

The Cost Surface Analysis as a Predictive Model for the Reconstruction of the Ancient Road Network in the Territory of the Protohistorical Tarquinia

GIULIANO PELFER

Center for the Study of Complex Dynamics (CSDC), University of Florence, pelfer@tin.it

ABSTRACT

The settlement organization and evolution in the territory of Tarquinia, in South Etruria, between the Final Bronze Age and the First Iron Age, during the process of urban centers formation, was associated with the availability, in such a territory, of the large resources: soils suitable for agriculture and breeding, wood from extended forests, maritime resources accessible by a network of navigable rivers and lagoons, minerals from the mines of the important mining basin on the Tolfa mountains. The utilization of these resources required a well organized network of communication roads that allowed their accessibility and control, in connection with the settlement strategies, starting from the position of the "first" Tarquinia settlement, located in the large plateau of La Civita. This paper presents a reconstruction model of the main communication ways, linking the urban center of Tarquinia, on La Civita, to its large surrounding territory, to the coast, to the internal band, to La Tolfa mines. This model has been developed within the author's PhD research that aimed to investigate the dynamics of the settlement evolution during the period of the urban center formation and the origin of the ancient city of Tarquinia: the analysis on the roads network has been only one of the considered factors concerning the process of city origin. The tool used for such an analysis is an archaeological GIS built using, because of its known advantages, the Open Source GIS GRASS, interfaced with the database PostgreSQL and with the statistical package R. The reconstruction of the road network has been done developing a model based on the method of Cost Surface Analysis and on the principle of minimum cost, in terms of expenditure of the physiological energy needed to cross an area corresponding to the DTM pixel. Also the effects of the terrain properties are calculated. The values of the parameters and constants used in the calculation have been derived from the ones published in journals specialized in the field of applied physiology. With the help of the used algorithms, we obtained the ways and we compared them with the layouts already identified in the previous archaeological bibliography, in the field surveys and on the aerial photo. The final results are in agreement with the parts of roads identified previously by the archaeologists or only hypothesized; at the same way, the results agree with the supposed seaworthiness of the main rivers, that were important communication ways, as it is underlined by many authors and sources. These results allow us to attribute to the proposed reconstruction of the main communication routes the value of a predictive model. That is, the obtained model can be considered correct also in connection with any information at the moment (and at the current knowledge status) unknown, undiscovered and only hypothesized.

1. INTRODUCTION

This paper investigates some of the factors affecting the urbanization process of the protohistorical Tarquinia, between the Final Bronze Age and the First Iron Age, through the application of an archaeological analytical GIS, realized for the first time on this territory.

The paper focused on the accessibility to the available resources in the territory surrounding the urban center and on the spatial settlement distribution for the territory control.

A model based on Cost Surface and Viewshed Analysis methods is used for calculating the roads network and the visibility from settlements strategically placed on the territory. This model does not include yet any approach based on cognitive landscape models, that could be used in the future research.

2. ARCHAEOLOGICAL FRAMEWORK

The urban settlement of the so-called "first" Tarquinia originated in the late Final Bronze Age. People moved-out from the older scattered villages (*synecism*) to the plateaux of La Civita (for an overview on the archaeological discussion: e.g. Pacciarelli, 2000; Carandini, 2003).

Such an urbanization process at La Civita took place together with a new organization of the Tarquinia territory for accessing new lands suitable for cereal cultivation and breeding, and for the exploitation of the maritime resources, as it is demonstrated by the settling in the coastal plain (Fontanile delle Serpi in Final Bronze Age, Le Saline in First Iron Age) and by the villages in the Monterozzi hill (Calvario, Infernaccio, Acquetta).

Le Saline settlement, along the sea coast, was moreover the landing place and the site for the increasing exchanges between the ancient Tarquinia and other Mediterranean areas.

Settlements, and other important sites like quarries and mines, were connected by the construction of a complex road network. As well, according to the urban settlement development, the older burials, starting from Final Bronze Age, were

placed around the La Civita plateaux, but in the First Iron Age the Monterozzi area will change into the ancient Tarquinia cemetery (Mandolesi, 1999).

3. THE ARCHAEOLOGICAL GIS

As in other archaeological cases (e.g. Madry and Crumley, 1990; Gaffney and Stancic, 1991), it have been used the analytical potentialities of the free software and Open Source GIS GRASS (rel. 5.0), for Linux Operating System (rel. RedHat 9.0), with its packages, the RDBMS PostgreSQL and R for the statistical analysis, interfaced to GRASS and between them. Available data and information from excavation and field surveys, from geomorphology, hydrology and soils, from DTM and historical maps, from agriculture, mining and technology, have been archived in the GRASS geographic and in the PostgreSQL relational databases.

4. ENVIRONMENT AND NATURAL RESOURCES

The urban center of the "first" Tarquinia was in a good geographical position, on the La Civita plateaux. The soils, in maritime organogenic limestone, were easy to excavate, and therefore suitable to build the needed settlement structures. This position of the settlement, connected to the sea by the navigable Marta fluvial valley, and well protected by the Monterozzi hill, allowed a powerful control on the surrounding territory and on its agrarian, maritime, mining resources.

4.1. LAND USE EVALUATION FOR SPELT CULTIVATION

The importance of the cereal production in ancient Etruria and Tarquinia is underlined by many authors and ancient sources. In this context, it has been done an archaeological evaluation about the soils suitability to the spelt cultivation in Tarquinia, on the coastal plain, along the river valleys, around the La Civita plateaux. The results of this analysis confirm the availability of a large extension of suitable soils around the La Civita plateaux and between La Civita and the sea coast.

4.2. LAGOONS, MARSHY AREAS AND MARITIME RESOURCES

The lagoons, located along the present coast, on the alluvial Holocenic soils of the coastal plain and along the fossil coast line of 10 m. a.s.l., originated because the eolian dune pillows, due to the Pleistocenic sea level changes, that stopped the alluvial waters (Pelfer, 1998, 2004).

The availability green grassland around the lagoons, also during the dry season, favoured the sheep and cows breeding. At the same time, the lagoons were useful as landing places for the maritime activities and the exchanges. A cartographic definition of the lagoons areas has been done, firstly, by extracting the depressions from the DTM, and after, by comparing the results with the grid referenced maps of XIX century. But have been also useful the pattern of the etruscan and roman roads, including the Via Aurelia Vetus and Nova, the roman town of *Graviscæ* (Pelfer, 1998, 1999, 2004; Pelfer and Mandolesi, 2002), the coastal settlements at Fontanile delle Serpi and Le Saline (Mandolesi, 1996; Pacciarelli, 2000).

4.3. MINING RESOURCES

The La Tolfa mines exploitation, as well the extraction and metallurgical activities in the ancient Tarquinia, are yet open questions in the archaeological discussion, but the large number and high quality of the metal artefacts and tools found at Tarquinia demonstrate the very important role played by the metal goods in its exchanges with the other Etruscan centers and with Sardinia in Final Bronze Age and First Iron Age. The mines of La Tolfa area, rich in copper, iron, zinc, lead, are the more important in South Etruria.

5. ROADS NETWORK

5.1. PROTOHISTORICAL ROADS FROM FIELD SURVEY AND AERIAL PHOTO ANALYSIS

The older archaeological field surveys and aerial photo analysis (Pallottino, 1937; Harari, 1997) identified some segments of protohistorical roads between the protourban center, on La Civita plateaux, and the surrounding territory, that used the so-called *cavoni*, excavated along the lower side of the hills and along the axis of the fluvial valleys. The main roads (Fig.1) linked the settlement to the coastal plain (Fosso dei Prati, Fontanile delle Serpi, Le Saline) and to the sea, crossing the San Savino fluvial valley and the cemeteries at the Monterozzi hill, or were directed to the fluvial valleys of Mignone,

Fosso Biedano, Marta, Fosso Leona, as the so-called Via Tarquiniense or Latina (Gamurrini *et al.*, 1972), probably related to the Final Bronze Age/First Iron Age.

5.2. PROTOHISTORICAL ROADS RECONSTRUCTION MODEL

The model for reconstructing the communication routes between the urban center and the surrounding territory is based on the Cost Surface Analysis and on the Principle of Minimum Cost. The amount of physiological energy needed to an individual to move across the surface corresponding to any single DTM pixel, is calculated taking into account a little constant weight, a constant speed, the terrain properties given from a N coefficient matrix which values have been published in journals on applied physiology (Givoni and Goldman, 1971; Soule and Goldman, 1972; Pandolf *et al.*, 1976; Pandolf *et al.*, 1977), and the slope calculated by the DTM matrix. From the cost surface for any DTM pixel, the total cost surface for going from

definite positions on La Civita to definite positions in the surrounding territory, using any possible way, has been calculated. The resulting routes with a minimum cost correspond to our reconstructed roads. The reconstructed roads are in very good agreement with the segments of the routes already found during the previous field surveys, and can be regarded as a first reconstruction of the roads network, that needs to be confirmed by new archaeological and environmental data (Fig.1).

In the hypothesis of the navigable Marta river, our model reconstructs very well the way for reaching the littoral from La Civita, by a first terrestrial road segment, and a second segment on the navigable river, to the river mouth and after to Le Saline along the sea coast.

6. VIEWSHED AND TERRITORY CONTROL

The Viewshed analysis (Fig.2) defined which parts of the territory were visible from given points of view, and therefore which positions were chosen for the control of the urban center of Tarquinia on the surrounding territory. The results allowed demonstrating that such a strategic control was played through the Monterozzi settlements of Calvario, Infernaccio, Acquetta (First Iron Age), that dominated the fluvial valleys of Mignone and Marta, the coastal plain and the important settlement of Le Saline. Le Saline will later control the coastal plain in the Late Iron Age, after the decay of the settlement area in Monterozzi, and its change as the main funerary area in Tarquinia. The role of control played by these villages is also confirmed by their intervisibility with the Pian della Regina, in the central and higher parts of the La Civita plateau, where it will be located the historical age temple.

7. DISCUSSION

The present reconstruction model of the roads network can be considered as a predictive model for every possible communication way in the ancient Tarquinia territory. The model confirms what it is known to the archaeologists. In fact, for the road construction, the people leaving in the ancient Tarquinia likely used the geomorphological characteristics of the terrain that facilitated the displacements, in particular the river valleys. The results of viewshed confirm that the urban settlement was located on La Civita with the aim to dominate the parts of the surrounding territory economically significant, like the Marta and Mignone fluvial valleys, the coastal plain and Le Saline.¹

In this context, also the viewshed analysis could have a predictive value by locating the sites at the moment not discovered or unknown, and allowing us to hypothesize that different coastal sites (e.g. at the fluvial mouth of Marta and Mignone) could also have played a role for the coastal control and not only for the maritime landing.

8. CONCLUSIONS

This model is based on the environmental variables related to the terrain properties, according to the bibliographical sources and all the available information about the navigability of the main rivers as natural communication ways to the inner parts of the territory and to the sea, without considering, in this specific case, the cultural, symbolic and cognitive variables. In any way, the agreement between the results and the known information seems to demonstrate that, in the studied age, the environmental, practical and empirical aspects would have played a central role in the evaluation of the space, so that the criteria to calculate the ways with a minimum cost were probably based specially on the minimum energy expenditure.²

9. AKNOWLEDGEMENTS

This paper presents some results of the Author's PhD research in Ancient Topography and Landscape Archaeology. The Author is grateful to the interdisciplinary Center for the Study of Complex Dynamics (CSDC) at the Department of Physics of the University of Florence, for his interest in this methodological approach applied to the historical process of the City Origin.

ENDNOTES

1 About the meaning of "control", although considering the present discussion, it could be not completely pertaining to this specific archaeological case and model, to discuss if such a concept implies a real visual dominance or a perception of the territory. In fact, taking into account, in the archaeological debate, the accepted suggestion about the likely origin of Tarquinia, as a protourban center, from a foundation and synecism, as well the described framework about the exploitable resources (specially the maritime and agrarian ones), in this context the chosen topographical location of Tarquinia in the La Civita plateaux would have allowed, through a good position, an enough powerful and concrete (that's important!) dominance of the meaningful parts of the territory for the development of the urban center.

2 In this model have not been applied the cultural variables related for example to the funerary data, also because such information have already been analysed in some detailed statistical and combinatory inventories by e.g. IAIA 1999 or PACCIARELLI 2000. Of course, it can be very interesting and stimulating to apply also these variables to the proposed model, validating it and its results also from this point of view.

REFERENCES

- CARANDINI, A. (2003) – *La nascita di Roma: Dei, Lari, eroi e uomini all'alba di una civiltà*. 2, Torino: Einaudi.
- GAFFNEY, V.; STANCIC, Z. (1991) – *GIS Approaches to Regional Analysis: A Case Study of the Island of Hvar*. Ljubljana: Research Institute of the Faculty of Arts and Science, University of Ljubljana.
- GAMURRINI, G. F.; MENGARELLI, R.; COZZA, A.; PASQUI, A. (1972) – *Carta Archeologica d'Italia (1881-1887). Materiali per l'Etruria e la Sabina*. Firenze.
- GIVONI, B.; GOLDMAN, R. F. (1971) – Predicting Metabolic Energy Cost. *Journal of Applied Physiology*. 30, p. 429-433.
- HARARI, M. (1997) – Tarquinia e il territorio suburbano nel rilevamento da alta quota: una lettura topografica. In BONGHI JOVINO, M.; CHIARAMONTE TRERE', C., eds. – *Tarquinia. Testimonianze archeologiche e ricostruzione storica: scavi sistematici dell'abitato. Campagne 1982-1988*. Roma: Tarchna, p. 5-17.
- IAIA, C. (1999) – *Simbolismo funerario e ideologia alle origini di una civiltà urbana. Forme rituali nelle sepolture "villanoviane" a Tarquinia e Vulci, e nel loro entroterra*. Grandi Contesti e Problemi della Protostoria Italiana. 3, Firenze: All'Insegna del Giglio.
- MADRY, S. L. H.; CRUMLEY, C. L. (1990) – An Application of Remote Sensing and GIS in a Regional Archaeological Settlement Pattern Analysis: the Arroux River Valley, Burgundy, France. In ALLEN, M. S.; GREEN, S. W.; ZUBROW, E. B. W., eds. – *Interpreting Space: GIS and Archaeology*. London: Taylor & Francis, p. 364-379.
- MANDOLESI, A. (1996) – L'insediamento villanoviano. Suppl. to *TEKNOS*, 9.
- MANDOLESI, A. (1999) – *La "prima" Tarquinia. L'insediamento protostorico sulla Civita e nel territorio circostante*. Grandi Contesti e Problemi della Protostoria Italiana. 2, Firenze: All'Insegna del Giglio.
- PACCIARELLI, M. (2000) – *Dal villaggio alla città. La svolta protourbana del 1000 a.C. nell'Italia tirrenica*. Grandi Contesti e Problemi della Protostoria Italiana. 4, Firenze: All'Insegna del Giglio.
- PALLOTTINO, M. (1937) – Tarquinia. *Monumenti Antichi Accademia Nazionale Lincei*. 36.
- PANDOLF, K.B.; GIVONI, K.B.; GOLDMAN, R.F. (1977) – Predicting Energy Expenditure with Loads while Standing or Walking very Slowly. *Journal of Applied Physiology*. 43, p. 577-581.
- PANDOLF, K. B.; HAISMAN, M. F.; GOLDMAN, R. F. (1976) – Metabolic Energy Expenditure and Terrain Coefficients for Walking on Snow. *Ergonomics*, 19, p. 683-690.
- PELFER, G. (1998) – Evoluzione del paleoambiente lagunare nella pianura costiera di Tarquinia fra i fiumi Mignone e Marta. *Bollettino Società Tarquiniense di Arte e Storia*, 27, p. 5-36.

PELFER, G. (1999) – The Via Aurelia in the Tarquinia Area. *New Results from an Aerial Photograph Study by the Matlab Image Processing Program*. In BARCELO', J. A.; BRIZ, I.; VILA', A., eds. – *New Techniques for Old Times. Computer Applications and Quantitative Methods in Archaeology, Proceedings of the 26th CAA Conference, Barcelona March 1998*. Oxford: Archaeopress. B.A.R. International Series S757, p. 51-55.

PELFER, G. (2004) – Caratteri distintivi delle lagune costiere di Tarquinia protostorica e loro delimitazione geografica attraverso l'analisi geomorfologica e degli insediamenti con il G.I.S. *GRASS. Agri Centuriati*, 1, p. 109-127.

PELFER, G.; MANDOLESI, A. (2002) – Rapporto fra l'insediamento umano ed evoluzione delle lagune nel litorale di Tarquinia dall'epoca protostorica al periodo romano contemporaneo alla costruzione della via Aurelia. In NEGRONI CATAACCHIO, N., ed. – *Atti V Incontro di Studi Preistoria e Protostoria in Etruria, "Paesaggi d'acque", 12-14 maggio 2000. Sorano-Farnese*. Milano: Centro Studi di Preistoria e Archeologia, p. 193-196.

SOULE, R. G.; GOLDMAN, R. F. (1972) – Terrain coefficients for Energy Cost Prediction. *Journal of Applied Physiology*, 32, p. 706-708.

FIGURES

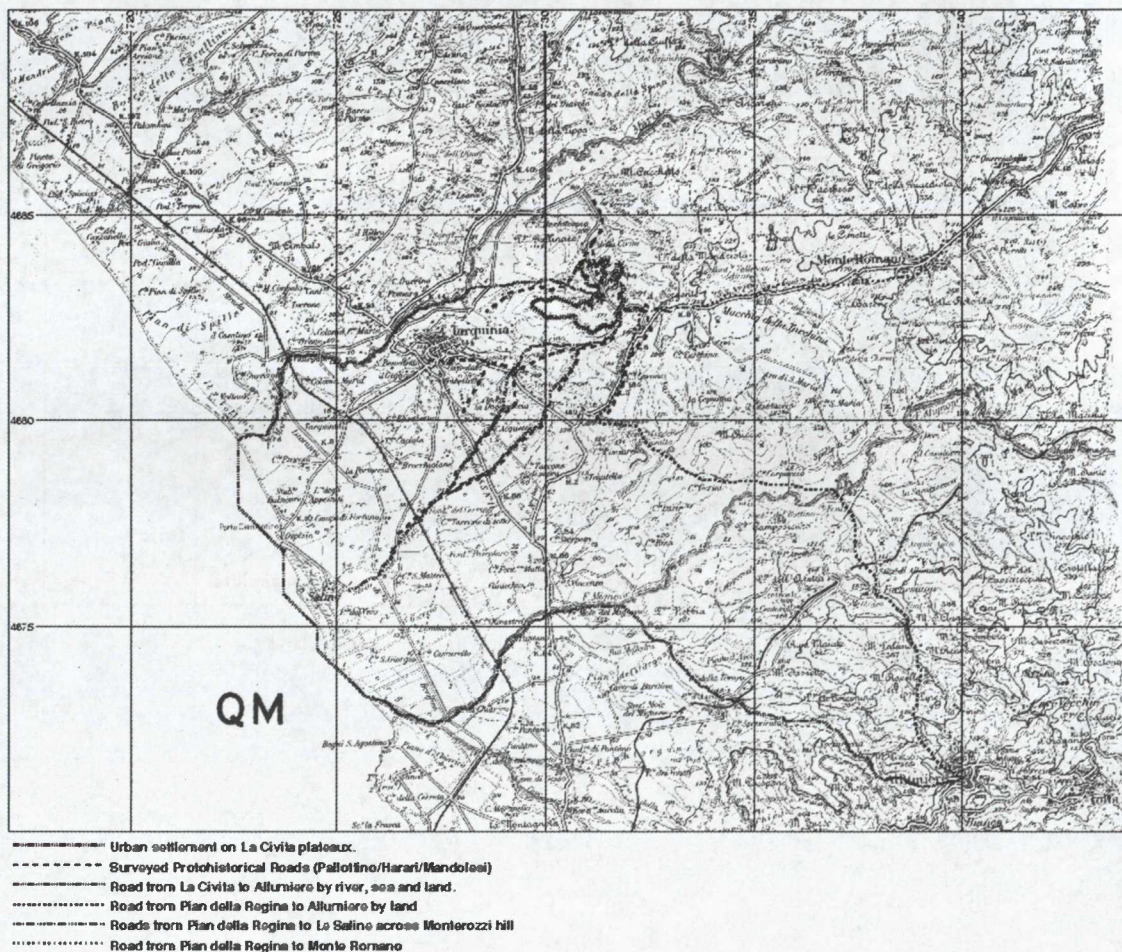


Fig. 1 – Surveyed and simulated protohistorical roads map in the Tarquinia territory.

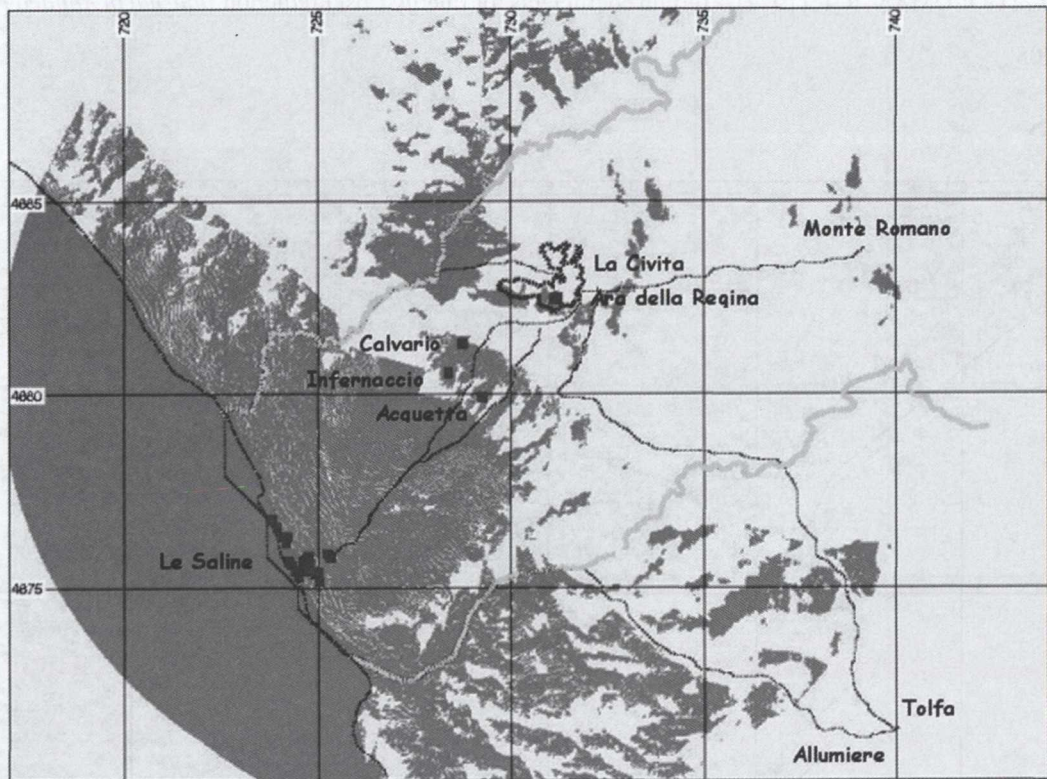


Fig. 2 – Visibility map of the Tarquinia territory from Viewshed Analysis.