Explicit Theoretic Pipeline: GIS Analysis and Data Integration for Archaeological Landscape Reconstruction

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Abstract

Reconstructing ancient landscapes is an interpretative and open process. It is often required by users' expectations, but archaeological research can also benefit from an interactive, three-dimensional and multidisciplinary approach, if used to analyse, interpret and reconstruct past landscapes. Reliable results can be achieved if a scientific method is applied and an explicit theoretic pipeline is followed. The development and the use of interactive, updatable 3D tools are therefore appropriate, while on-line cooperative environments – based upon spatial references – might offer adequate space for research on interpretation and reconstruction. Internet publication seems appropriate for their specific results, especially if transparency problems are taken into account.

Keywords

Ancient Landscape, reconstruction, Virtual Reality, GIS

1. Reconstructing Ancient Landscape

Ancient landscape reconstruction is an interpretative and open process, where both science and "vision" (Semir 1999) are important. Its value, if referred to a research field, lies in processing available data through an *explicit scientific methodology* (Bell 1994) and through an *interpretative process*. It is an *open process* based on "interpretative cycles", where each cycle leads to the production of new data, new observations and new analyses.

Landscape reconstruction produces more than just "communicative" results for end-users. Thanks to interaction and transparency potentiality [London Charter], more or less realistic and immersive visualisation of territories and meta-territories should be considered *part of* the research activity. Communication should be regarded as *integrated* in the research interpretation process, when it is used, for example, to test theories (Forte and Pescarin 2007). This paper tries to demonstrate this position, describing a potential methodology applied to three case-studies: the Appia Project, Certosa Museum Project and the Virtual Museum of Ancient Via Flaminia.

In the approach the author has followed, the ancient landscape was considered and treated as an *ecosystem*, requiring interdisciplinary and integration characterised through its connection with the concepts of space, time and relation. It was also considered as a *dynamic system* whose continuously changing aspect depends upon geomorphology, climate characteristics, elevation, anthropogenic modifications, the use of which has also been linked to cognitive and perceptive aspects (Levy 1996; Gibson 1999; Ingold 2001).

In this perspective, landscape analysis and interpretations take into account as fundamental considerations not only geo-spatial data, temporal and three-dimensional dimensions, but also data interconnections and relations, interactivity during the interpretation process and updatability of the entire reconstruction process. A first step of the work was considered to be the "mapping" of the existing archaeological landscape.

The project "Virtual Museum of Ancient Via Flaminia" (Forte *et al.* 2007; Pescarin 2007) was an experimental attempt to put this approach into practice.

2. Previous works

The work carried out for the Flaminia project and the reconstruction of its archaeological and ancient landscape is based on two previous projects. These projects demonstrate how the approach described in this paper has been developed in accordance with an initial phase of evaluation and test of available tools. The first project involved reconstructing the archaeological and past landscapes of the city of Bologna during the early Imperial Roman and Etruscan periods (Certosa necropolis area). This

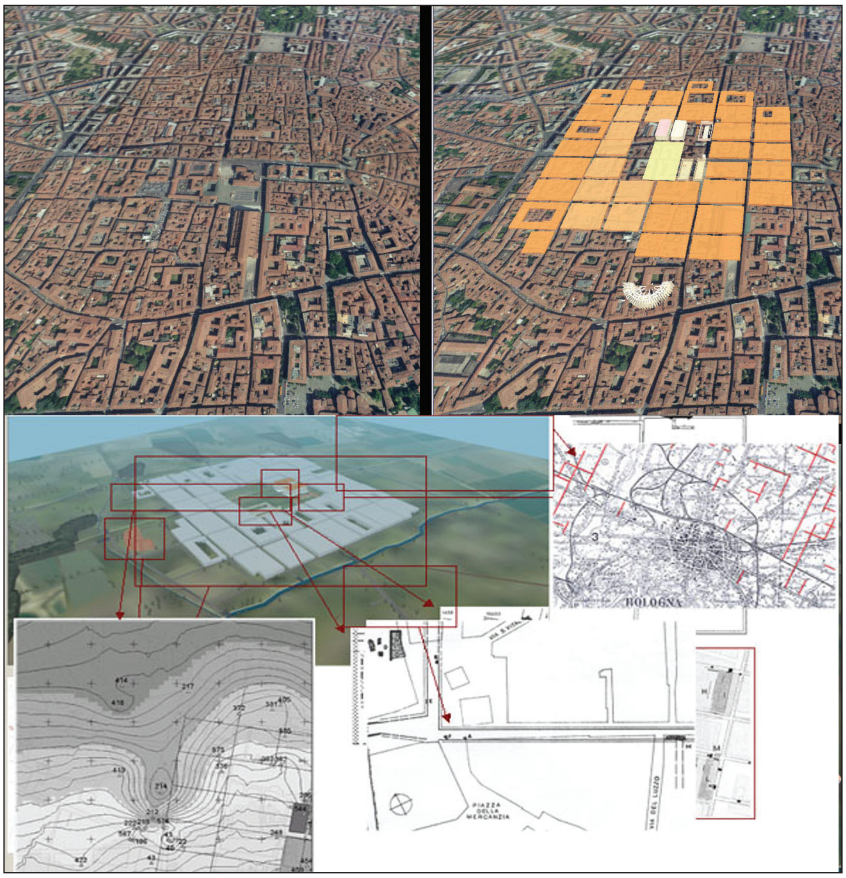


Fig. 1. Virtual Bononia Project. The reconstruction of the Roman landscape of the city of Bologna, Italy.

project lasted for more than 6 years (2000–2006) and the resulting 3D spatial system is actually still open to revisions and updating. For this project, information coming from all archaeological excavations was used to create a model of the contemporary archaeological landscape and to propose a hypothetical and didactic model of ancient landscapes (*Fig. 1*). The tools tested were terrain generators, especially addressed to military purposes (Terrex Terravista), and tools for DTM and geospatial imagery generation (ESRI Arcview 3.2 and ErMapper). Part of the interpretative work was carried out using a real-time open source tool, VTP Enviro (www.vterrain.org). Thanks to this kind of tool, it was possible to plan interactive 3D sessions where researchers could debate reconstruction hypotheses in real time. This interactive activity has been particularly useful in studying complex problems regarding the landscape, raising new questions (e.g. boundary of the city, artificial water channels, location of the central square) (Pescarin 2001; 2002). The manual work carried out to reconstruct the natural aspect of the landscape (and to create the spatial imagery to be used on top of the reconstructed model) has been a serious limitation, since it did not allow a sufficient level of connection with the GIS and spatial database.

This project underlined the importance of using updatable models when reconstructing ancient territories. Off-line and manual operations needed to be solved.

A second project, aimed at creating a Virtual Narrative Museum of an archaeological park (the Appia Park in Rome) was therefore also dedicated to the development of an on-line 3D spatial archive, with the aim of obtaining a dynamic and updatable 3D spatial system focusing on the archaeological landscape. In order to achieve this, an open source plug-in, OSG4WEB was developed (in its first release for MS Explorer). The idea was to enable users not only to explore an archaeological landscape interactively, but also to add various 3D or vector thematic layers derived from the GIS or modelling software (Forte *et al.* 2005; Pescarin *et al.* 2005) on top of the territory (*Fig. 2*).

Fig. 2. Appia Project. Real Time 3d session with VTP Enviro and the web interface for interactive exploration of archaeological landscape (www.appia.itabc.cnr.it).

3. The reconstruction of Roman landscape: Via Flaminia Virtual Museum

The Appia project and its OSG4WEB plug-in represented a partial answer to the initial problem. Still missing, however, was a reliable methodology for reconstructing not only such archaeological landscapes as the Appia case-study, but also past landscapes. The Virtual Museum of Roman Via Flaminia represented a perfect test-bed. This project, in fact, would have required reconstructing both the actual archaeological landscape and ancient "potential" landscape (Pescarin 2009). The final goal was in fact the creation of a multi-user VR installation dedicated to exploring the territory around the Roman road Via Flaminia, in the north part of Rome, as it is today and as it might be during the 2nd century AD. The result of this work is visible at the Roman National Museum – Diocletian Thermal Baths in Rome, where the installation opened in January 2008 (Forte 2007; Forte *et al.* 2007; http://www.vhlab.itabc.cnr.it/flaminia).

The work was carried out in a wider perspective, with the aim of analysing the possibility of identifying a more general method for reconstructing ancient landscapes through the use of an explicit formal process (Renfrew 1994; Bell 1994) and of series of "connected algorithms." The reason for such an approach, with its ineluctable generalisation, was the idea of finding an open process, where, despite the number of available data, observations and assumptions might be controlled step by step; and where it was possible to modify, almost automatically, the final result, when initial input data were changed (modifications or new introductions). In comparison with previous works and with the GIS approach normally followed (Clarke 1977), Virtual Reality applications seem to present a challenge, although still problematic and under development. The interactivity of such applications could – in fact might – be stressed and further developed in order to obtain up-to-date visual systems, each based time on the final outputs of the process.

The tools and methods employed were kept strictly connected. Different tools were used in order to obtain interdisciplinarity, reliability and updatability. Although reliability depends upon available data (quality/quantity), the creation of an updatable system relates to the method used.

Reconstructions followed a four-step process that required a:

1. reconstruction of the archaeological landscape;
2. reconstruction of ecological attitude;
3. landscape interpretation (interactive sessions);
4. reconstruction of the ancient potential landscape.

As a result of step 1 and 4, the following digital objects have been created:

a) a digital terrain model (morphology),
b) one or more geospatial images (land use),
c) several 3D models (sites, monuments, but also 3D vector layers),
d) several models of plants (instances of a common library).

Since the reconstruction of archaeological landscape (1) and of DTMs (a) has been treated in various papers (Pescarin 2002), I will focus more on the final part of the process (4) and mainly on land use reconstruction (b, d).

In order to obtain a reliable result, the plan was to start reconstructing the ecological attitude of the territory and to combine any useful archaeological or historical sources, in order to reconstruct its potential ("potentiality model"). Ancient Landscapes cannot be reproduced nor considered in their reality or truthfulness, but we can work on the "*potentiality*" of the landscape, considering it as an open process, each time closer to the truth, with continuous approximations.

The "Ecological Attitude" is the natural condition of a territory, if not modified. There are studies in natural sciences that can be taken as reference for studying and reconstructing the potential vegetation of a territory. In the case of Roman landscape, the application of such studies (Di Fidio 1990, 215; Dramstad *et al.* 1996; Chiusoli 1999; Tomaselli 1970) has enabled the definition, in the Flaminia case, of two main classes of land: "wooden" and "agricultural lands" (mainly cereals, vineyards and olive trees). Each class supported different vegetation species. In order to define these species exactly, archaeological, historical (Latin sources such as Varro's "*Rerum Rusticarum*" and Columella's "*De Re Rustica*") and paleo-environmental studies have been used. The work was used to build a library of digital plants typical during Roman Imperial times at that latitude (Messineo 1991; Santillo and Klynne 2005; Volpe and Arnoldus Huyzendveld 2005; Di Gennaro *et al.* 2005) (*Fig. 3*).

In order to assign the mentioned classes to the territory, GIS spatial analyses were carried out. At the end, the territory was subdivided into areas that were finally used during the final digital creation of the three-dimensional landscape (Forte *et al.* 2007).

The entire reconstruction process was subdivided into single connected sub-processes, each one represented by an algorithm. The goal was to enable the whole process to be updated and obtain

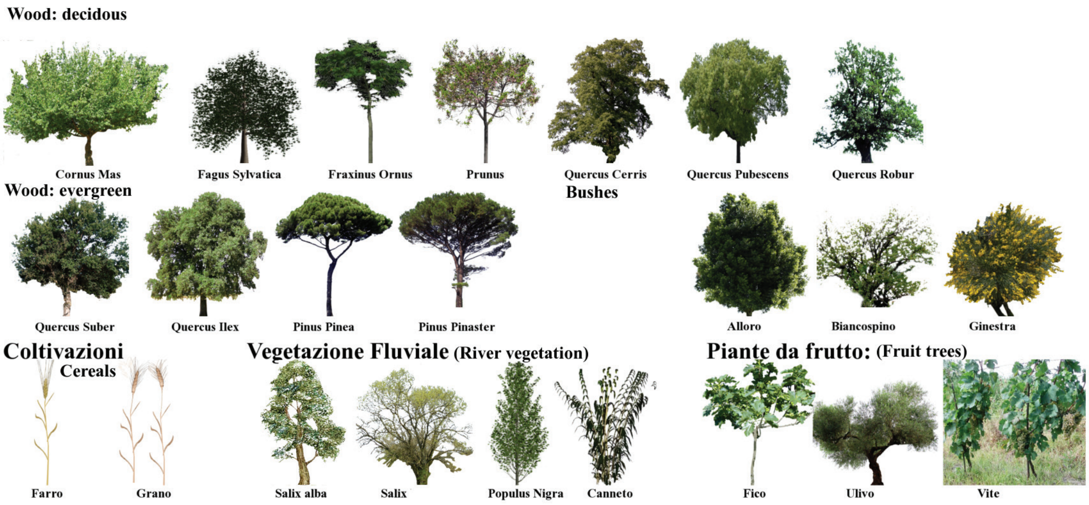


Fig. 3. Roman vegetation library.

Uncertainties	*Possible solutions*
Input data not available	Reliability Map, Fuzzy logic
Input data partially wrong	Open interactive and transparent system:
Input data not well defined chronologically	3D transparent elements overlayed to observed landscape
Input data irregularly distributed	Reliability value of an element
Input data partially hypothetical	Information on Used Sources availability
Input data not discrete	

Table 1. Examples of uncertainties and possible solutions.

new results without starting from the beginning, but producing new results as new input data were integrated (Schafersman 1994).

The most problematic aspect has been the management of uncertainties. Unfortunately, humanities cannot be considered totally "hard" or experimental sciences (Dionigi 2007). An experiment can be repeated until uncertainty is removed, but in archaeology we have to face uncertainties: history cannot be repeated and its interpretation is always subject to infinite controversies. Nevertheless, uncertainty can be in some case predicted and estimated, especially when there is a direct control on input data and on the process used (*Table 1*).

4. Landscape Reconstruction and Scientific Method

Since uncertainty is part of the archaeologist's daily life, the importance of building a reconstruction process with a scientific method was evident in the Flaminia project. The scientific approach has allowed reliable analysis and reconstruction, to acquire new information, propose new explanations, generate critical discussion and correct existing data.

Table 2 shows a practical example of how the scientific approach was used in case of the Flaminia project.

The main issue to solve was what the landscape could have looked like during the early Imperial period in the *suburbium* (the area outside the city) between Rome and Malborghetto. This problem has been divided into easier to solve sub-problems, such as the identification of Roman vegetation, climate conditions for that period and latitude, anthropogenic aspects (archaeological sites and remains excavated or surveyed or predicted in archaeological maps), cultural aspects (funerary habits), and so on. The archaeological landscape was then reconstructed, the GIS project developed and vector information overlaid [1]. We have then assumed that the ancient landscape could be defined by its "potentiality model" (valid for a certain historical period, latitude, climate, geomorphology, etc.), based on its "Ecological Attitude" [2]. The potentiality model could then be modified on the basis of known anthropogenic changes. We could now define several main Classes, connected to each sub-questions, such as vegetation, ancient river and roads system, etc.

In the specific case of the Flaminia project, the reconstruction of the potential Roman landscape started considering that the ancient DTM should be slightly different when compared with the actual. It was therefore modified, recognising that most significant elevation modifications occurred during the last centuries, in order to obtain a new DTM.

Scientific Method	*SM in Landscape Archaeology*	*Steps in ancient potential landscape reconstruction*
1. Identification of significant questions 1b. Subdivision into sub-questions	1. Identification of significant questions 1b. Subdivision into sub-questions	1. Wat was Roman landscape like during the Early Imperial Period? 1b. Type of vegetation, climate, anthropogenic or cultural elements?
2. Collection of information and main data	2. Collection of information (published, ancient sources, on the field) and main data. Geo-Referencing	2. Distribution of archaeological sites; paleobotanic analysis; geological analysis, etc.
3. Definition of hypothesis that could explain the question	3. Definition of hypothesis that could explain the question: reconstruction of ecological attitude of the territory and integration of anthropogenic and cultural elements.	3. Ancient landscape can be defined by potential landscape and anthropogenic/cultural modification; how can a simplified theory be formulated with algorithms?
4. Hypothesis or explanation testing	4. Testing with VR 3D tools	4. 3D terrain generation, main eco-systems, anthropogenic elements; implementation in 3D real-time engine for testing in 3D.
5. Acceptance or rejection of the hypothesis 6. Theory definition	5. Get back to previous step for further work and new tests 6. Definition of possible theories on the reconstruction of ancient landscape	5. Get back to GIS project, new data implemention even in the 3D engine 6. Reliable reconstruction of ancient landscape
7. Experimenting, test of the theory and acceptance or rejection	7. Theory verification on other landscapes and other data. Accept, modification or rejection	7. Use of the same algorithm with other case studies
8. Results publishing and data validation through peer-review mechanism	8. Results published through traditional scientific publication, web and other open tools	8. Results published in scientific publications and over the web (through VR?)

Table 2.

	L1b	**L2a**	**L2b**	**L2c**	**L3b**	**L4b**	**L5a**	**L5b**	**L5c**
S1	C7	C-V (C6)	C-F (C2)	C7	C7	C7	C-V (C6)	C-F (C2)	C7
S2	C7	O-F (C3)	P	C7	P	P	O-F (C3)	P	C7
S3	WP	WP	WP	CWP	WP	WP	WP	WP	CWP
S4	BWP	BWP	BWP	BWP	BWP or	BWP	BWP	BWP	BWP
S5	P	P	P	P	P	P	P	P	P
S6	-	-	-	-	-	-	-	-	-

Table 3. Identification of main classes of vegetation through the combination of slope values (S1-S6), lithostratigrafic (L1-L5) and depth information. All possible farming terrains are identified, mainly cereals (C), vineyard (V), olive trees (O) or other fruits (F). Not-farming terrains were also considered: woods (W), bushes (B), pasture (P).

The indication of each modification was kept. In the future it should be possible to add new information. This was also taken into account for each of the subsequent phases. The idea was to connect all useful and available information in order to obtain the Classes needed for the reconstruction.

After the creation of the Roman potential DTM, five main slope categories were built, each one with a land-potentiality assigned. The slope map was combined with a lithostratigraphic map and ground depth information. A matrix was built to identify all possible farming potential terrains (*Table 3*). Sun exposition was also calculated. Distance from rivers and also from main roads and monuments was taken into account: these areas were assigned to separate categories of vegetation, such as in the case of River vegetation (*Fig. 4*). The lack of very detailed information lead to the creation of a multidimensional grid where more than one value could be assigned for each cell (area). Just in a few cases we had a better knowledge of the original agricultural and natural situation, thanks to archaeological excavations and paleobotanic observations (Messineo 2005).

The Roman road system was reconstructed using the archaeological map of Rome (Carta dell'Agro): it was divided into two main categories according to the type of road, importance, and kind of pavement (basolata, glareata). The position of such archaeological remains as Roman villas was identified. This information was used to generate "areas of interest" through the definition of modified Thiessen polygons, adapted to follow road and river structures plus geomorphology, and also defined by the known importance of the owner. Even hypothetical villas were located, based on geomorphology and comparison analysis (Messineo, 2005; Carandini 2007)

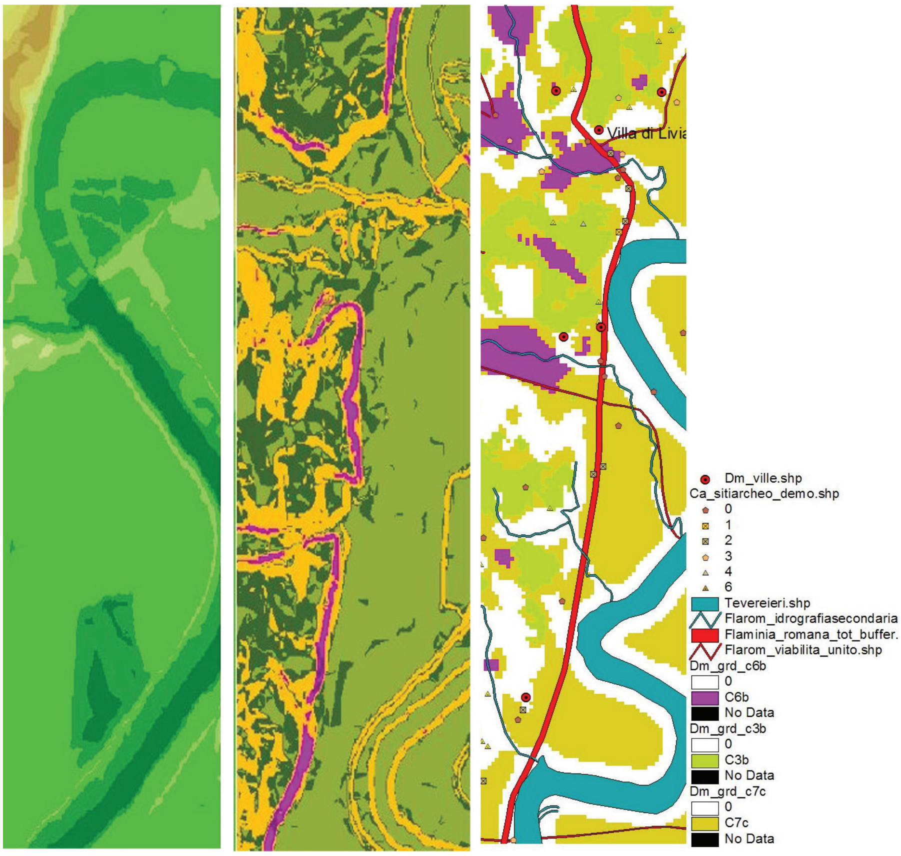


Fig. 4. GIS analysis and production of Virtual Ecosystem.

Fig. 5. Result of the interpretation process. Limites and ancient roads in the Roman Potential Landscape.

A partitioning system of the fields (*limitatio*) was only proposed, since there is insufficient evidence: only some weak marks could be identified in some aerial photos from the 1940s (Palombini and Vassallo 2007, 70–72).

The final process and its result was expressed as follows:

[AL] = {[DTMa + VegA + HYDRa + wet]} + {[VIABa + VIL + ArchB]}[1]

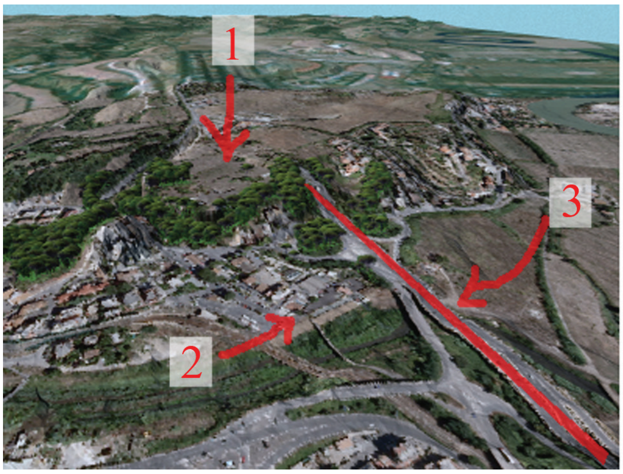
5. Conclusions

The reconstruction method proposed in this paper is a preliminary work that will require further tests on other case-studies in order to verify the extent to which it may be applied.

At this stage we found that the connection of GIS with Virtual Reality can be a challenge for the interpretation and reconstruction of ancient landscapes. GIS spatial analysis potentiality and the interactive VR 3D approach to data, if combined, can allow the formulation of new questions, better verification and observation, plus simulations. It should also be noted that, since results are strictly connected and depend upon scale, quantity and quality of available data, meta-information should also be maintained during the entire process.

In the Flaminia project the obtained classes were used to define Virtual Ecosystems and to generate 3D terrains, then implemented in a 3D real time application. Software such as Visual Nature Studio was particularly useful to create such ecosystems, since it imports and exports GIS data and processes them based on a set of "rules of nature." Moreover, it can be modified and adapted to specific needs, such as the creation of libraries of ancient plants or specific ecosystems, typical for a given historical period. Thanks to these capabilities, GIS data have been processed as to obtain several possible virtual worlds, then exported while maintaining the GIS format and finally published online through the OSG4EB plug-in (*Figs 6–7*). The final online version has recently been implemented into a cooperative environment built for the Virtual Rome project (Pescarin 2009, 205). The possibility of returning each time to modify the results after the introduction of different data is essential in this activity, that can be defined as *collective research work*. Every

1 Where: [AL] is Ancient Landscape, [DTMa] is ancient Digital Terrain Model, [VegA] ancient vegetation, [HYDRa] ancient rivers, [wet] wetland, [VIABa] ancient roads, [VIL] villas, [ArchB] archaeological sites after post-processing.



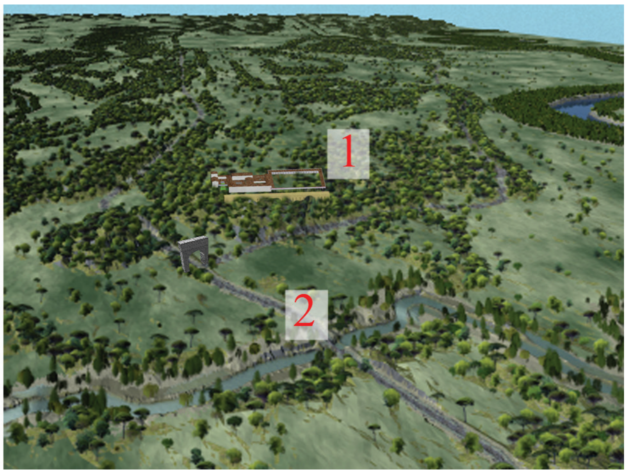


Fig. 6. Archaeological Landscape (left) and Ancient Potential Landscape (right): comparisons in the area of Livia's Villa.

hypothesis can be theoretically debated and demonstrated as false. But, as Popper stated (Popper 1934), an hypothesis may be falsifiable and a theory cannot be defined as scientific, if it does not admit the possibility of being demonstrated as false. In fact, it should be always possible to produce an observation that can demonstrate the theory is false, even if the observation has not been formulated. In the case of landscape reconstruction, after the interpretation process has been carried into a 3D VR interactive environment, it might be possible to get back to the previous stage each time by editing the algorithm and the database, by adding or modifying data that will again be tested, rebuilding the Classes with the same algorithm.

Fig. 7. Reconstruction of the Potential Roman Landscape: the area of Livia's Villa.

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