND CONCLUSIONS

The main topic of this paper focuses on the amalgamation of different methods (geophysical prospection, space syntax, 3D modeling, 3D visibility analysis) aiming to retrieve quantitative data regarding the intra site spatial arrangement of the Neolithic Thessalian settlements of Almyros2 and Perdikal. The importance of the specific methodology stems from the exploitation of geophysical data that can be obtained through non-destructive methods and which can provide a bulk of information regarding the settlements themselves and their surroundings. Space syntax, on the other hand, has not been widely used for the study of prehistoric settlements. Coupling the above methods with 3D visibility analysis can offer us a different perspective about the arrangement of space within prehistoric settlements. The limitation of this study is the absence of archaeological excavations in the specific sites and, consequently, the uncertainty of their reconstruction, which is only based on the geophysical results and geographic analogies. Despite these limitations, upon which the model of the settlements have been reconstructed, the application of convex analysis, axial analysis, and 3D visibility analysis has been thought to add quantitative information to the archaeological research, especially when excavations are limited or not possible. The obtained data from such kind of analysis may suggest a particular spatial organization of settlements and highlight the advantage of combining different techniques and tools to enhance archaeological interpretations.

Measurements derived from convex and axial maps based on the plans of the geophysical results can extract valuable information regarding the level of integration, connection, movement, and segregation of the inhabitants within the settlements. The numerical indices derived from the above quantitative analyses do not by themselves constitute an absolute measure, but rather an instrument that contributes to approach questions related to the usage of space with different possible implications in terms of the social relations of the inhabitants. As Cutting (2003) mentioned, axial and convex analysis can be "a tool to think with". Knowing which spaces are more integrated and/or connected, or understanding the level of integration, connectivity, and movements of a settlement could provide us an additional tool to perceive the prehistoric societies. Similar is the role of 3D visibility analysis, which has been developed quite recently and applied in landscapes and architectural studies. The frequency of visibility maps demonstrates the degree of visual exposure within different sections of the terrain. The synthesis of the results gained through these two techniques may lead to an enhancement of the study and interpretation of spatial and social relations within settlements.

In our study, the above analyses were applied in the Neolithic settlements of Almyros2 and Perdikal in Thessaly, which were investigated extensively through a variety of geophysical methods. The interpretation of the geophysical features indicated a very rich layout characterized by about 50 structures, a core area at the top of the tell, ditches, and encircling walls. The congruence between the results of space syntax and 3D visibility analysis is well demonstrated in the case of Almyros2, where one of the most connected and integrated areas, located right outside the southern access through the walls surrounding the core of the tell, is exposed to high visibility. A similar situation is also documented for the second occupation phase of Perdikal, where the eastern part of it, in front of the passage through the ditches, exhibits a high integration index and a high visual exposure. The

consistency of the above results suggests a constant low level of connectivity within the two settlements, which is also manifested by a very low level of a preference (choice) in the movement through them. Only a limited number of basic pathways are joining the entrances of the settlements with most of the neighborhoods within them acting as the spinal cord of each village. Segregation of the households is manifested not only from the low degree of integration, but also from the relative, random clustering of the dwellings, forming neighborhoods that seek a partial isolation from each other. However, a few areas that might be suitable for gathering are evident. At Perdikal, the most connected space at the north-central part of the site is surrounded by very low connected spaces. It is quite distant from the assumed main entrance at the eastern side of the settlement, but still reachable from there by the most connected, integrated, and chosen axis. It also constitutes one of the less visible area of the settlement. The above may suggest that this large zone could be used for particular occasions. It is easily reachable from one of the entrances and close to the heart of the settlement, but still not as visible or surrounded by densely occupied spaces.

The above results, which are not limited to the expounded case studies but to all four sites examined under the same methodology, may confirm what Nanoglou (Nanoglou, 2001) highlighted about the settlement of Dimini, where visibility of the households becomes even more restricted in late Neolithic period. He also mentioned the tendency of the households towards isolation, already considered by Halstead in his study about the distribution of spaces in Neolithic villages (Halstead, 1999). The low connectivity observed in this research, along with the presence of walls and ditches, points indeed towards a motivation for isolation of single or small groups of constructions, that may be interpreted as a society built on self-sufficient inhabitants. The development of LN mounds in Macedonia based on the concept of independent households has been also suggested by Andreou (Andreou, 2001). Kotsakis associated symbolism and competition to this independency of the dwellings and he hypothesized that the control of spatial order was probably stronger on tell sites than flat extended settlements (Kotsakis, 1999). Segregation of space and regulation of movement was also claimed by Nanoglou (Nanoglou, 2008). Their hypothesis seems to be confirmed by the extremely low level of choice observed in the analysis of space syntax.

It is difficult to elaborate hypotheses on the function of the spaces of Neolithic settlements without having any information about the associated material culture residues. Still, the methodological approach we followed opens new frontiers to reason about the social relationships of the dwellers according to the connectivity and the integration of spaces and axes, and according to the visibility of the spaces. From a spatial analysis perspective, the results demonstrate that the constructions of the investigated Neolithic site were segregated and not well inter-connected while simultaneously seeking a visual exclusion from the external environment. The results of this manifold approach support the existence of a non-hierarchical community, despite the different manifestations of habitation in the tells or the flat settlements.

The research methodology cannot provide straight answers to the social aspects of space but at least it can constitute a tool contributing further to the study of the intra site organization of prehistoric settlements and more analyses are needed in this direction. GIS spatial analyses and virtual acoustic analyses are under progress to improve even further our understanding of the way that Neolithic settlements were evolved.

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