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The Application of 3D Reconstruction Techniques in the Analysis of Ancient Tarraco's Urban Topography

Abstract: The widespread implementation of GIS-based 3D topographical models has been a great aid in the development and testing of archaeological hypotheses. In this paper, a topographical reconstruction of the ancient city of Tarraco, the Roman capital of the Tarraconensis province, is presented. This model is based on topographical data obtained through archaeological excavations, old photographic documentation, georeferenced archive maps depicting the pre-modern city topography, modern detailed topographical maps and differential GPS measurements. The addition of the Roman urban architectural features to the model offers the possibility to test hypotheses concerning the ideological background manifested in the city shape. This is accomplished mainly through the use of 3D views from the main city accesses. These techniques ultimately demonstrate the 'theatre-shaped' layout of the city (to quote Vitrubius) as well as its southwest oriented architecture, whose monumental character was conceived to present a striking aspect to visitors, particularly those arriving from the sea.

Introduction

The implementation of GIS-based 3D topographical models has been a great aid in developing and testing archaeological hypotheses. However, one of the most evident problems of these models is that, being constructed on the basis of modern topographic maps or on-site spot height measurements, they reflect modern topography that cannot reliably be extrapolated into past periods of time. The topography of modern Tarragona has been largely developed as a result of the use of its maritime façade and neighbouring areas of quarries providing stone to build the 18th and 19th century port structures. This has changed the topography of the city drastically, rendering 3D models obtained through modern maps inadequate in the analysis of the Roman city layout.

The aim of this project is to develop a methodology that allows the reconstruction of the abrupt relief in which the ancient city of Tarraco was settled. In addition, an attempt will be made to determine to which degree topography influenced the distribution of major public buildings. The topographical reconstruction of Roman Tarraco will be combined with various data sources to aid interpretation and facilitate the process of archaeological hypothesis generation.

Methodology

Different sources were employed to recreate the topography of the ancient city; each of them providing different data not only in their form but also in the way in which they must be dealt with. These sources of evidence must be further differentiated according to the kind of reconstruction they allow us to make, whether coastline, archaeological elements, ancient spot heights or other elements.

Although this methodological approach is part of an ongoing project, enough information has been gathered to produce some firm preliminary results.

Initial ideas and data were obtained from Gabriel (2001) who also produced a topographical reconstruction using analogical means from photographic evidence and old maps. The work by Fiz (2001) and Fiz / Macias (2004, 14–20) provided a methodological framework and the initial GIS geodatabase from which this project developed.

Ancient Map Analysis

Analysis of old maps can provide important evidence on the ancient coastline and may aid in the location of the ancient Roman harbour and other topographical and archaeological elements of the area.

A set of twenty maps covering the last five centuries were selected and scanned, maintaining a definition higher than 1 m/pixel in each case.

In order to introduce old maps into the GIS they have to be georeferenced. The significant landscape change that took place in the city since the 17th century made it impossible to find appropriate ground control points (GCP) from which the oldest city maps could be georeferenced. A regressive georeferencing methodology had thus to be applied in order to overcome this problem. In practice GCPs were identified on modern maps from which 19th century maps were georeferenced. From those, 18th century maps were in turn georeferenced and, finally, from these it was possible to georeference the oldest maps available. The use of chronologically intermediate maps proved to be essential in order to relate modern maps to the oldest ones, ensuring their correct geographical referencing. Root-mean-square error (RMSE) values resulting from the georeferencing process were interpreted as an indication of the differential accuracy of the various maps.

Once the maps geodatabase was developed it allowed the extraction of features of interest, mainly the ancient coastline and the Roman harbour, but also architectural elements, building plots, paths and channels. From the three ancient maps with lower RMSE values the coastline was extracted as a line feature *(Fig. 1a)*, which was then transformed to point features *(Fig. 1b)* that were, in turn, interpolated into a new mean line *(Fig. 1c)*. In this way the mean coastline can be extrapolated from the more accurate ancient maps. Following a similar process the Roman harbour, still visible in the oldest maps, can also be relocated.

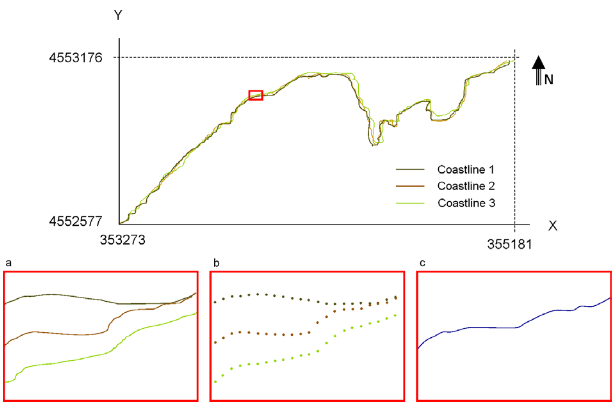

Fig. 1. Methodology followed in the process of obtaining a mean coastline.

Analysis of Archive Photographs

Analysis of old photographs allows approximate calculations of the ancient ground level. Many reference features with known height can be still employed to assign a height to lost ancient landmarks present in old photographs. Pictures dating back to the end of the 19th century testify the employment of Tarragona's maritime façade as a quarry *(Fig. 2)*. This was a fundamental process since it drastically modified not just the urban topography, but also the ancient coastline through the construction of the modern port. Spot heights, extracted from old photographs by Gabriel (2001), have been employed in the generation of the 3D model outlined in this study.

Archaeological Excavations

Archaeological excavations can provide extremely useful evidence for the reconstruction of ancient topography. Roman ground levels are measured as a standard procedure in every excavation. The advantages of this type of elevation data are many. Firstly,

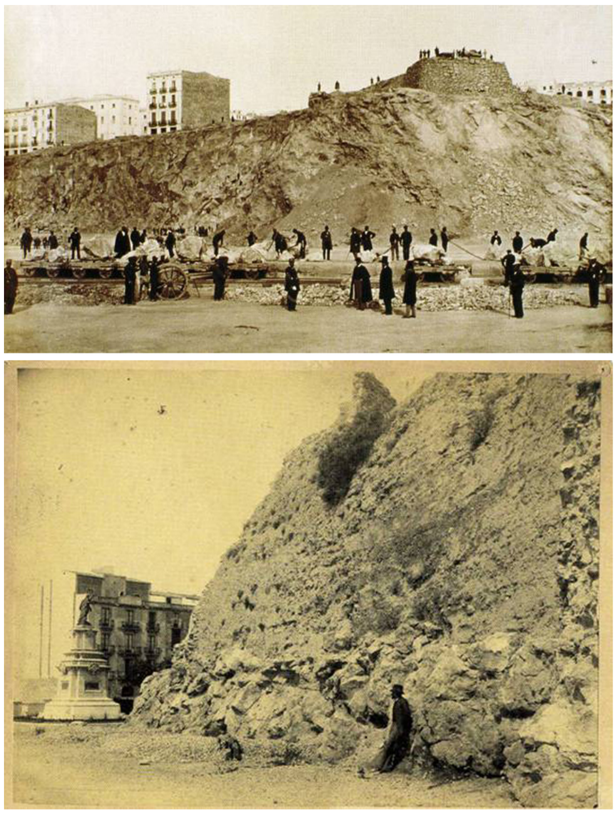

Fig. 2. Old photographs showing major changes in the city shape.

they are the only source, together with standing archaeological features, that provides ground level measurements for the study period. Secondly, their accuracy is much higher than that obtained from old photograph or ancient map analysis, being second only to GPS measurements. Finally, Roman ground levels can be easily and securely extrapolated, particularly in the case of large plane extensions, such as the provincial forum or the city circus. However, this method is not flawless as it is impossible to test, considering that the evidence has been destroyed and, in many cases, ground level is measured in relation to other features or to arbitrary base points, which complicates the calculation of global spot heights.

Standing Archaeological Features

Standing archaeological features are plentiful in modern Tarragona. The theatre, amphitheatre, parts of the circus, parts of the provincial and city forum, the Roman city walls, and other features provide the same advantages as archaeological excavations, but can be also checked on site and, by means of differential GPS measurements, to offer high precision spot heights. These elements are particularly useful since, being grand public works, their ground level can be extrapolated to large surfaces. It is indicative that in the case of the provincial forum the first level square covers 4–5 ha of levelled ground.

Preserved Ancient Bedrock

This information is more difficult to handle due to the problematic identification of undisturbed bedrock surfaces. These are typically located outside the walled city, forming strong gradients but their weathered appearance can often be deceptive. Old maps were employed to identify areas that have witnessed no major changes during the last three centuries. This temporal lapse is considered to be critical since it was the construction of the 19th century and modern harbours that motivated the use of the maritime façade as a stone quarry. It is likely that surface bedrock areas occurring before 1792 were also present in the Roman period (Gabriel 2001).

Their correct location is important for the reconstruction of suburban areas, primarily those facing the sea, which form an essential part in the re-creation of the city's maritime façade.

Modern Topographical Maps

1 : 5000 scale maps with spot heights from the Cartographic Institute of Catalonia plus 1 : 500 City authority maps were employed to create a surface from which interpolations could be drawn for those areas where no or insufficient evidence was available.

The Creation of a 3D Topographic Model of Roman Tarraco

Once all the elevation data was obtained a 3D model was created through the use of a triangulated irregular network (TIN). This method was preferred because there was no interpolation involved and the data were kept without further modification. An additional advantage is that the TIN does not use many system resources and is easy to explore. The latter is an important aspect as the key aims of the model are for it to be flexible and easily updated as new information becomes available. With the clipping of the reconstructed ancient coastline and the Roman harbour to the TIN the topographic model was completed.

Finally, archaeological information was introduced into the model to allow an approximate view of the city in the Roman period. The schematic reconstructions of the Roman buildings were created in a 3D CAD environment and exported in a GIS compatible format. Some of the buildings were easy to model as they were particularly well preserved. Nonetheless, most of the modelled buildings followed the plans published by Macias et al. (in press). The final result is presented in *Fig. 3*.

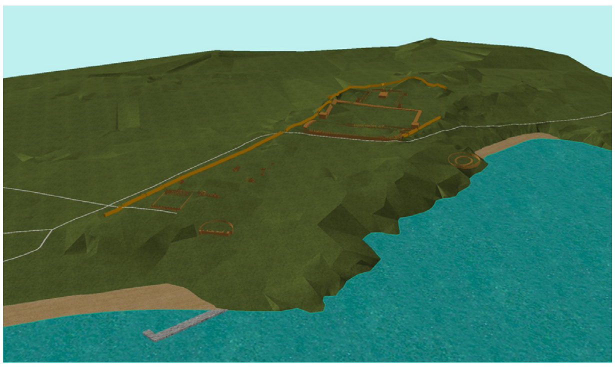

Fig. 3. 3D model including documented roads, the Roman harbour, the ancient coastline and archaeological features.

Proposed Analysis: 3D GIS-based Visual Analysis

3D GIS offers new visualization possibilities that can go beyond the simple generation of raster viewsheds. In this section an attempt will be made to utilize meaningfully the possibilities offered by the model. Traditionally, pictures, drawings or engravings have been left out of any GIS geodatabases. However, they provide a great amount of information since they depict landscapes as seen in a given moment from a given location. Some of those artistic representations can be very old landscape views; an important precedent of aerial views and modern maps. This is the case in one of the most representative drawings of Tarragona: Van den Wyngaerde's view of Tarragona from the tower of Saint Fructuós Church, 1563. This drawing depicts elements of historical interest that no longer exist and have not been located by modern archaeological research, the most important of which is a stretch of the Roman city walls *(Fig. 4)*. As a result of the previous process of ancient maps georeferencing it was possible to locate accurately Saint Fructuós Church tower, as it appears in a map from 1641. Other elements appearing in Wyngaerde's drawing were also located in the georeferenced maps.

The 3D model allowed the generation of 3D views from the exact point from which Wyngaerde produced the drawing, using the model to recreate the landscape as seen by the artist *(Fig. 5a)*. The 3D views were oriented towards those elements accurately located in old maps or still existent in the landscape that corresponded with elements from the painting. These views can be then employed as a test field where lost historical features still present in the drawing may be relocated. In this case it was possible to estimate the location of that lost stretch of the Roman city walls present in Wyngaerde's drawing *(Fig. 5b)*.

It is also possible through the use of 3D views to test hypotheses relating to urban topography and the distribution of public buildings. A series of 3D views were developed from the various documented city entrances and the roads leading to these entrances. None of these showed a comprehensive view of the city and its monuments. Many public buildings were hidden by the topography or by other architectural features, mainly the city walls. Finally, a 3D view of the city from the port was generated and it was immediately evident that from this location it was possible to see all the important public buildings apart from the amphitheatre *(Fig. 6)*. There is a strong suggestion that the city developed visu-

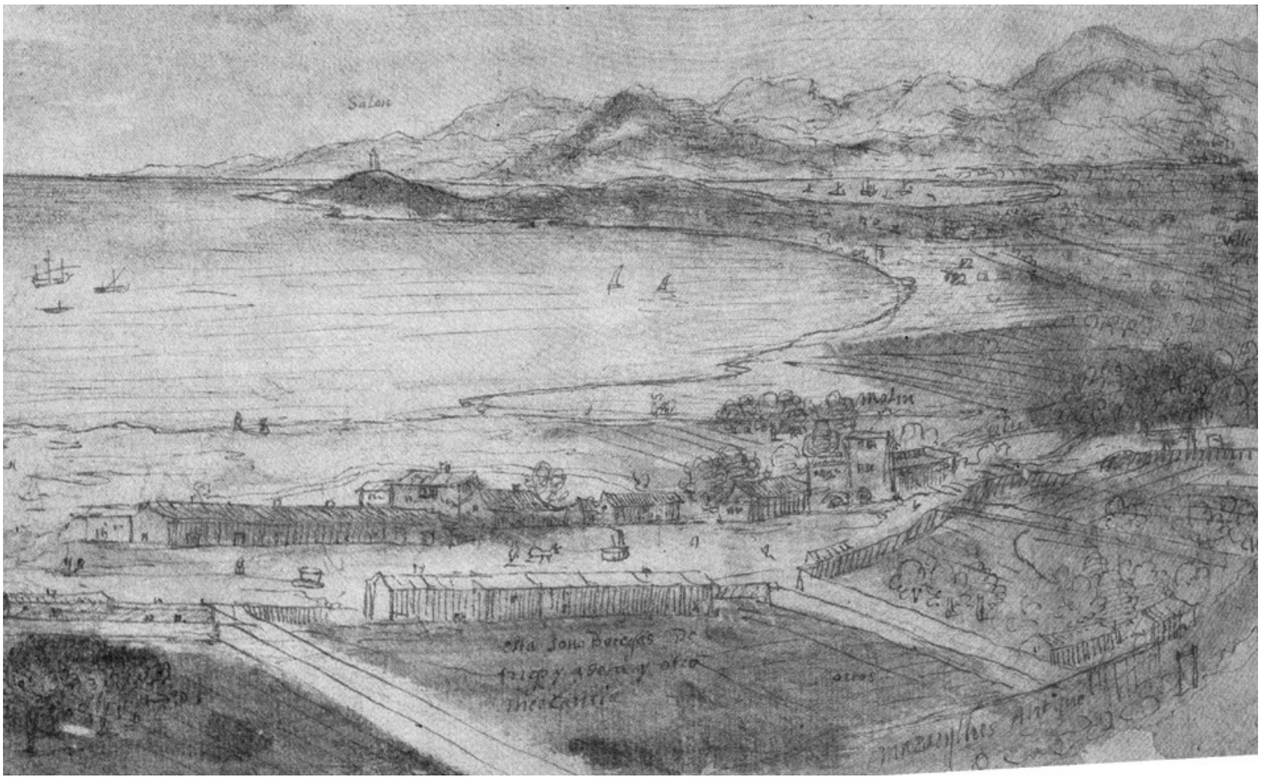

Fig. 4. Fragment from Wyngaerde's painting showing the ancient walls (from Remola 2004, 69, Fig 16).

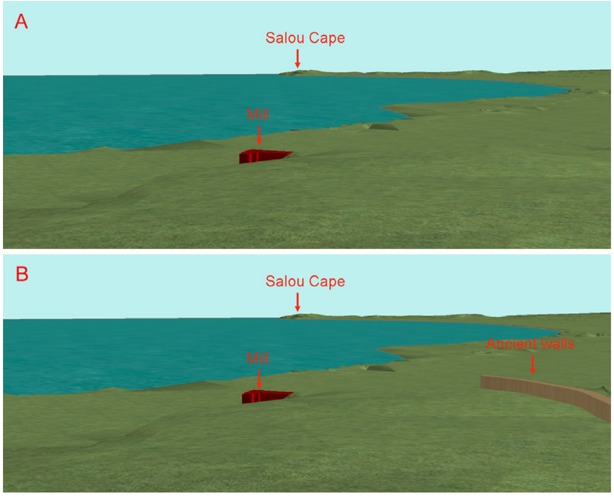

Fig. 5. 3D views from the tower of Saint Fructuós Church orientated as in *Fig. 4*.

ally from this location, with the distinctive terraced architecture designed to maximise visual impact with respect to this approach. This 3D view clearly shows how the topographical setting of Tarraco's public buildings was conceived to be seen from the harbour, arguably the city's main "gate", following Hellenistic concepts typical of terraced cities, such as Pergamon. Vitruvius (II, 8, 11), referring to Halicarnasus, states that '*Is autem locus est theatri curvaturae similis*'[1] while Diodorus (XIX 45.3 and XX 83.2) uses the same term to describe the city of Rhodes. These classic authors were comparing the shape of Halicarnasus and Rhodes with a theatre – a description that would also be applicable to Tarraco.

This theory has been previously outlined by Mar (1993, 107) and Ruiz de Arbulo (1998), who have highlighted the levelling of the hillside through rock

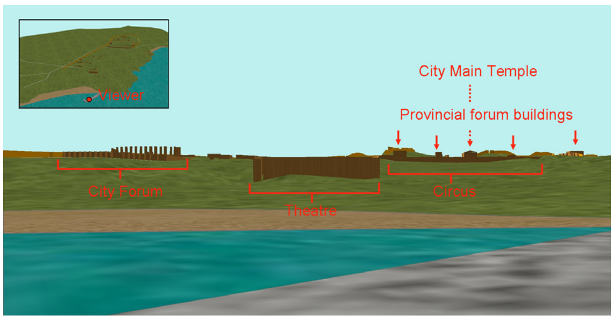

Fig. 6. 3D view from the roman harbour, showing the city's main public buildings.

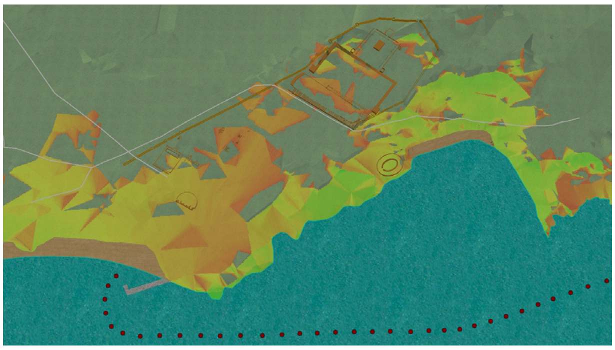

Fig. 7. Cumulative viewshed from the path a ship would follow when approaching the city from the northeast.

cuttings, terracing walls and soil movements in order to keep a superimposed axial view of the city, with the main temple on top of it. Ruiz de Arbulo has also stressed the imposing view of the city when arriving from the sea.

A cumulative viewshed was developed to test this hypothesis. 33 view points were distributed along the path a ship would follow when approaching the city from the Northeast. The results *(Fig. 7)* show that the view from the ship encompasses only the cliffs of the maritime facade and the city walls. When the ship reaches the harbour the view suddenly expands to include most of the city area including all those public buildings inside the city walls. Thus, it is clear that the sudden appearance of the city in all its magnificence to the people arriving from the sea was designed to maximise the visual impact of its monumental stratified architecture. The maritime southwest approach would not be that magnificent, nevertheless, this trajectory is aligned with the viewing axis of the city and, consequently, it would have allowed the gradual emergence of the city's façade.

Conclusions

While the methods and results presented here are only preliminary, some significant conclusions can be drawn. Although 3D models have been widely used within GIS-based archaeological analysis, the methodology presented in this paper, combining multiple lines of evidence, allows a better reconstruction of ancient topographic settings with a

[1] This other place is similar in its shape to a theater's bend.

higher degree of accuracy. In particular, 3D models have been employed here to allow the generation of positioned and oriented 3D views with the incorporation of pictorial data, so often ignored by GIS users, by comparative means. Thus, with the aid of a series of known reference points in the artistic representation and the place from which it was produced, it was possible to virtually relocate lost features of archaeological interest.

This analysis demonstrates that the combination of the topographic model with 3D reconstructions of known architectural features is not only useful in the analysis of the distribution of the city's public buildings and their relation to topographical settings, but also contributes to the understanding of the ideological concepts underlying city planning.

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