SOFIA PESCARIN

RECONSTRUCTING ANCIENT LANDSCAPE

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Different views of ancient and archaeological landscape in Rome
(3d reconstruction by VHLab of CNR ITABC; cover design by M. Pescarin)

Back Cover Illustration:
Virtual Rome VR webGIS: fly through exploration of the Imperial Forums area in Rome and of its mindscape during Roman times (CNR ITABC VHLab, aerial images provided by Seat Yellow Pages*)*

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To my family,
for their patience, their support, their critique

Contents

Preface

The world's cultural and natural heritage is vanishing at an alarming rate, as everything from development to tourism, conflict to looting, and climate to disasters threaten our past. Yet technology and processes now exist that can help us document, interpret, and communicate our heritage, helping save this disappearing world.

This book is an important new milestone in the developing field of Archaeological Landscapes. As our understanding of heritage and archaeology have evolved, the need to work in context beyond the individual site has grown. The UNESCO Convention Concerning the Protection of the World's Cultural and Natural Heritage, or World Heritage Convention as it is more commonly known, brought the idea of internationally protected sites of outstanding universal value to the world in 1972. Twenty years later, it became the first international legal instrument to recognize and protect a broader sphere, incorporating the idea of cultural landscapes. To date 55 properties have been identified and protected for the values of their cultural landscapes.

Archaeology encompasses more than just the individual site, and digital tools have the potential to help us document, interpret, and 'see' this broader context. From the early days of computer graphics and virtual reality, there has been an interest in communicating the past and seeing the unseen. Early visualizations of ancient sites, such as those done by Taisei Corporation in the late 1980s for Japanese public television, helped open our eyes to the possibilities. In my own work, helping develop one of the first long-range 3d laser scanners in the early 1990s, it was clear that emerging sensing technologies we and others were developing could bridge the 'local' and the 'remote', and play a useful role in helping capture the broader reality of heritage, from site to landscape and beyond. By the mid-1990s, pioneering work by Canadian media artist Dr. Charlotte Davies helped us see landscape in a new light, using evocative 3d graphics, transparency, and a novel "immersive" interface. Yet despite the early progress, much remains to be done. Only a small subset of the archaeological and heritage communities have yet tapped the full power of technology to document, interpret, communicate, and thus ultimately conserve, our heritage.

From its "ten golden rules for landscape reconstruction", to explanation of the spectrum from landscape to 'mapscape', 'pastscape', 'mindscape', and 'webscape', this book helps break a complex subject into clear components and easily understood processes. Using the pioneering projects of Italy's National Research Council Lab in Virtual Heritage as examples, the tools and processes of modern digital landscape reconstruction are illuminated.

A rich resource for both heritage managers, researchers, and students, it is my hope that this book will inspire and guide a new generation of Virtual Heritage and reconstructions of the ancient world. It is a great pleasure to welcome this important new work by my colleague and friend, Dr. Sofia Pescarin.

Alonzo C. Addison
Berkeley, California

Introduction: Notes on the Ecology of Mindscape

I am writing a few introductory notes not just for a book but for a very important research activity on the landscape's reconstruction and interpretation I shared with Sofia Pescarin for almost 15 years: in the first pioneering period at CINECA (Supercomputing Centre of the University of Bologna), in a second period at CNR-ITABC of Rome (in my position of Director of the Virtual Heritage Lab) and in the last period at the University of California, Merced (where I am professor of World Heritage). In all this long period of work we have experimented different methodologies and techniques for analysing, interpreting and communicating ancient and archaeological landscapes through 3d digital integrated technologies: GIS, remote sensing, laser scanning, computer vision, photogrammetry, 3d modelling, and virtual reality. The study of landscape needs a multidisciplinary approach in investigating the relations-affordances between territories, maps, shapes, cognitions, natural and cultural models. In the Bateson's sentence "The map is not the territory" (Bateson 1979), there is the key for a correct interpretation: the map is the code for understanding the landscape-ecosystem, for creating a synoptic access to the unknown space of the territory. The map represents the mental mind, the perception, the feeling, the vision of landscape, its mental representation in a word, "the mindscape" (Forte 2003a). An unusual feature of land can be a sign, a storytelling, a meaning of power, whose diversity depends on the different societies and cultural contexts. The landscape is not just a background of cultural and social life; it is a meme (Dawkins 1976), an information unit. As meme the landscape represents an important cultural code for contextualizing and communicating any process of territorialization of human societies: the creation of that sense of place which characterizes the affordances between humans and space. The affordance is the relation between societies and interpretation of the environment; the landscape's meaning is mediated by mental perception, by human adaptation and cultural communication.

The memetics of landscape refers to the occurrences which compose the holistic vision of the ensemble of features, signs, symbols, elements, characterizing the cultural model. I call this ensemble, the "matrix" of the landscape. The matrix represents the cultural model of landscape and changes according to time, space and societies. For example we can identify a landscape featured by the Roman centuriation in the main river plains and valleys of Northern Italy. In this case the orthogonal shapes of axes, roads, canals, creeks and so on, constitute the matrix of the landscape; there is no other landscape like that in the world. In a completely different context, in China, at Xi'an, we have series of mausoleums and tombs characterized by small hills with truncated-pyramidal shapes. They represent 11 mausoleums of the Western Han Dynasty and their shapes and size fill the skyline of North-West part of Xi'an: very visible even from a long distance, they are a spectacular example of sense of power of the emperors. What's more: in Syria each Tell is an archaeological site (usually an ancient city or settlement) dating in the Bronze and Iron Age. We could continue with other descriptions and lists of other sites and landscapes: every memetic matrix, as cultural ensemble, is able to transmit a complex code, fully recognizable only by those communities who identify themselves in that code and context. The dichotomy between ancient and archaeological landscapes is in the code-map for interpreting the cultural context: the archaeological landscape lives in the contemporary world, the ancient landscape pre-existed just in the mind of the ancestors. Therefore any attempt to reconstruct it will be partial and incomplete.

In the above mentioned cases and in many other situations, all these traces of ancient landscapes persist in the contemporary ecosystems. The level of persistence draws the archaeological landscape and modifies the affordances men-environment; in this code of persistence there is the DNA-matrix of landscape.

What the archaeologists learnt from the landscapes' studies is that we cannot really separate cultural-artificial and natural landscapes, since both are mindscapes. If we study the aborigines' landscape of Australia, they are apparently "natural" because there are no visible infrastructures; but if we read them through the aboriginal "song lines", the storytelling of local communities, part of them are cultural landscapes, living organisms, representing the power of divinities, spirits and ancestral meanings. Even "empty" spaces can be artificial; a place is always a mental place. A place is always a cultural item.

Given these difficulties in interpreting cultural ecosystems, we need to use a different approach and different technologies in the reconstruction process. For example, a GIS is a necessary good basis for this kind of scientific work, but it is not enough. It is necessary to improve methods and technologies able to generate, represent and simulate multivocal potential landscapes. The potential landscape is the best outcome of a research methodology on landscape's reconstruction: it represents the Aristotelian "actuality" of landscape.

The book of Sofia Pescarin is a remarkable example of a multidisciplinary approach and overview on the study, interpretation, communication and reconstruction of ancient and archaeological landscapes. It is very clear here that the reconstruction process pushes new questions, investigations and guidelines. The integration of different technologies, the focus on environmental studies, the informational analysis on the ecosystem and not just on sites and anthropic activities, generates a different vision of the ancient landscape. This different vision starts from the study of the landscape as dynamic ecosystem in perpetual evolution where the activities, natural and anthropic, are the core of the ontological process. In some ways the landscape can be considered a living organism. We cannot just observe, we need to be part of the system for studying and interpreting the spatial connections and interactions. If we study environmental processes in a virtual ecosystem, such as a 3d web or an immersive system, we increase the dynamic capacities of getting information and interpretation by simulation, not by reconstruction.

Pescarin distinguishes the following categories: archaeological landscape, interpreted landscape (mapscape), ancient potential landscape (pastscape), perceived landscape (mindscapes), network landscape (webscape). This is interesting, but I think we could continue with additional names, metaphors, qualities and definitions (technical and metaphoric). It is impossible to comprehend all the undertones of the landscape: each category involves sub-fields, themes and processes. The landscape is a dynamic ensemble and a processual ecosystem: process by process, action by action, the landscape is transformed in space and time: it changes in any case, because of the collective cognitive-symbolic consciousness of the societies interacting with it.

The issue of the reconstruction is apparently focal in the landscape interpretation: how do we reconstruct the past? Is the past reconstructable? In methodological sense it is impossible to reconstruct the past but it is possible to simulate it; or we can create a condition for improving multiple simulations and interpretations, like in a virtual reality system or in computer graphics. The map of landscape is a synthetic and discrete way to interpret data, models and perception; it is not just a geometrical characterization. We like to call this process potential past: the past is actualized by multivocal simulation and behaviors.

In this framework many methodological questions are still pending and a typical bottle-neck in the interpretation process regards the factors of contextualization: nowadays the center of traditional archaeological methodology is still the site (or just the site) and not the landscape. This archaeology site-centered has unfortunately discarded all those crucial relations between humans and environment, avoiding a correct re-contextualization of cultural and environmental links. In this way many affordances and information are lost or misunderstood. In addition, the rigid and peremptory separation or segmentation between artificial and natural landscapes does not help a correct understanding and interpretation of the landscape according to a holistic vision. The most appropriate approach should be aimed to consider the ecosystem as center/goal of the research, involving in this all the natural-environmental and anthropic features and information.

Probably in the future we will need to implement cybernetic maps aimed to the interpretation of the landscape. A cyber map should be able to show the informational interconnections inside the landscape: symbols, meanings, perceptions, sites, settlements and so on, generated by cybernetic codes and not

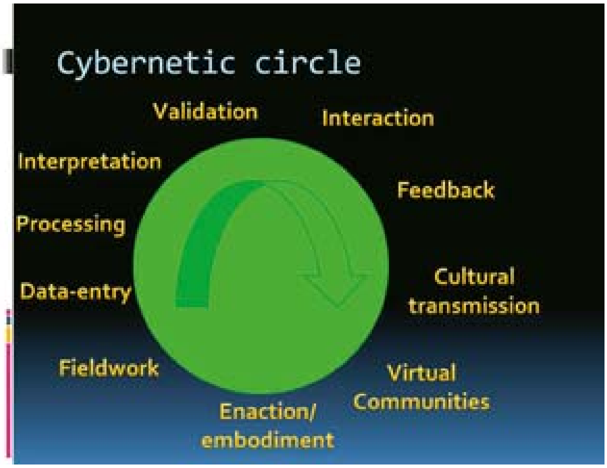

Fig. 1. The cybernetic circle.

necessarily by geometric shapes or georeferenced cartographies.

In *fig.1* I represent a possible scheme of the cybernetic circuit in archaeology and in the simulation process. The informational cycle starts typically from the fieldwork and data capturing, then it involves post-processing, interpretation, validation, interaction, and feedback. This part of the cycle is aimed to the generation of a transparent and multivocal outcome of the simulation/ reconstruction. The last part comprehends the communicational process, namely cultural transmission, virtual communities and enaction. The enaction designs the process of embodiment in the cyber-informational-circuit, it is the last step of the simulation, but totally interconnected with the others. What about this interconnection? How can we describe this phenomenology of landscape? In this case I find appropriate the metaphor of Deleuze and Guattari (1987) on the rhizome: Rhizome as a mode of knowledge. They used the term “rhizome” to describe theory and research that allows for multiple, non-hierarchical entry and exit points in data representation and interpretation. In this rhizomatic model, knowledge is negotiated, and the learning experience is a social creation process with mutable goals and constantly negotiated premises (Deleuze – Guattari 1987).

Another interesting metaphor on the rhizome is represented by puppet strings (*Fig. 2*), as a rhizome or multiplicity, are tied not to the supposed will of an artist or puppeteer but to a multiplicity of nerve fibers, which form another puppet in other dimensions connected to the first: “Call the strings or rods that move the puppet the weave. It might be objected that ITS MULTIPLICITY resides in the person of the actor, who projects it into the text. Granted; but the actor’s nerve fibers in turn form a weave. And they fall through the gray matter, the grid, into

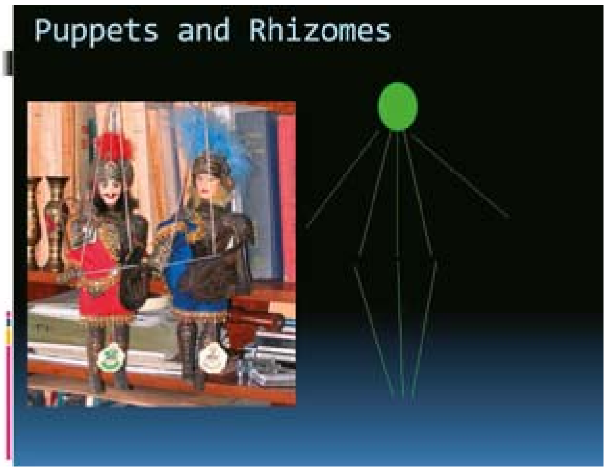

Fig. 2. The metaphor of puppets and fibers.

the undifferentiated” […]”(Deleuze – Guattari 1987).

There is an interesting comparison between the sentence of Bateson “the map is not the territory” and the “map is not a tracing” from Deleuze and Guattari. What distinguishes the map from the tracing is that it is entirely oriented toward experimentation in contact with the real. The map does not reproduce an unconscious closed contact with the real. The map is open and connectable in all its dimensions; it is detachable, reversible, susceptible to constant modification. In the metaphor of the orchid and the wasp, the wasp is nevertheless deterritorialized, becoming a piece in the orchid's reproductive apparatus. But it reterritorializes the orchid by transporting its pollen. Wasp and orchid, as heterogeneous elements, form a rhizome (Deleuze – Guattari 1987). It could be said that the orchid imitates the wasp, reproducing the image in a signifying fashion. In the same way the cybernetic observer becomes part of the ecosystem and it contributes to its evolution and transformation. Settlements, inhabitants, human and natural forces are the "wasps" of the landscapes, deterritorialize and reterritorialized in the same time.

The mindscape

The word "mindscape", mind + landscape indicates the perception of the environment by mental maps. We interpret though mental maps. The human ecological thinking is able to construct complex relations with the ecosystem ruled by affordances, connections, feedback, perceptions. In particular the affordances construct the cybernetic difference between interactors-agents and ecosystems; they redesign the informational input-output of the environmental cycle of life. Tools, actions, behaviors, artificial features characterize the properties and features of the landscape. Roman centuriation, Nazca lines, Iron Age tells, tumuli, monumental tombs, pyramids and so on represent the cultural-formal aspect of the archaeological landscape, but they cannot be perceived without affordances and a mental consciousness of them. The perception of the environment changes through the time and the link (or missing link) between contemporary and ancient societies, living people and ancestors. Some links are conscious, some other links are unconscious: the persistence of shapes, settlements and overlaid sites can follow a criterion of convenience and practice or show a real spiritual link with the past, or both. In China for example near Xi'an there are many modern tombs buried near Western Han Mausoleums or monumental tombs: it is a very tangible example of Feng Shui. The new tombs get power and protection because of their contiguity with the imperial tombs. Similar situations are documented in Peru, within the Inca landscape (for example in the area of Tambo Colorado, an Inca administrative site), where the people from the pueblos in the countryside are buried in the same Inca collective tombs. I have personally seen hundreds of skulls and human remains mixed to the Inca mummies in big pit tombs.

The idea of Mindscape shows that the senses of place, the sense of presence, the embodiment depend on mental perceptions, awareness and feeling of the environment. Each action creates a cybernetic difference, an informational exchange between organisms and ecosystems. The evolution of the mind of Sapiens, of the symbolic thinking, demonstrates that whereas there are human communities we have mindscapes and the same mindscape can co-evolve across different communities because of the cultural diversity. The main goal of the mindscape is the cultural identification, the cultural belonging but, first of all, the cultural transmission and communication; it is a complex message since it involves the social communication of entire communities. The mindscape is not a background, is the place where we live, communicate, and perceive our existence and cultural relations with the environment. Where we have a mindscape there is a map (to the Bateson's thinking), a coded place; where there is landscape, we have a territory, an uncoded space. The knowledge and cultural transmission pass through the maps and not the territories, so our interpretation of present and past societies has to re-contextualize and interpret mindscapes and not landscapes. The mindscape is aimed to the comprehension of the environment and to preserve collective memories of the past and cultural-social meaning of the living spaces. In some ways it tends to generate multiple relations between societies and places and to produce memes destined to the future generations.

Future works have to explore the phenomenology of mindscape also between real and virtual communities, analyzing the capacity and the attitude of the human mind of transmitting complex informational codes generation by generation and place by place. How do we transmit culture? How can the culture be transmitted in conscious or unconscious way? Which codes can represent the "survival machine" described by Dawkins (Dawkins 1976)? A key principle of cultural transmission is based on memetics (Dawkins 1976): the transmission of memes is by fecundity, longevity and copying-fidelity. The memes, as cultural information units, can be spread out in the environment by traditions, models, documents, landscapes, sites and cultural communication. They mark and characterize the environment as informational-cybernetic models, fight and compete for surviving and transmitting knowledge. Therefore, in a possible memetics of landscape, it will be necessary to investigate all the relations of the rhizome for understanding-interpreting-simulating the matrix of the past.

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Chapter 1

Reconstructing Ancient Landscape

“Primum, Agricultura non modo est ars,
sed etiam necessaria ac magna;
eaque est scientia, quae sint
in quoque agro serenda ac facienda,
quo terra maximos perpetuo reddat fructus”.
(Varro, De Re Rustica I.4)

How and where did man use to live in antiquity? What relationship did he have with his neighbours? How did he use, organize or modify his landscape? These are some of the questions that landscape reconstruction tries to answer.

But is it possible to reconstruct ancient landscape in a reliable way? Are there methods, tools, or other indications applicable to this activity?

Although it’s impossible to know what *real* landscape was like in the past, nevertheless its reconstruction remains a fundamental process, that cannot be relegated to a “dissemination phase”. Vice-versa it regards the entire archaeological process, from data acquisition to interpretation, to knowledge acquisition *and* dissemination. Communication is a part of it. And archaeology isn’t the only discipline involved.

Recently, interest in environmental aspects has also reached those fields of archaeology traditionally more focused on “material culture”. We are slowly moving towards an *archaeology of everyday life*, where research, adopting a more ecological perspective, is finally dealing with aspects until now considered superfluous or unimportant.

1.1 Ancient landscapes

In recent decades, the word “landscape*”* has become increasingly used in many contexts, and on various occasions. As the environment and environmental issues have assumed a central role in worldwide debates about future development, attention to *landscape* has also gained in importance. Even in the archaeological field, the traditional approach, mainly directed at excavation and identification of anthropic remains, has been changing, substituted by greater attention to the surrounding context: the natural environment, traces of agriculture, land use, etc.

This new approach has evolved into *Landscape Archaeology*, a relatively new field ('90s), commonly associated with British studies (D'Agostino 1992: 19), although its origins may be traced as far back as the end of the 19^{th} century, with Metzer's research (Roberts 1987: 78–79).

This discipline has several definitions (Barker 1992; Bernardi 1992; Lock – Stančič 1995; Ashmore – Knapp 1999; Gillings *et al.* 1999), also because it has been approached in different ways by British and European, and American scholars. The former have concentrated their studies more on visual and physical landscapes, while American researchers have expanded its meaning so as to include a cognitive and perceptive approach.

In this book, landscape archaeology is intended as the *discipline that deals with the relationship between men and their environment, between the people of the past and their places, as shaped by them consciously or unconsciously*. For this reason I will be adopting a strong (geo)*spatial and multidisciplinary* approach, including reference to several different disciplines, technologies and methodologies (Barker 1992: 265; Forte 2007b: vii; Renfrew 1994). Landscape cannot take a back seat in archaeological studies, but has to be seen as a *determinant factor* for the development of ancient cultures, the result of a dynamic combination of geophysical, biological, cultural and anthropic elements in continuous evolution (Bertrand 1978: 5).

In archaeology, unfortunately, in many cases the fieldwork or excavation is aimed at reconstructing a *single site* and *not a landscape.* In this way it may become very difficult to acquire sufficient data for a consistent reconstruction (Forte – Pescarin 2006).

To study, analyse, interpret and reconstruct this landscape, an ecological and multidisciplinary perspective is necessary, requiring the application of disciplines such as remote sensing, GIS analysis, aerial photo interpretation, field survey, spatial 2d and 3d digital data acquisition, paleo-environmental researches (geoarchaeology, palaeobotany, etc.), geophysical prospecting, but also data post-processing and integration in spatial (interactive) systems.

The goal of this process is the *reconstruction of the ancient landscape as it could have been, in its potentiality*, and it requires the development of virtual (conceptual, realistic) models. The result can be useful to get back to interpretation itself, but it is also a powerful tool to visualise synthetically and immediately the results of several research projects. It can be integrated into communicative tools, such as virtual museums, and become part of a three-dimensional immersive experience, transformed into part of our historical awareness of the past.

Ancient landscape reconstruction cannot therefore just be considered a marginal activity, that can eventually be added on to the end of some archaeological research, just for (relatively unimportant) "communicative" purposes. It is a part of the research process, a *framework for the study, the interpretation and the communication of many different aspects of ancient man's life, integrated in a natural environment and defined by cognitive aspects*. It allows us to connect several layers of information – deriving from history, archaeology, art history, but also geography, sociology, economy and other disciplines – to places, and to investigate connections and relationships among and inside ecosystems. We will therefore be dealing with *potential reconstructions* and not with *reproductions of past realities,* impossible to state scientifically in an extensive way. More specifically, this book deals with the *reconstruction of* v*irtual ecosystems*, which include *archaeological*, *interpreted, potential*, *perceived and networked landscapes* (*Table 1.1*). Moreover, I will suggest an *open* approach: landscape reconstruction is in fact a never-ending process.

Archaeological Landscape	*We are in the landscape: actuality, three-dimensionality, spatiality, dynamism*
Interpreted Landscape (Mapscape)	*We think they were: interpretation*
Ancient Potential Landscape (Pastscape)	*They could have been: potentiality, 3d, spatiality, dynamism*
Perceived Landscape (Mindscape)	*They perceived their territory: perception*
Network Landscape (Webscape)	*We connect over the net*

Table 1.1.

Over the last ten years I've been working on many projects relating to landscape research and reconstruction, at CINECA Supercomputing Centre of Bologna and at the National Council of Researches, the Institute of Technologies Applied to Cultural Heritage (CNR ITABC) in Rome, and in the VHLab, directed by Maurizio Forte until 2007. With a background in archaeology and topography, with a specialist qualification in spatial digital systems, I was able to follow the entire digital pipeline of data acquisition and post-processing and its further exploitation in communicative networks, from the fieldwork to virtual reality applications. I've been giving several seminars on these topics, for post-graduate and post-doctorate students. During these courses I've become aware of students' urgent need to acquire practical skills and, most of all, to experiment a multidisciplinary approach. At the end of each course they seemed satisfied, because they had been able to create connections between specific fields they were already skilled in, "bringing data to life", changing them into dynamic information. When I usually start a seminar on this topic, I can feel the varied expectations in the audience: the defiance of those persuaded of the usefulness of virtual reconstructions, and also the hope of those interested in finding reassurance, regarding the worth of the studies they are doing, or would like to do.

In these years, I've tried to compare the work I have been doing with similar projects and approaches, to analyse various possible solutions and discuss problematic aspects. I have found much good work that has reached excellent results, but each one in a specific field: GIS, remote sensing, cognitive analysis, geoarchaeological and palaeobotanical studies, ICT applications, etc.

Dealing with the landscape, on the other hand, requires a broader, multidisciplinary approach, which forces us to overcome that kind of "solitary attitude" that often characterizes researchers in the humanities. For this reason, I have tried to collect and connect some of this specific research work and bring it into a broad digital methodology, including concepts, hardware and software tools and formats, and also practical suggestions and technological solutions, through the analysis of some case studies.

The topic is very complex: it deals with something continuously changing, uncertain and made up of very many different interconnected aspects. There are many risks to be taken into account.

Let's start with the title of this book.

What is ancient landscape? Why reconstruct it? How can it be analysed, interpreted and reconstructed in a coherent way? What are the main problems in the interpretation process and in the ICT process? How many reconstructions have been done? How many are widely available? How many are reliable, well-documented or transparent? How far should we go, in terms of a technological and epistemological development? What is the state of the art in the field of ancient landscape reconstruction?

Ancient landscape, in its archaeological and geo-spatial dimension, is one of the most complex topic both for analysis and reconstruction. Not just from an archaeological and environmental point of view, but also for Computer Sciences. This is why it is dealt with from a variety of perspectives, such as anthropology, archaeology, computer science, history, architecture, geography, topography, geology, etc. This doesn't mean that anyone interested in landscape reconstruction necessarily possesses all these skills. But he/she should *understand* the entire process and have a basic knowledge of the topics, so as to address the work correctly and involve the right experts.

Reconstructing ancient landscape includes various perspectives and approaches, such as cybernetics, cognitive archaeology and ecology (Bateson 1972; Renfrew 1994; Maturana – Varela 1980 and 1999; Forte 2007a). The process involves reconstruction at different levels: archaeological landscape, interpreted landscape, ancient potential landscape and networked landscape.

Archaeological Landscape is the contemporary landscape in its diachronicity; it includes everything around us, such as archaeological remains and past historical traces. In this perspective *we are* in the landscape. The analysis of an archaeological landscape requires us to deal with actuality, three-dimensionality, spatiality and relation. Mapping is the primary central activity. Without it any reconstruction cannot be carried out. A typical bottom-up approach is commonly followed, since it requires the acquisition of information in the field, through surveys, archaeological excavations, photo-interpretation, geological and botanical explorations, georadar and other geophysical acquisitions. It is generally studied through landscape archaeology, aerial archaeology and topography (Forte *et al.* 2005: 79–81; Cambi – Terrenato 2004; Campana – Piro 2008).

Interpreted Landscape is the *Mapscape.* It is the geographical spatial visualization of the interpretation process, the representation of knowledge acquisition processes and levels through maps. It includes its results: *collections*, *selections*, *essential characteristics,* but it can also include *excluded elements*. Its visual result is made up of 3d and 2,5d maps, layers in overlay, vector themes, raster grids, and databases. It is also an open working environment, closely or inextricably connected to archaeological and potential landscape reconstruction and to spatial and geophysical characteristics. A mapscape is a visualization of the landscape obtained by a digital classification process (satellite, aerial images, geophysical, spectral, etc.) (Forte *et al.* 2005: 79–81). It can be a representation indicating spatial relations or a diagrams in which spatial relationships are configured (Renfrew 2003: 168). Although it is a symbolic environment, can it be also treated as a real landscape? We have to be aware that "*the map is not the territory, it represents, but, if correct, it has a similar structure to the territory*", "*which accounts for its usefulness*", as Korzybski stated in 1933 (Korzybski 1933: 58), but we should also notice that a part of us, probably the right hemisphere of our brain, normally identifies a representation with the object represented. Even a flag on a map, with the name of a country, becomes the country itself (Bateson 1979: 47). In this sense a mapscape can be a useful meta-universe of interpretations, where we can find our direction, our questions, our points of view.

Ancient Potential Landscape is the *Pastscape.* It is how the landscape might have been during a certain historical period, at a defined latitude. It is not a reproduction of what *it was*, but a reconstruction of what *it might have been, potentially,* based on explicit theories and scientific method, from an analytic, holistic and ecological perspective (Renfrew – Bahn 1991). It requires us to evaluate three-dimensionality, spatiality and terrain potentiality. Starting from its main attributes, such as latitude, altitude, climate, morphology, soils and so on, it is possible in fact to define the natural attitude of a terrain unit (Di Fidio 1990). Sometimes more useful resources are available, such as Soil Maps or Land Use Maps, although not for every region (FAO 1976). Potential landscape can then be compared with other available information and data, regarding the specific historical period. Archaeological maps or historical maps can be used to develop an analytic system, based on GIS spatial analysis and consisting of connected algorithms. During this process we very frequently have to face much uncertainty. This is why it is very important to build it on a solid, scientific, open and transparent interpretation process. This promising approach was born at the beginning of the *New Archaeology*, when Binford and other archaeologists started to support the idea that conclusions should be based on an *explicit approach*, developed through logical arguments, and not just on the authority and prestige of the scholar. In the UK, thanks to archaeologists such as Clarke and his *Analytical Archaeology*, the analysis was focused on more quantitative techniques. (Renfrew – Bahn 1995: 29; Binford 1968; Clarke 1977b). For the first time, they reconnected archaeology to other sciences, that were used to building their theories on *scientific method*.

Sometimes this is not enough.

Logic and quantity have proved to be inadequate tools to describe organisms, their interactions and their organisations (Bateson 1979: 37). New tools need now to be tested and adopted. *Perceived Landscape* is the *Mindscape.* It is how the territory was perceived in the past. It requires us to deal with concepts such as relations and perception (Forte 2003a). Richard Gregory in 1973 stated that *perception* has one main characteristic: it is a *hypothesis*[1] (Gregory 1973: 49–96) and as such, it can be contradicted. The original idea of considering archaeology

[1] For example when we see just a part of a table, because it is hidden behind an object, we assume it is a table, basing it on the past visual experiences.

beyond its material culture, including the concept of perception, comes from *Cognitive Archaeology* and *Anthropology* (Renfrew – Bahn 1991; Renfrew 1994). Although archaeology and anthropology are still thought of as two distinct disciplines, since they use different methods and techniques, they are also very similar when they deal with the study of long-term temporal processes based in the landscape. Cognitive archaeology tries to answer questions such as "what did they think?". It studies how ancient men thought and what they believed, starting from the analysis of what they left: archaeological remains, symbols, ancient representations, rituals, myth and religious beliefs (Renfrew – Bahn 1991: 345–377). It aims at understanding how past communities organised their lives and their settlements, or how they used and modified their landscapes. Recent developments in *Virtual Reality* applications enable us to adopt new interesting approaches, through the development of interpretative models that look at how ancient man lived and perceived his landscape.

Webscape represents specifically *relations* and *connections* among characteristics' variability, objects, people, characters and cyberspaces. Networked landscapes (their topology consists of characteristics, interconnections and feedback) are a result of an iteractive application of input and feedback; the landscape can be altered through the adjustment of network internal parameters (connection weights). Neural networks algorithms might be used to develop this kind of landscape.

1.2 Beyond the view

How can we reconstruct an ancient landscape? Let's start from some basic considerations. Firstly, we cannot achieve any reconstruction without interpretation, comprehension, and knowledge. Secondly, we shouldn't work on the reconstruction of the past, without considering and mapping the present, i.e. the archaeological landscape. Thirdly, the only way to approach the present is by changing our perspective and viewpoints. Fourthly, our vision is the main activity involved in the entire process. Fifthly, knowledge acquisition depends upon the comparison of different characteristics and on the identification of *differences.*

The final purpose, interest in and focus on studies and research regarding our past landscape and our history, can be found in the structure of our mind. Day by day we try to acquire information (and knowledge) from the complexity that is around us, using our brain. We specifically use a part of it, that is connected to our vision (*visual brain*), whose main function is exactly "to acquire knowledge about this world”, as stated by neurobiologists (Zeki 2007: 4). We need to *observe* carefully all the details we can *see*, in order to classify them, to find essential “ambiguous” characteristics. We do this primary for biological reasons (Chapter 2).

We use an analytical process consisting of a *de-composition phase*, where we distinguish different aspects and we systematize them, and a *re-composition phase*. In the first case we organise information into archives, databases, or GIS systems. In the second we use more advanced visualisation systems, such as virtual reality environments or 3d models. Unfortunately there is a risk implicit in the process: each time we re-compose the “picture”, we lose information.

The problem is that if we want to use the reconstruction process as an active part of the interpretation, we need to work out how to find a way to preserve the details. Secondly, we should also be aware that visualisation of 3d realistic models, through movies or other broadcasting products, is often incredibly effective, in terms of knowledge transfer, since it can transform a “lesson” into an “experience.” On the other hand, it also creates “dependency” on this opaque visualisation (Turkle 1997). There aren’t any good or bad visualisation systems or media, we should just take into account which is the right communication system for a specific purpose (Chapter 5).

Although there is a lot of resistance and suspicion in cultural heritage, due mainly to a lack of credibility, of authority reference, and peer-review control, there are at least three good reasons why we should persist, intensifying the research in this field. First of all, we should be aware that a wider public is increasingly asking for a better understanding of past history and archaeological landscape, through the employment of visual interactive tools. Secondly, research teams are increasingly using VR tools as *working* tools, as we will be seeing in the next chapters, and not just for presentation purposes. Finally, *representation* is often the basis of *protection.* Although it is not the only way to propose areas for protection, it does contribute to draw public attention to archaeological finds, providing a consistent way to identify them through their knowledge.

Moreover it is quite evident that the sharp resistance to a certain theory, to a new methodology or approach, is part also of its cultural impact. Academic culture has confined philosophy inside seminar classes, but new computer systems are bringing it into everyday life (Turkle 1997: 167–174).

Although we need to follow a clear and schematic interpretation process, reducing complexity, abstracting essential characteristics of the objects (Zeki 2007: 5), we can also develop and implement in our visual systems complex models, to better explain living and dynamic phenomena, getting closer and closer to complexity. A cybernetic approach will be more adopted in the future even to landscape reconstruction, through the application of artificial intelligence algorithms, neural network programs, chaos theories, fuzzy logic, etc.

At the end of each interpretation process, we can deal with ideas and hypotheses regarding past landscapes inside visual spatial systems, where, in interactive sessions, we could select and gather together all available data, interconnecting it in the same cyberspace, and define constants and stable properties. Thanks to the selection of these constants it is possible to classify and order objects in categories, eliminating those not pertinent, in a continuous battle between complexity and classification.

Probably in the near future a new generation of VR applications, as virtual shared dynamic environments, will contribute to the development of this field, offering new solutions for different data integration, and multidisciplinary collaborative work for more reliable reconstructions.

1.3 Digital pipeline

With the continuous evolution of technologies, applications in the field of Virtual Archaeology are increasing. Some of them seem to be driven simply by an interest in a specific technology (in a top-down approach); others by the consideration of a single typology of sources (in a bottom-up approach). Nevertheless, we should consider those that provide outstanding results, trying to bring them as much as possible into a single pipeline.

Ancient landscape, in its archaeological and geo-spatial dimension, is a complex topic to deal with, to analyze and reconstruct, not just for the archaeological interpretative process, but also for computer science. That's why it is viewed from a variety of perspectives, involving anthropology, archaeology, computer science, history, architecture, geography, topography, and geology. Moreover it requires the reconstruction of a virtual ecosystem, with its environment and its multiple relations and interconnections. Virtual Reality applications can be successfully used for its exploration and interaction, and also for its creation itself. To obtain a coherent result, this process needs to be carefully defined by a *digital pipeline,* since it requires the interconnection of several methodologies, formats, software, inputs and outputs.

A digital pipeline is an explicit definition of all digital processes and sub-processes involved. It can be a flow-chart representation, a guidelines document or a simple drawing. The main issue is that it should be shared by all the teams involved in the project. It is commonly divided into principal activities, such as "acquisition", "post-processing" and "reconstruction". It includes a list of software and hardware used in all the activities. It should also include import/export formats. Connection lines can be drawn between sequences of activities in order to clarify which formats are needed, together with specifications and requirements connected to the final use of the reconstruction (*Table 1.2*). Spending some time in the initial phase of a project on pipeline definition, helps save a lot of time in case of mistakes or difficulties, cropping up at the end. Many common problems can be easily avoided in this way, such as: differences in geographic coordinate systems or projections, the wrong level of simplification or optimization of 3d

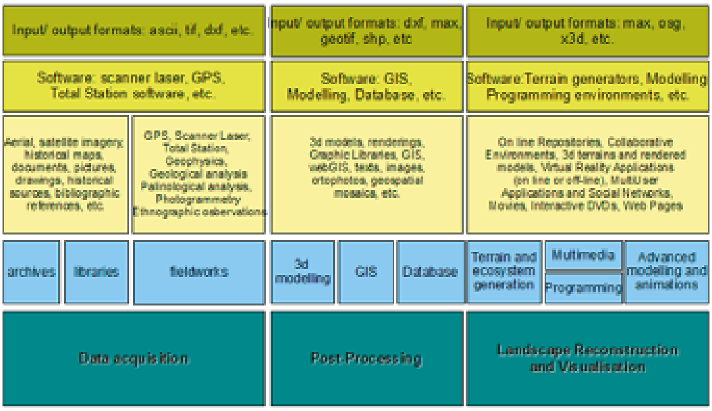

Table 1.2. The schematic representation of the process through the definition of a digital pipeline.

models, naming mismatching, not supported file format, etc.

In the case of landscape reconstruction, the process is usually focused on the acquisition of four categories of data:

I. Digital Terrain Models (DTM),
II. geospatial imagery (Geoimages),
III. vector thematic layers, representing interpretative levels,
IV. other thematic layers (3d models) representing the natural and anthropic aspects of the landscape: monuments, forests, crops, etc.

DTM and Geoimages are essential components in the creation of the three-dimensional terrain model and in the definition of analysis dedicated to potential landscape reconstruction. To these data, we should eventually add also metadata and multimedia information.

A Digital Elevation Model (DEM) is "a digital and mathematical representation of an existing or virtual object ant its environment. It is a generic concept that may refer to elevation of ground but also to any layer above". DTM, Digital Terrain Model, is generally used as referred specifically and "limited to ground elevation", providing information about elevation of any points on ground (Kasser – Egels 2002:160–161). DSM, Digital Surface Model, is an elevation model that represents the highest available elevation of each points (top of trees or of houses for instance). These digital elevation data can have three data structures: (1) regular grids, (2) triangulated irregular networks, and (3) contours, depending on the source and/or method of analysis[2].

The pipeline starts with "mapping" activity, acquisition of information regarding the archaeological landscape (Chapter 3). The creation of a GIS project accompanies this activity, constituting the spatial base of the entire process. It is essential to take into account the spatial dimension of all the data: geospatial images, historical maps, any vector information on archaeological sites or remains, plans, and so on. Even 3d models, acquired on the field with different techniques (such as photogrammetry, 3d scanning and so on) should be connected to geospatial information (georeferenced plans, the georeferenced centre of the model).

Although mapping technologies are becoming more and more efficient in terms of speed and accuracy (a scanner laser can acquire an entire area of a territory with sub-millimetric resolution, in accordance with the chosen instrument, in very short time), the longest part of the work is surely that carried out in the lab ("post-processing" activities: Chapter 3). Here raw data are downloaded and processed in order to obtain a first digital prototype of models: the terrain model, the 3d model of a monument, plans, etc. At the end, single elements of the archaeological landscape are ready to be visualised, interactively or otherwise, further analysed,

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2 Square-grid digital elevation models have some disadvantages: the size of the grid mesh often affect the quality of the results, not handling abrupt changes in elevation. TINs are based on triangular elements (facets) with vertices at the sample points, usually constructed with Delauney triangulation. They are quite efficient because the density of the triangles can be varied to match the roughness of the terrain. The third structure divides landscapes into small, irregularly shaped polygons (elements) based on contour lines. Good reviews of digital elevation data sources and data structures are presented by Carter 1988; Weibel – Heller 1991, and I. D. Moore *et al.* 1991.

or become part of a collaborative environment. Ancient landscape reconstruction starts at this point (Chapter 4).

Along the pipeline, there are some characteristics that should be stored, while carrying on the activities, since they influence the final result:

- acquisition method,
- processing method,
- data resolution,
- accuracy,
- reconstruction reliability level,
- sources references,
- institution and team member in charge.

1.4 Scale, level of detail, accuracy, and reliability

The result of a reconstruction is necessarily connected and conditioned by the scale, the level of detail, the accuracy and reliability of available data (input) and processed data (outputs). It can be conducted, in fact, even on a single level, such as the local level (site, intra-site, farm, single field, etc.) project level (inter-site, settlement), or regional level. Each level requires different kinds of survey, different acquisitions, different resolutions, and produces different outputs: from a very detailed reconstruction of the local level, to the semi-detailed or reconnaissance level (FAO 1985) of the regional level.

Each measurement and acquisition is in fact limited in accordance with the instrument and the method we are using.

The *scale* is commonly related, in cartography, to the ratio or relationship between a distance or area on a map and the corresponding distance or area on the ground, commonly expressed as a fraction or ratio, but it is also used to indicate the degree of detail or content represented, i.e. in a GIS. Scale refers to the "level of spatio-temporal" representation in archaeology. With the current use of digital cartography and GIS, which are substituting the limits imposed by the printed map, this concept (spatio-temporal scaling) is also opening new methodological problems . Any representation of the landscape, indeed, is linked to the level of accuracy and resolution in available data: any further analysis, therefore, should be very careful over stating "absolute" results. When we move then from GIS to the realm of Virtual Reality, even greater care should be taken, since in VR the accuracy level may be very difficult to define (Lock 2000: xix–xii).

Accuracy and precision are used when a measurement instrument is evaluated. “Any measurement system involves errors that can be roughly divided in systematic and random errors. Each type of error originates a corresponding wrong behavior which is identified as *accuracy* and *uncertainty* (or *precision*), respectively” (Guidi *et al.* 2007: 60).

Accuracy is connected to the quality of the obtained *results*, while *precision* relates to the *quality* of the *operation* by which the results are obtained. Precision concerns the reproducibility of an acquisition done several times on the same sample (Artiola *et al.* 2004: 19–20). In spatial systems accuracy concerns the level of data correctness in accordance with some agreed-upon level of precision in the coordinate system in use.

Resolution is the amount of spatial detail that can be observed. It is the minimal mapping unit for vector data and the dimensions of the pixel (or cell) for raster data. In satellite images, the spatial resolution can vary “by order of magnitude, (such as Spot of 10 meters, Ikonos of 1 meter). There is also a *temporal resolution* that is the minimum duration of an event that can be observed. *Thematic resolution* refers to the precision of the measurements of the attributes, it can depend upon a measuring device or the number of categories. *Spectral resolution* refers to the number, spacing and width of wavelength bands of electromagnetic energy that a sensor can detect (Aron – Patz 2001: 85–86).

3d photogrammetry (imaged based semi automatic)	> = 1 cm
3d Laser scanner	< 7 mm
DGPS dual frequency	< 1 cm
DGPS with Racal satellite correction	< 25 cm

Table 1.3.

Consistency is to the *absence of contradiction* in the data, in terms of space, time and theme, while *completeness* regards the absence of missing information.

Reliability concerns to what extent a reconstruction can be called correct, in accordance with resources used (historical, archaeological, etc.), input data accuracy and resolutions, the processing method followed (level of simplification, etc.), and scientific method applied.

1.5 Virtual Archaeology: state of the art

Virtual Archaeology, in the definition of Maurizio Forte, regards the reconstructive digital archaeology, computational epistemology, and the reconstruction of three-dimensional archaeological ecosystems (Forte 2000; Forte 2007a: 8). Although it was originally used for 3d computer models of ancient buildings and artefacts (Reilly 1990: 133–139), the concept goes beyond the simple digital treatment of archaeological data, since it is related to the increased value of the information. The reconstruction of ancient landscape, although it has a wide perspective, is part of Virtual Archaeology.

Within this specific field, in the last 15 years there have been several examples. Unfortunately we cannot obtain a complete list, since most of these projects have been developed inside research groups, seen by just a limited number of specialists.

Nevertheless, I've started to create an archive of virtual archaeology projects[3], analysing papers presented during well-known conferences in the field and published in the proceedings, such as CAA (Computer Application in Archaeology), VSMM (Virtual Systems and MultiMedia), VAST (Virtual Reality, Archaeology and Cultural Heritage conferences), Eurographics, SIGGRAPH and so on. Other projects have been found during Internet searches inside institutions web-pages. While awaiting a serious, scientific repository, I will try to summarize some results on projects regarding landscape reconstruction, emerging from the research. In *table 1.4* are described the parameters taken into account.

Parameters	**Sub parameters**
GIS based or geospatiality	In input; In output; in input and output; none
Three-dimensionality of final results	Y/N
Interactivity	Interpretation process; Resulting application; Research or/and dissemination purposes.
Web-based	Research process/resulting application
Collaborative environment and networking	On line/Off line
Final results availability and accessibility	On line/off line; publication/multimedia/VR
Sources availability	Y/N
Acquisition methods availability and accessibility	Y/N
Processing methods availability and accessibility	Y/N

Table 1.4.

[3] This work is still in progress and so has not yet been published.

The projects examined have various aims and follow a variety of methodologies. Some of them regard the construction of models and algorithms to understand the territory better, and reconstruct it better. This is the case, for instance, of the reconstruction of landscape evolution and cultural transformation at Durres, Albania (Santoro – Monti 2003), which followed a geospatial analytic

Fig. 1.1. The medieval monastic complex of Jure Vetere and the sorrounding territory reconstructed through spatial analysis and computer graphics (Reconstruction by F. Gabellone).

approach; the reconstruction of the territory and its catchment limits, during medieval times, at Jure Vetere (Calabria, Italy: *Fig. 1.1*, *Fig. 1.2*), through the application of a *Cost Surface Analysis* algorithm (Fonseca *et al.* 2007: 87–132, Sogliani *et al.* in print); the stratigraphic landscape reconstruction in Daunia, carried on by the University of Foggia with the project Itinera and the creation of a VR environment "Time Machine".

Some projects have a stronger ecological approach, for example in the case of the study and reconstruction of ancient woodlands in Hungary (Szabó – Müllerová in print), or in the Ca' Tron project (*Fig. 1.3*) where archaeologists, geologists and botanists have worked together to reconstruct 20,000 years of history (Bondesan *et al.* 2009). In some cases, interactive applications have been developed to enable a wider public to access cultural knowledge, inside physical museums or on line, as with the "Narrative Museum of Appia archaeological

Fig. 1.2. A detail view of the reconstruction of Jure Vetere (Roubis et al. *in print).*

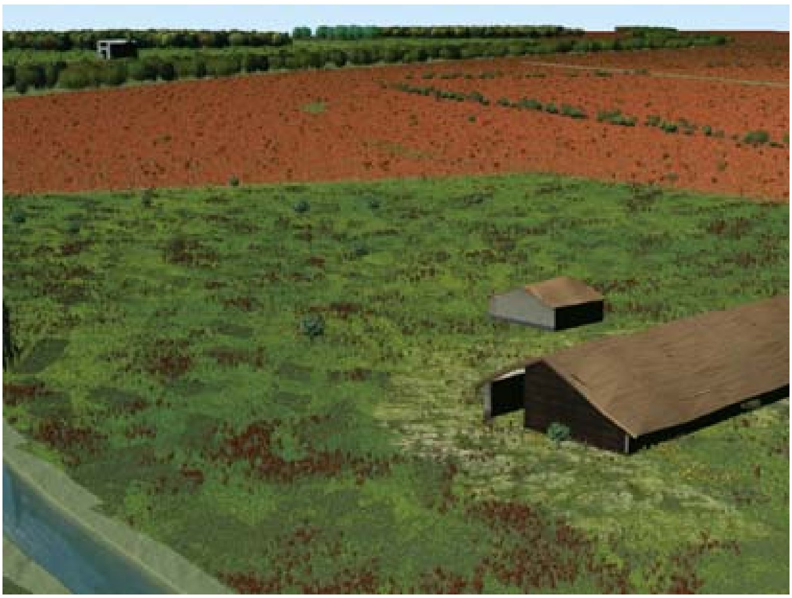

Fig. 1.3. Ca' Tron project: reconstruction of the Roman landscape with a sheepfold (Busana S., Cerato I., Palombini A., Vassallo V.).

Fig. 1.4. Virtual Museum of the Ancient Via Flaminia project: reconstruction of the Roman potential landscape at the Villa of Livia (Pescarin S., Palombini A.).

Park", the "Virtual Museum of the Ancient Via Flaminia" (*Fig. 1.4*) and "Virtual Rome" projects (Appendix A).

Although it is a simplification, we can divide projects into two main kinds of applications: "GIS-oriented" and "VR-oriented". GIS-oriented projects are developed mainly by archaeologists, historians, geographers, geologists and ecologists. The products are used for the visualisation of scientific results aimed at the scientific community, for knowledge dissemination, and, in some cases, for preventive and predictive archaeology. Examples of products are geospecific GIS, webGIS and repositories, drawings and digital images, paper and traditional publications and videos. Tools commonly used are GIS software, database, terrain generators or ecosystem generators (Appendix B).

VR-oriented projects are mainly built by computer scientists, architects or designers interested in landscape, and the computer-game industry; only rarely by archaeologists, art historians or artists. The products are mainly used for scientific visualisation or entertainment, although there are also some examples in the field of collaborative environments (CVE) (Chapter 7). These projects are based on: advanced 3d programming, massive use of computer-graphic and 3d tools for off-line or on-line interaction; in some cases game engines (Torque, OGRE, Quake engine, Unreal, etc.) authoring platforms for VR and games creation (VirTools DEV, Unity 3d, etc.), 3d graphics toolkits (OpenSceneGraph, OpenSG, etc.) or social network platforms (Second Life, Active Worlds). They are more oriented to small-medium scale projects, more than to a wider scale (large territories). Examples of products are: videos (interactive or not-interactive), multimedia, VR application on line and off line.

1.6 Conclusions

As we have seen, the approach to landscape reconstruction is absolutely multiple. Landscape reconstruction is a complex process that includes tools for analysis, interpretation, visualisation and communication. It concerns the reconstruction at different levels: the archaeological landscape, mapscape, mindscape and webscape.

There are many interesting projects, but in most cases they are known only at a local or national level. Even in the case of international publications, final results remain rather unknown, often confined inside laboratories or research groups. For this reason, there are projects which develop the same topics. Transparency therefore is still a long way off in terms of commonly, applied scientific practice. Although almost every project has underlined the importance of multidisciplinary approach, there are few examples of data sharing or collaborative environment. Three-dimensional visualisation is considered, by researchers themselves, useful mainly: for the presentation of scientific results, to enhance the general interest in archaeological research, to communicate contents that facilitate interpretation or the grasping of ancient territory distribution for visitors. The E-learning perspective is also considered in the creation of virtual worlds for immersive facilities or for web based learning environments. The 3D interactive visualisation of reconstructed landscapes is also felt to be important to attract the attention of cultural authorities. There is also an increasing awareness over considering 3d and VR applications as useful for research, if aimed at exploring and studying past living spaces through virtual and simulation models, or at developing perceptual analyses and alternative modes of appreciating and constructing places.

I put forward some useful guidelines at this point that will be further discussed in the book, ten golden rules for ancient landscape reconstruction:

1. Use scientific method, while defining your digital pipeline,
2. Acquire all available archaeological, historical, architectonic but also environmental information (a multidisciplinary approach is required),

3. Start mapping the contemporary archaeological landscape, then work on interpretation, and finally propose a hypothesis on potential landscape reconstruction,
4. Consider the spatial and temporal dimension of all data (2D and 3D),
5. Consider relations among data, objects, sites, etc.,
6. Organize your data in a structured way (database, GIS etc.): get used to annotation during the acquisition, interpretation and reconstruction phases,
7. Use an open approach: landscape reconstruction is a never-ending process. Use open standards and formats as much as you can: landscape reconstruction is a collective process and you probably need to share data, information and results,
8. Make use of virtual spatial systems,
9. Practice observation, comparisons and critical debates to correct or improve your reconstructions,
10. Use Internet and publish your results in a transparent way.

Chapter 2

Interpretation and Reconstruction

2.1 Vision, interpretation, and knowledge

Interpretation comes from the Latin *interprete(m),* whose meaning is originally 'intermediary' or 'mediator'. In fact it consists of *inter* (in the middle) and *pretium* (price) (Cortellazzo – Zolli 1999). Interpretation plays an important role in the cognitive process, because it creates a link**,** a bridge between vision and knowledge, among archaeological findings, observations or sources and knowledge.

Landscape reconstruction final output is a visual result: the reconstruction or reconstructions. It is therefore a visual activity. In addition, it is a product of our brain and must follow its laws. Although an archaeological reconstruction is commonly labelled "dangerous" by scholars since it freezes one personal vision of the world, shaping it as the real truth, without possessing enough data, we will see that this is inaccurate, first of all from a neurobiological point of view.

How do we acquire knowledge of the world? This is a central issue in the process of analysing available information and producing reliable interpretation, in order to obtain a better knowledge of the past. As we have seen in the previous chapter, *we observe to obtain a knowledge of the world*. The world around us is complex, because of the quantity of information, but also because of the speed this information changes. We must survive without going mad, keeping what we need. Our brain's activity is continuously focused on the identification of constant characteristics. It is essential, in fact, to classify what we see into categories, in order to understand. The classification takes place in three separate processes: *selection*, *exclusion* and *comparison*. We select constant properties from different variable information, then we eliminate what is not relevant and finally we compare it with what is already visually registered in our brain (Zeki 2007: 4–23). Even a philosopher such as Gregory Bateson has defined the process of knowledge acquisition as an activity of comparison among differences (Bateson 1972).

We can build reconstruction of the landscape that can really help the acquisition of knowledge about our past. The use of vision is extremely useful in the extraction of essential information from the quantity of available data. The landscape itself is a perfect example of inconstancy: it is continuously changing. The attempt to define its essential characteristics, selecting constant elements, opens up a more durable interpretation of reality (Zeki 2007: 28).

From a neurological point of view, the discoveries of the last thirty years have changed what we know about our brain and about the way it works. At the beginning of the 20th century scientists like Henschen and Flechsig developed a theory which distinguished a main area of the brain, devoted to vision – interpreted as passive and primitive activity – and a second area around it, known as the "associative cortex", devoted to understanding – an active task –, obtained from the association of the received image (main area) and other images stored in this second area. In this first approach, passive observation was distinguished from active interpretation (Flechsig 1960: 75–89). Recently, new observations have changed this theory. It is quite accepted today that there is a main area, known as V1 or "primary visual cortex" and located in the bottom left hemisphere of the brain, whose function is vision, and several distinct areas around it (V2, V3, etc.), committed to specific visual aspects, such as: *shape, colour, movement, depth* and *relation.* The entire observation process is therefore an active task, starting from vision itself, since it is a selective activity, defining essential characteristics (Zeki 2007: 38). While we are watching a scene, we are already making choices, selecting constant aspects, referring to the shape, the colour and also to the *relation* among objects, situations or concepts.

Maps are perfect examples of the representation of essentiality, as they are built after a process of observation, selection and exclusion. Interpreted landscape should make use of interactive maps, exploiting their power to create mapscapes. A useful constant concerns the identification of similar characteristics, common to a variety of situations, which can help to define a *representative condition*, called by neurologists "situational constant" (Zeki 2007: 41). A mapscape is a depiction, a description of a representative landscape, a simultaneous representation of many realities, valid for most cases. Furthermore, it can really help in the interpretation process, proposing various potential visions. *Ambiguity* in this sense becomes a positive aspect, since it lies in the presentation of many different visions that contribute to the interpretation. A mapscape is also an interactive vision. Through the connection to sources and data it acts as a bridge between observation and knowledge, as an interpretation space.

How reliable is a reconstruction?

We should say that every interpretation uses the "comparison" with what is already stored in our brain. It is therefore intrinsically *personal,* since it is based on previous knowledge. Many archaeological interpretative processes are commonly considered subjective, since they depend on the skill of the interpreter, their experience and training. But they are subjective firstly in another sense: they are part of a personal process. Moreover, there is no uniquely "true" situation or correct answer. Nevertheless, what we have described may grant that the visualisation of reconstructions isn't restrictive. Virtual reconstructions should be striven for to obtain constants and permanent shapes from multiple situations, an essential representative vision, reaching for a greater awareness (Schopenhauer 1859: §38). Virtual Reality can represent the world in an essential shape, with such *intensity* and evidence that it can be considered as reality itself.

The use in the reconstructions of *ordinary* situations, ordinary characters, ordinary and not specific objects can contribute to maintain this ambiguity and representativeness. Ambiguity drives a user to put new questions, activating connections with previously stored information or stimulating to find new answers from new data.

Another neurological trick that enables a more effective interpretation is the "*unfinished*", an *implicit constant*. Artists such as Michelangelo left many pieces of art unfinished, revealing the power of multiplicity; the observer participates in the work with his imagination, adapting different concepts and representations of his mind (Schulz 1975: 366–373; Zeki 2007: 48). In this sense a reconstruction can be considered close to art, when it helps interpretation with the power of *evocation,* widening its horizons and its cognitive potential. Observing that reconstruction, we should be able to acquire information of the represented categories. Nevertheless, we should also remember that any represented objects cannot substitute the incredible wealth and complexity of a brain representation.

Reconstructions should present, if possible, *detailed* visualisations. The brain is interested in details, aiming to bring them into a more general scheme. But images are stored in our brain if they are recognized. Memory is connected to the temporal cortex and to the several specialized areas of the brain, above mentioned. Probably the specialization of these areas (the identification of colours, shapes, etc.) contributes to the memorization and the cognitive process (Logothetis *et al.* 1995: 552–565).

In this perspective, the use of a *cybernetic* approach, which takes into account the complexity, will help to maintain a detailed visualisation.

The word “cybernetics” was introduced by the mathematician Norbert Wiener in 1948[4]. It comes from the Greek word *kybernetes* (steersman, governor). It was introduced as a way to solve a military problem: how to create an efficient anti-aircraft mechanism for artillery, capable of hitting a moving object (such as an aeroplane)? The required system had to take the trajectory into consideration, but also predict any possible irregular changes in its position, integrating a feedback mechanism for a continuous correction in accordance with its real-time behaviour. The problem therefore was the management of complex situations in a future perspective.

Fig. 2.1. Procedural Modelling of Pompeii (P. Müller, City Engine).

Immoderate simplification can preclude a real understanding, and it is in this sense that complexity should be taken into account. The goal in fact isn’t, again, the impossible reproduction of past realities, but a contribution to their interpretation, through the construction of models of the past. A technique that in the future will be increasingly adopted for this purpose is procedural modelling. It uses and develops algorithms for producing environments, using shape grammar, starting from a set of rules that can be part of the algorithms and also modifiable through parameters. An example applied to Roman architecture

[4] Norbert Wiener (1948), *Cybernetics or Control and Communication in the Animal and the Machine*, (Hermann & Cie Editeurs, Paris, The Technology Press, Cambridge, Mass., John Wiley & Sons Inc., New York, 1948).

and the procedural generation of Roman cities has been applied successfully. In this test case, the Roman city of Pompeii was completely reconstructed, using a "shape grammar" (called CGA shape), with the production of rules that evolve, creating more and more details (*Fig. 2.1*). An advantage of this method is that the hierarchical structure and the annotation of the models can be reused, creating different procedural variations (Müller *et al.* 2006).

Dynamic, chaotic and not linear systems, based on neural networks algorithms, can be used to build very complex environments which can evolve, independently from initial conditions. Neural networks, as explored by the mathematician and pioneer of chaos theory Edward Lorenz, can be very useful to deal with complex systems and to build relations. Today there are also new approaches which can be applied even to landscape reconstruction. While at the beginning scientists were much more interested in finding a way to create a replica of the human mind, today studies are more focused on the development of relations. There are new generations of neural networks, known as smart adaptive systems, that can better represent dynamic scenarios, continuously changing. These systems are built to adapt themselves to an evolving (over time, space, etc.) environment, recognizing changes and reacting accordingly, but they are also designed to answer problems very familiar to those who work in the field of landscape archaeology: is it possible to build a system, starting from very little information, through incremental learning?[5].

Some projects on *Artificial Life* (AL) are trying to answer this question. AL is the discipline which is in charge of creating organisms and systems, that might be considered alive if found in nature (Turkle 1997: 174). One of the first applications, known as "the blind watchmaker", was developed by Richard Dawkins, while others have been created as computer simulations of nature development, such as "Tierra", created by Thomas Ray in the early 1990s, or "SimLife", a sort of ecological virtual system and genetic game. These simulations can be really challenging, to understand better how natural realms work.

Genetic algorithms represent another example of artificial intelligence, since they are built to include different variables, each one representing the solution to a problem. These algorithms create several *similar* solutions, maintaining some basic characteristics. They have no auto-organisation, although they evolve in different ways, maintaining some essential basic characteristics. In the near

[5] See EUNITE – the European Network of Excellence on Intelligent Technologies for Smart Adaptive Systems which from 2001 is working on the field (http://www.eunite.org).

future, I believe they could be successfully applied also to the reconstruction of Ancient Potential Landscape, since they seem to be very powerful means of enhancing explanation and communication. A good example of the application of such an approach is the so-called G*enerative Art*. Generative Art creates artificial digital objects whose common characteristic is that they have the same "genetic code" (*Fig. 2.2*). We can say that in these kinds of artworks what is stored are the essential characteristics of objects. As the artist Celestino Soddu states, a generative project is a concept-software that works producing three-dimensional non-repeatable events as possible expressions of the generating idea identified by the designer as a subjective proposal of a possible world (Soddu 1991).

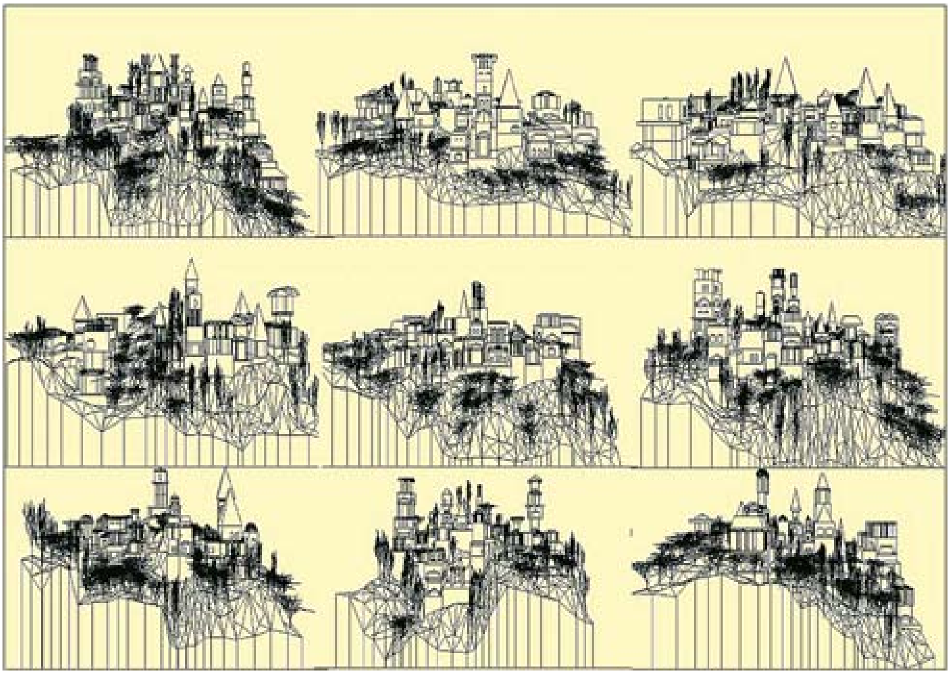

Fig. 2.2. A generative project realised by Celestino Soddu. It represents several versions of a hypothetical medieval Italian town, which keep all the genetic characteristics of the "medieval".

Some scientists have applied artificial intelligence to sciences more related to landscape archaeology. Lovelock and later Margulis have developed the *Gaia*

Hypothesis, defining the earth as a huge single organism that can self-regulate[6]. All the components (organic and inorganic elements) of the earth are strictly connected and can be thought of as one organism, a single system in which many retro-action rings keep chemical and physical conditions stable, thanks to an automatic control for example of the global temperature, transforming it into an inhabitable place to live. All the components normally evolve together: life maintains conditions suitable for its own survival[7]. Lately other scientists suggested that this auto-organisation can modify evolution speed, and this can be seen by a progressive increase of complexity. Although we live in a chaotic and not casual system, where does the organisation we see everywhere around us and inside us come from? Complexity generates very much of the order of the natural world. Selection then acts to further refine it. Every system is in the middle between chaos and order, at the boundary (Kaufmann 1995). The interpretation of ancient landscape should take into account organised and chaotic elements and it should consider schematic and evolutionary approaches since a successful exploration of our past lies in a sort of transition between order and disorder. We will often have to consider, for example, how a population has shaped its territory. Even in this case, we should know that communities that have not limited themselves to the exploration of a territory, and arrive at more remote areas, will find better and more stable conditions. We often face the problem of neighbouring communities (some GIS analysis, such as Thiessen Polygons, involves the identification of areas of influence), where a co-evolutionary approach should be considered: "in co-evolving systems, each partner clambers up its fitness landscape toward fitness peaks, even as that landscape is constantly deformed by adaptive moves of its co-evolutionary partners" (Kauffman 1995: 20–27).

The way we work on the interpretation of our past has changed in the last century. Computers allow us to manage complex systems and a large quantity of information together, which was impossible to handle before. The continuous and rapid access to different information opens up new perspectives in the knowledge of ancient landscape, but it can also be "dangerous", since it hides the risk of

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[6] James Lovelock, 2006, *The Revenge of Gaia: Why the Earth Is Fighting Back – and How We Can Still Save Humanity*. Santa Barbara (California); Lynn Margulis, 1982, *Early Life*, Science Books International, Margulis, Lynn, 1998, *Symbiotic Planet: A New Look at Evolution*, Basic Books, Margulis, Lynn and Eduardo Punset, eds., 2007 *Mind, Life and Universe: Conversations with Great Scientists of Our Time*, Sciencewriters Books.

[7] http://www.gaiatheory.org

superficiality. In the simulation era, understanding depends upon exploration and upon personal paths, not just upon analysis. In the continuous navigation from one piece of information to another, we might stop at the vision of the surface, viewing the word as a collection of signifiers with no meaning. The risk of being manipulated by our simulations should be considered in the rapid and multidisciplinary access to information, for a greater awareness of research contributions (Turkle 1997).

Another aspect highlighted by researchers such as Maturana and Varela is the concept of *autopoiesis* (Maturana – Varela 1980). This new approach can give useful suggestions also in our case, since it stresses the prominence of *relationship,* rather than properties of living elements. The analysis of relations should necessarily follow that of separate characteristics and properties.

2.2 Interpretation: a theoretically explicit scientific approach

Reconstructing ancient landscapes is an interpretative and open process, where science, but also imagination and art, are important. Its value lies in its reliability, in the process of available data analysis through an explicit methodology (the scientific approach) and an interpretation process (imagination – art). As Schopenhauer stated, the most important things should always be left to the *imagination* (Schopenhauer 1859: § 34).

It is, moreover, an open process, since each "interpretative cycle" leads to the production of new data, observations, and analysis.

Landscape reconstruction doesn't just produce a "communicative" result for an end-user. More or less realistic and immersive visualisation inside territories and meta-territories can be considered part of the research activity. And this is thanks to interaction and transparency potentiality. Communication is integrated *in* the research process of interpretation, when it is used, for instance, to test theories. Chris Langton is considered the founder of Artificial Life (ALife), director of the Santa Fe institute in New Mexico. He worked on developing programs that evolve autonomously in the computer. He creates communities of individuals who initially learn some basic rules and then evolve autonomous ways. Langton tried to recreate *"life as it could be*" and not "*life as it is",* opening up to the reconstruction of its potentiality (Langton 1989).

Also ancient landscape can be considered an ecosystem, a complex system that needs interdisciplinarity and integration (of data, tools, formats, etc.) to be engaged in. It is strongly connected to space, time and relation concepts. It is something more than a simple "object" that needs to be reconstructed. It is a dynamic system whose aspects, whose creation and evolution are connected with each other, and depends upon geomorphology, climate characteristics, altimetry, anthropic modifications, and also cognitive and perception aspects.

In this perspective, each analysis and interpretation that takes into account the territory, should consider the spatial dimension of all data as fundamental. Moreover, it should start with mapping the existing archaeological landscape. Without the archaeological and observed landscape, in fact, it won't be possible the get essential information on ancient landscape reconstruction.

We started working on these concepts in the project of the "Virtual Museum of ancient via Flaminia". The aim was the realisation of a multi-user VR application regarding an archaeological landscape, in northern Rome, crossed during Roman times by the road *via* Flaminia. Although the final result of the project was a public installation inside a museum, with evident communication priorities, the reconstruction process of the landscape was based on a serious interpretative work, based on a GIS project, on the processing of all available data, on raster map analysis and on new data definition. At the end of the process, inside the reconstructed landscape, high resolution 3d models of archaeological sites have been integrated (*Fig. 2.4*; Appendix A).

The reconstruction of Bologna during Roman Times has been another project following the same direction. Archaeological urban landscape has been first created and used as reference for the reconstruction of Roman geomorphology (potential landscape), based on all available archaeological excavations. The simulated geomorphology has then been used to perform further GIS analysis on the potential hydrography and on the use of urban space (*Fig. 2.3*; Pescarin 2002).

In the case of the Via Flaminia project the aim was to reconstruct the actual archaeological landscape, but also the ancient potential landscape. The work was carried out in a wider perspective, with the idea of analysing also a possible and more general method to reconstruct ancient landscapes, through the use of a formal explicit process and of a series of connected "algorithms". The reason for this approach was the idea of defining an open process, where observations and assumptions could be controlled step by step, and where it was possible to modify, almost automatically, the final result, as initial input data changed (modifications, new introductions). At the end, a VR application based on final outputs of such a process was used to test the hypothesis, working with interpretations. A variety of tools were used to obtain inter-disciplinarity, reliability and updatability. Although

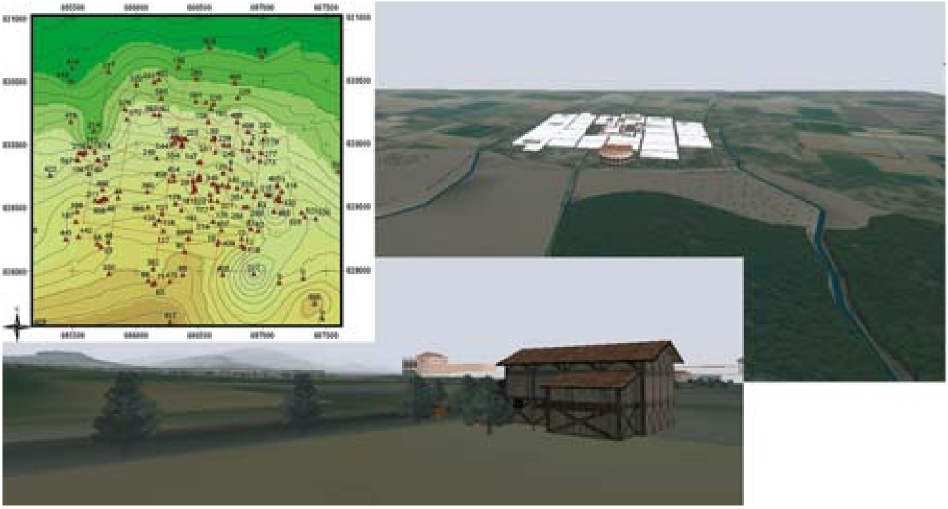

Fig. 2.3. The reconstructed Roman territory of Bononia (Bologna) and the initial archaeological dataset (top left).

Fig. 2.4. Roman Landscape in the Roman suburbium (Flaminia project).

reliability depends strictly upon available data (quality/quantity), the creation of an updatable system was connected to the method used.

The final and accepted result was then used and implemented inside the MultiUser Virtual Reality application, created appositely inside a new room of the Roman National Museum at the Diocletian Thermal Baths in Rome.

Ancient landscape reconstruction is achieved through various phases: the reconstruction of the archaeological landscape, of the ecological attitude, of interpreted landscapes and the reconstruction of ancient potential landscapes.

In the case of historical landscapes, through the study of the ecological attitude of a territory it is possible to reconstruct classes and related sub-categories, such as woodlands and agricultural lands (mainly for cereals, vineyards and olive trees, but also pasture) (Di Fidio 1990: 215; Volpe – Arnoldus-Huyzendveld 2005; Dramstad *et al.* 1996; Chiusoli 1999). In order to obtain these classes, spatial analyses should be carried out on different raster grids. At the end what we obtain are vector layers, that can be further modified during following processing. These layers can be used as input in 3d terrain generation software and VR application development.

Although uncertainty is part of archaeologist's daily life, the importance of scientific method is quite evident. A scientific approach allows reliable analysis and reconstruction, with the final goal of getting to know new elements, propose new explanations, generate criticism and discussion, and correct/emend existing data, thus providing a positive impetus to research. The definition of an accurate and consistent representation of ancient landscape is an open and collective process which allows us to formulate an interpretation model of past landscape. Ancient landscape cannot be considered real or true, but we can work on the potential landscape, to be thought of as an open process, each time closer to the truth, with continuous approximations. The creation of potential landscapes will be further described in Chapter 4.

Table 2.1 proposes an example of how the scientific approach can be used, as referred to a Roman landscape. The initial input was how the landscape should have appeared, during the early Imperial period, in the *suburbium* (the area outside the city). This question was then subdivided into sub-problems easier to solve: such as the identification of Roman vegetation, of climate conditions for that period and latitude, of anthropic elements (archaeological sites and remains excavated or surveyed or predicted in archaeological maps), of cultural elements (funerary habits, and so on). The archaeological landscape was reconstructed, a GIS project developed, and vector information overlaid.

Scientific method	Scientific method in landscape archaeology	Steps in Roman potential landscape reconstruction
1. Identification of significant question	Identification of significant question	What did the Roman Landscape look like during the early Imperial age?
1B. Subdivision into sub-questions	Subdivision into sub-questions	Type of vegetation, of climate, of anthropic or cultural elements?
2. Collection of information and main data	Collection of information (published, ancient sources, on the field) and main data. Georeferencing	Distribution of archaeological sites; paleo-botanic analysis; geological analysis, etc.
3. Definition of a hypothesis that could explain the question	Definition of a hypothesis that could explain the question: reconstruction of ecological attitude of the territory and integration of anthropic and cultural elements	Ancient landscape can be defined by potential landscape and anthropic/cultural modification; how can theory formation be simplified with algorithms?
4. Hypothesis or explanation testing	Testing with VR 3d tools Tools of Virtual Reality enabling us to carry out further verification and observations	3d terrain generation, main ecosystems, anthropic elements; implementation in 3d real-time engine for testing in 3d
5. Testing of hypothesis	Testing of hypothesis even with VR tools for further observations	Terrains 3d generation, main ecosystems; anthropic elements; implementing in a real time engine
6. Acceptance or rejection of the hypothesis	Get back to previous step for further work and new tests	Get back to GIS project and re-implementing of new data also in the 3d engine
7. Theory definition	Definition of possible theories on the reconstruction of ancient landscape	Reliable reconstruction of ancient landscape
8. Experimenting, test of the theory and acceptance or rejection	Theory verification on other landscapes and other data. Accept, modification or rejection	Use of the same algorithm with other case studies
9. Results published and data validation through peer review mechanism	Results published through traditional scientific publications, the web and other open tools	Results published in scientific publications and over the web through VR webGIS open source application

Table 2.1.

The archaeological landscape can be employed during “interpretative sessions” involving archaeologists, computer scientists, geologists and botanists. Interactive 3d and 2d tools might be used for this purpose, such as VR systems, webGIS and VR webGIS. New thematic layers are then defined so as to identify main landscape classes (such as vegetation, hydrography, roads, etc.). These classes represent specific sub-questions, valid in a certain historical period, latitude, climate, geomorphology, etc. Each time a new set of data is created (specific DTM, farming terrains, potential land use maps, hydrography, location of archaeological sites, etc.) it is also tested inside a 3d or shared environment, where verification and observations are carried out from “inside” and are employed to create further analysis (new areas of interest, predictive maps, etc.). At the end of the process 3d terrains and main ecosystems are generated, then implemented in a 3d real time application obtaining a final result. If the entire process is formalized and discreted, through the implementation of single analytic algorithms, connected to each other, it is possible to have a different final result each time initial inputs change or are modified (*Fig. 2.5*). Despite the solid confidence that emerges from the application of this process, it *should* be said that every hypothesis can be discussed and demonstrated as false. Nevertheless,

Fig. 2.5. Different potential landscapes obtained with the variation of input data.

as Popper observed in 1934, a hypothesis *should be counterfeitable*, and a theory cannot be called scientific if it doesn't admit the possibility of being demonstrated as false. Theoretically, in fact, it should be always possible to make an observation that can demonstrate that the theory is false, even if this observation hasn't yet been made (Popper 1934).

After the phases described, it is possible to obtain a more general theory, a self-consistent explanation of the initial question, based on a valid hypothesis. The definition of a theory helps to trace the new predictions for further testing.

At the end, it is also essential to publish results, for validation by the scientific community through peer-review mechanisms, even using digital publications or more advanced interactive systems. Unfortunately, in the humanities it is almost impossible to define "general laws" and to get to definitive interpretations, without any uncertainty. Also for this reason archaeologists tend to postpone this moment as long as possible, although if we consider the development of research in a broader and collective sense, it would be better to take greater care over documentation production and results sharing (Pescarin 2006: 137–155).

2.3 Conclusions

Every reconstruction is the result of an objective and subjective process at the same time. Final results' transparency of interpretation, therefore, visible through simulation and reconstruction models, is obtained through interactivity and an open approach (Pescarin 2006; Forte – Pescarin in print b).

Following a scientific approach, maintaining as much as possible the detail, can help in overpass risks and the limits of virtual reality simulations.

The work done in recent years by the Virtual Heritage community has demonstrated that the convergence of different disciplines in landscape archaeology can bring about a more efficient, valid study of the territory, providing at the same time new interpretation keys of ancient landscape.

This convergence also allows a more appropriate and aware use of available technologies, using and modifying them in accordance with requirements.

The projects described can demonstrate how far ancient landscape reconstruction can go, and how reliable and valid they can be, if based on an explicit interpretation process (Pescarin – Ruzza 2004; Guidazzoli *et al.* 2004; Pescarin 2000; Pescarin *et al.* 2007; Pescarin 2007; Forte *et al.* 2005: 79–92; Forte *et al.* 2006).

Chapter 3

Archaeological Landscape Reconstruction: Mapping the Space

Every project concerning ancient landscape reconstruction should start from the archaeological landscape, that is the contemporary landscape, considered in its diachronic dimension, consisting of monuments, sites, scattered remains, signs of agriculture, natural characteristics and so on. It is therefore necessary to start "mapping the space".

As we outlined in chapter one, the archaeological landscape is made up of several elements (natural, anthropic material and immaterial, etc.) and by the relations which connect these elements.

The reconstruction process does not involve only "visible" aspects (reality-based reconstruction), but also "invisible" ones, such as cultural and relational aspects, or all those elements that might be deducted in the interpretation process or discovered with the use of specific technologies. In the past, any visualisation was "restricted" by its scale: objects beyond a certain threshold, unable to be represented on a map, were drawn at a certain scale. Moreover, the territorial scale was usually treated separately from the intra-site scale. Sites or monuments were often reconstructed as single detailed monographic studies, rarely even placed in relation to their absolute geographical dimension (see chapter 1). Also in terms of computing capabilities, the two realms, territory and site, were treated separately in an attempt to solve the various problems arising, and in developing different technologies to acquire them. Today, there is increasing interest in a sort of "global" integration, driven also by the technical capabilities of new hardware and software: terrestrial and aerial 3d scanners, the developed potential of photogrammetric applications, the accuracy of new cameras and DGPS, etc. integration of dataset at different resolution is leading, slowly, to new problems, in terms of precision, data structure, etc., as has emerged from projects such as Virtual Rome or 3d-ARCH (Pescarin *et al.* 2008; Remondino *et al.* 2009 and *Fig. 3.1*). How can we visualize models with different resolutions, and built to different scales, in a single frame? Can we merge aerial views with the internal reconstructions of monuments? Should we express the difference explicitly or had we better develop more homogeneous landscapes? Could these be threshold visualised, e.g. through transition surfaces (Agugiaro – Kolbe 2009), and how?

Also from a "perceptive" point of view, this problem has great impact. The process will probably remain slow, at least until high quality acquisition devices, such as 3d scanners, though already considered mature, become more affordable for Cultural Heritage and Environmental applications (Cignoni – Scopigno 2008).

*Fig. 3.1. High-resolution 3D model of Valer Castle (Trentino region, NE Italy) inserted in the landscape model of the region available in GoogleEarth (*REMONDINO *et al.* 2009).*

A common characteristic of all this data is *spatial dimension*. The geo-location of all elements, although often neglected, is central. For this reason it is important to have a *basic* knowledge of archaeology, cartography, image processing and 3d modelling issues. These are very different fields that commonly make use of different languages, different approaches, and produce different results. Landscape modelling requires us to manage and interconnect them. In spite of the fact that, in the development of the specific tasks required by a project, these fields should be approached by specialized experts, results can be more satisfactorily obtained if the latter have a *basic* knowledge also of interconnected disciplines.

The following sections will analyse various techniques and methodologies for data acquisition and archaeological landscape reconstruction. Communication and final visualisation will be further described in chapter 5.

Table 3.1 proposes a sequence of activities related to the creation of the observed landscape.

General activities	**Methodology/data/sources**
GIS project creation	GIS software selection, projections and coordinate system, thematic layers and levels of detail definition
Generation of contemporary DTM	Elevation data mosaic
Processing of geoimagery	Geoimagery georeferencing, mosaic, equalization (satellite, aerial, etc.)
Import (in the GIS) of acquired and georeferenced data	Archaeological map, historical maps, soil maps, etc.
Overlay with acquired data on the field	Data acquisition on site with integrated technologies (GPS, 3d scanner, etc.) and creation of detail survey of the monuments
Identification of critics in the datasets	Data validation based on the comparison with all dataset
Data correction and new layers creation	Data correction and creation of new vector layers (GIS and modeling software)
Final thematic layers creation	Export of useful thematic layers: hydrography, road system, etc.
3d terrain generation	3d model generation of the territory, based on processed geoimagery and DTM
Vegetation generation	2d/3d vegetation integration at different details
3d models integration	Further postprocessing of 3d models and integration on correct location (lat/long/elev)

Table 3.1. Steps of archaeological landscape reconstructions.

3.1 Visible landscapes

The reconstruction of visible landscape is obtained mainly with *mapping* activities. The first step is to verify the existence of available data, such as cartographic maps, thematic maps (vegetation, geology, etc.), aerial or satellite images, elevation models, planimetries, sections, etc. or any other sources useful in the construction of the basic digital dataset. A basic dataset is made up of at least one *geoimage* (or mosaic of geoimages), and one *Digital Terrain Model*.

Thematic layers, vector or 3d models, are complementary. In the past, the usual way to obtain this data was to find printed images or a paper map, scan them, georeference and orthorectify them, and finally manually digitize contour levels or elevation points in order to produce DEM, or other required themes.

These datasets can easily be purchased from specialized companies at various rates, mainly depending on data resolution. In some cases, they can be freely downloaded from on line repositories, such as Global Land Cover Facility (GLCF) or USGS[8].

GLCF is a centre for land cover science focused on the analysis of cover change through remote sensing. It is an on line database of many satellite images and elevation models, accessible through the Earth Science Data Interface (ESDI: *Fig. 3.2*)[9]. Here, Landsat series imagery can be downloaded: Landsat MSS (Multi-spectral Scanner), TM (Thematic Mapper), and ETM+ (Enhanced Thematic Mapper Plus). The highest available resolution is of 30 mt (15 mt for the Panchromatic[10] L7: *Table 3.3*). There are today many types of satellite images,

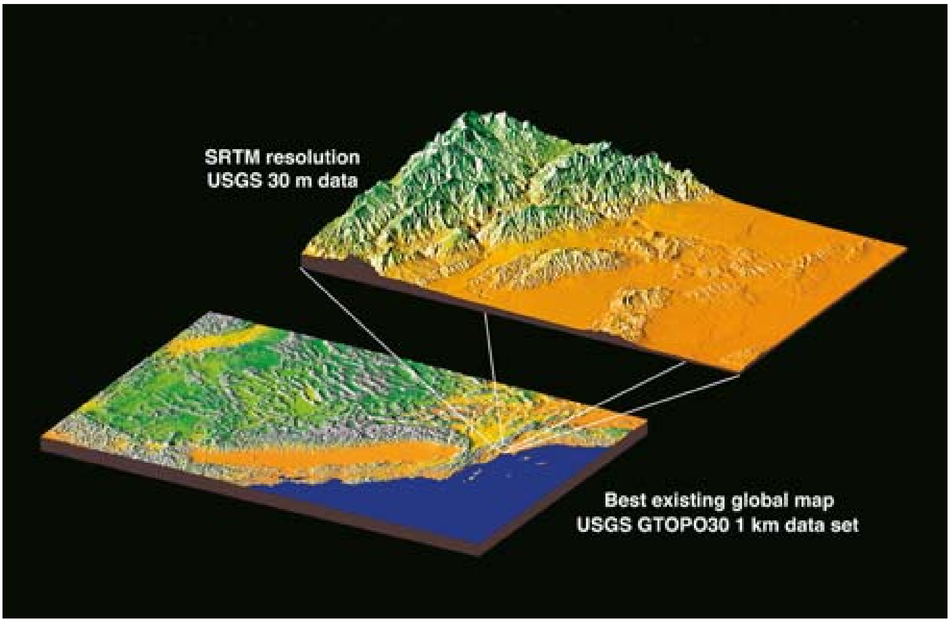

Fig. 3.2. SRTM and USGS Gtopo30 (1 km dataset).

8 http://edc.usgs.gov/products/elevation/
9 http://www.landcover.org; http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp
10 Panchromatic: Imagery Single-band or monochrome imagery.

with a variety of characteristics. Knowing these characteristics helps to find the right source for a project. *Table 3.2* reports available images on the market, with indications of their main use and resolution. Other available imagery products are aerial ortho-photos[11].

Sensor	Description	Resolution
ALOS /2006	It has 1) Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for DEMs mapping, 2) Advanced Visible and Near Infrared Radiometer (AVNIR-2) for land coverage observation, 3) Phased Array type L-band Synthetic Aperture Radar (PALSAR) for land observation.	2.5 m to 10 m
ASTER /1999	It monitors cloud cover, land temperature, land use, vegetation patterns, etc. The multispectral images are in 14 different colours, used for change detection and land surface studies including vegetation and ecosystem dynamics.	15 m to 90 m
CARTOSAT-1 /2005	Built by the Indian Space Research Organization as part of the Indian Remote Sensing series (IRS). It has 2 panchromatic cameras that take black-and-white stereoscopic pictures in the visible region of the electromagnetic spectrum, used to create accurate 3d maps.	2.5 m
CBERS-2 /2003	Born of a partnership between Brazil and China. Used for deforestation and fire control, soil occupation, etc. It includes cameras for optical observations.	20 m to 260 m
CORONA	photographic surveillance satellite used from the late 50's through the early 70's, after de-classification 860,000 images are available through Earth Explorer[5]	2.75 m to 1.8 m
EROS /2000	provides 1.8 meter panchromatic imagery (areas: 12,5x12,5 km)	1.8 m
FORMOSAT-2 /2004	It is used for land distribution, natural resources research, forestry, environmental protection purposes.	2 m to 8 m
GeoEye-1 /2008	Capable of acquiring image data at 0.41 meters panchromatic (B&W) and 1.65 meters multispectral resolution.	0.41 m to 1.65 m
GeoEye-2	Forthcoming	0.25 meter
IKONOS /1999	Used for urban and rural mapping of natural resources, agriculture and forestry analysis. Available Ikonos Stereo Images for the production of Digital Surface Models (DSM's) or Digital Elevation Models (DEM's) with postings of ≤5 m.	0.82 m to 3.2 m

11 Examples at: Terraserver (www.terraserver.com); FlashEarth (www.flashearth.com); DigitalGlobe (www.digitalglobe.com); TerraFly (www.terrafly.com); Italian CGR (www.cgrit.it), and in many other countries.

12 http://edcsns17.cr.usgs.gov/EarthExplorer/

Sensor	Description	Resolution
IRS	Acquired over the visible green to near infrared	5.8 m
LANDSAT 7 + ETM /1999	First earth observation satellite. It has seven spectral bands that range from visible to thermal infrared regions	30 m
QuickBird /2001	High resolution satellite: Pan: 61 cm (nadir) to 72 cm (25° off-nadir); MS: 2.44 m (nadir) to 2.88 m (25° off-nadir)	0.61 to 2.88 m
SPOT-5 /2002	It has VEGETATION 2 instruments which provide continuity of environmental monitoring. An image covers 60 x 60 km or 60 km x 120 km, and there is good balance between high res. and wide-area coverage	5 m to 10 m
WorldView-1 /2007	A high-capacity, panchromatic imaging system features 0.5 m resolution	0.5 m
WorldView-2	Forthcoming: it will provide a high resolution Panchromatic band and 8 Multispectral bands	1.8 m to 2.4 m

Table 3.2. List of main satellite imagery. (Source: Satellite Imaging Corporation).

Satellite	Sensor	Spectral Range	Band #s	Scene Size	Pixel Res
L 1-4	MSS multi-spectral	0.5–1.1 µm	1, 2, 3, 4	185 X 185 km	60 m
L 4-5	TM multi-spectral	0.45–2.35 µm	1, 2, 3, 4, 5, 7		30 m
L 4-5	TM thermal	10.40–12.50 µm	6		120 m
L 7	ETM+ multi-spectral	0.450–2.35 µm	1, 2, 3, 4, 5, 7		30 m
L 7	ETM+ thermal	10.40–12.50 µm	6.1, 6.2		60 m
L 7	Panchromatic	0.52–0.90 µm	8		15 m

Table 3.3. List of Landsat imagery sensors.

DTMs with grid sizes of 500 up to 1 m are increasingly available for different parts of the globe, such as through the US Geological Survey (USGS), the Ordinance Survey, the Italian Istituto Geografico Militare (IGM)[13] or Parma CGR[14] repositories. Low resolution Digital Terrain Models are also available on line from the USGS site, e.g. the GTOPO30, available since 1996 thanks to the work of the USGS Center (recentely also higher resolution ASTER Global DEM: http://www.gdem.aster.ersdac.or.jp/). This global DEM, based on the Shuttle Radar Topographic Mission, has horizontal grid spacing of 30 arc seconds (approximately 1 kilometer) deriving from several raster and vector sources of topographic information. Unfortunately the absolute vertical accuracy of the elevation data is 16 meters (at 90% confidence). Most of the available DTM are the result of photogrammetric data capture, performed

13 http://www.igmi.org/

14 http://www.cgrit.it/prodotti/modello_digitale.htm

with stereoscopic interpretation of aerial or satellite images through manual or automatic systems. DEMs can be acquired also by digitizing contour lines on old topographic maps and also by conducting ground surveys, with GPS devises[15].

When it is impossible, in fact, to use or find the desired spatial datasets, or when more details are needed, we can still obtain them by planning *fieldwork* and organising a direct acquisition. Traditionally, archaeology has used specific investigation techniques such as excavations and field surveys (Renfrew – Bahn 1981). Technology today offers a wide range of techniques to acquire, model and visualize archaeological landscapes with many different scales and varied resolution, limiting excavations to few important cases.

Archaeological and environmental data are acquired by means of many kinds of survey and analysis, obtained with terrestrial or aerial acquisitions, direct or indirect. Usually it is convenient to use them in integration, in order to get better results on large-scale reconstructions for both intra-site and inter-site aspects. Terrain acquisitions can be used for detailed cartography, planimetric restitutions and the 3d modelling of sites, monuments, right up to single remains. On the other hand, aerial acquisitions can provide their context and location.

The main aim, for all of the techniques described below, is to acquire information to produce a *model* of the archaeological landscape. There are basically two types of system in the creation of 3d models. The first is based on measurements, acquired either with contact or non-contact techniques. The second one doesn't use measurements, e.g. in the case of computer graphics (through 3d modelling software such as 3D Studio Max or Maya, etc.) or surveying (Remondino – El-Hakim 2006).

3.1.1 Terrestrial acquisition

Terrestrial acquisitions are used for reality-based modelling. They make use of several different techniques and devices, and the most widely used are: GPS, laser total stations, 3d scanners and digital cameras for photogrammetric purposes. Instead of entering into a detailed description, I will provide general information with bibliographic references.

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[15] There are several archives of old aerial or satellite images in many countries, such as Historical Aerial Photography in UK (www.oldaerialphotos.com) or the Italian Fototeca (www.iccd.beniculturali.it/Istituto/Organizzazione/aerofototeca).

The widespread use of *Global Positioning Systems (GPS)*[16] provides many opportunities for the definition of the position of point on Earth surface and for the collection of elevation data, producing reference points for integrated surveys or detailed micro-topographic surveys. The introduction of *Differential GPS* (DGPS) has particularly increased survey accuracy. This enhancement of the traditional GPS, originally developed to solve the problem of Selective Availability (SA), can obtain better results, thanks to the use of a ground-based reference stations network, in charge of correcting the satellite signal through an in-built UHF band radio modem. Estimated accuracy can be under 10 cm. Differential GPS measurements can also be computed in *real-time* by some GPS receivers, when the correction signal is received using a separate radio receiver, as in the case of *Real Time Kinematic (RTK)* surveying.

There are many advantages to using GPS. For example, it is possible to *selectively* acquire position or elevation information. This operation can be further simplified by the use of PDAs, or other portable PCs, with GIS software installed in it, connected to the GPS. In this way it is possible to directly create a GIS in the field, at the same time controlling accuracy and the results of the work in progress (*Fig. 3.3*). Nevertheless, the use of this system to create Digital Terrain Models seems to have been made obsolete by 3d scanners, for speed and precision. Yet despite its well known problems, GPS remains the fundamental tool to *geo-locate objects on the earth*. For this reason it has been integrated into other kinds of acquisition devices, such as Total Station or Laser Scanner. Recently the market also offers a combination of Laser Scanner and GPS mounted on a car, for mobile mapping.

There are other techniques that don't require direct contact with the object and use various systems to obtain a measurement, such as light, X Rays, microwaves (i.e. radar), or ultrasounds.

Light is used by *Range-Based Modelling* (RBM) and also by *Image-Based Modelling* (IBM), through active sensors (3d scanner, laser total station) or passive sensors (photogrammetry or shape recovery from edges, texture, or shading) (Remondino – El-Hakim 2006).

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[16] Some references to GPS in archaeology: Wheatley, D. – Gillings, M. *Spatial Technology and Archaeology*, London-New York 2002; Campana S., Sordini M., *Laser Scanner e GPS in archaeologia: geografia dei servizi e delle risorse in Internet*. In Laser Scanner e GPS. Paesaggi archeologici e tecnologie digitali 1 (Campana S. – Francovich R. eds.), Firenze, 2006.

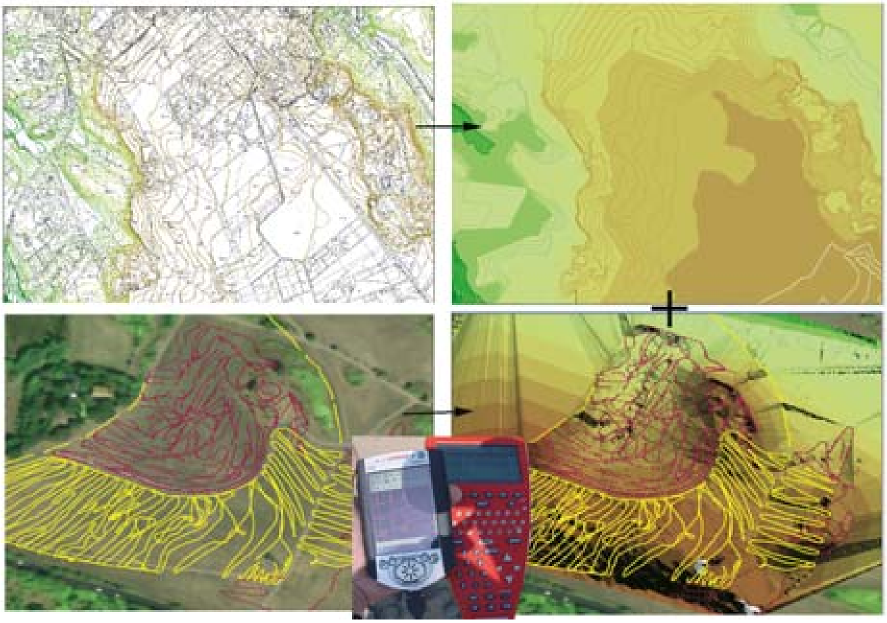

Fig. 3.3. Appia field survey with DGPS connected to PDA.

3d scanner technology is relatively widespread in the field of archaeology and is an example of RBM[17]. It uses active sensors, which acquire objects in 3D, through triangulation or time-delay (TOF) methods. How do they operate? “They shoot some sort of light over the surface of the artefact and reconstruct its geometry by checking how the light is reflected by the surface”. Time-of-Flight (TOF) scanners are largely employed in landscape reconstruction. They “compute the time elapsed between the emission of a pointwise laser beam and the detection of the return beam reflected by the surface” (Cignoni – Scopigno 2008: 3). They are generally used for large-scale acquisition projects. Triangulation 3d scanners use a different technique: they project a single spot or a pattern on to the object. Reflected images are acquired by an imaging device nearby, allowing you to compute the 3d position of the points by geometric triangulation. These scanners are commonly used for small-scale objects.

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[17] An overview on 3d scanning is offered by Curless, B. Seitz, S., *3d photography.* In ACM SIGGRAPH Course Notes, Course 19. There is a review article on 3d scanning in the Cultural Heritage field: Cignoni, P. – Scopigno, R. *Sampled 3d Models for CH Applications: a viable and enabling new medium or just a technological exercise?* In the ACM Journal on Computing and Cultural Heritage, Vol. 1, No.1, Art.2, Jun.2008.

A typical sequence of activities include: scanner acquisition in the field, post-processing in the lab where Range-Maps[18] can be aligned, merged, edited and simplified), colour and texture mapping. These activities are supported by commercial software, although academic tools can present more advanced features[19]. There are several advantages in the use of RBM for landscape acquisition and reconstruction, such as the relative speed in the acquisition process and the accuracy of acquired data and of the final 3d model. Unfortunately there are also many disadvantages, due to the still very high cost of devices and of commercial processing software, to the complexity of post-processing, and to difficulties in managing very big 3d datasets. There is another important reason why this sector is still not found very widely, although successfully tested, in landscape archaeology; this is the "monolithic" way data are captured, not allowing an easy object extraction and selection. These problems emerge increasingly in aerial acquisitions[20].

3.1.2 Photogrammetry and 3d automatic modelling

An example of *Image-Based Modelling* (IBM) is Photogrammetry[21]. It is commonly used to document, reconstruct, and visualise sites. It is a "measurement technique" that allows "the modelling of a 3d space using 2d images" (Kasser – Egels 2002: 1), through the identification of corresponding points in the images (automatic, semi-automatic or manual). A mathematical model can be used for this purpose, or other methods such as shape from shadows, from texture, from specularity, from contour or from 2d edge gradients (Remondino – El-Hakim 2008: 271). Given the specific purpose of this book, I just mention some techniques useful for the reconstruction of 3d territories. Generally different

[18] *Range Maps* are single views of the acquired object that encode sampled points' geometry (Cignoni – Scopigno 2008: 4).

[19] For a review of the software available on the market: Campana – Sordini 2006 (cited). Examples of commercial software are: RapidForm, Geomagic, PolyWorks. Examples of academic tools are: MeshLab, TexAlign, Vrippack, Volfill, PointShop, Scanalyze.

[20] Many of these problems are handled in: *Laser-Scanners for Forest and Landscape Assessment*. In Intern. Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences (Thies, M. – Koch, B. – Spiecker, H. – Wienacker, H. Eds.), Vol. XXXVI, PART 8/W2, 2004.

[21] A good general review can be found in: Remondino – El-Hakim 2008 and specifically directed at site reconstruction, in Grün 2000.

views are needed to obtain a 3d model, although some attempts have been made in the direction of using a single image (El-Hakim 2001).

3.1.3 Aerial acquisitions

The reconstruction of the archaeological landscape requires the development of models representing the territory (DTM and Geoimages), its natural aspect, the identification of preserved archaeological sites, and also of anthropic/natural traces. We have seen that sources can be purchased or built in various ways. This section is dedicated to those techniques which can be used to obtain aerial bi- and three-dimensional representations of a territory and its characteristics, through the acquisition of 2d images or 3d datasets.

Acquisitions can be taken with different sensors mounted on satellite, airplane, kite, balloon (*Fig. 3.4*), small helicopter, plane or paramotors. While it's impossible to have control over satellite programs, we can, on the other hand, directly plan air-campaigns, organising and participating in flights over a

Fig. 3.4. Grottarossa acquired with an aerostatic balloon and reconstruction of the archaeological landscape.

territory, when this is possible, or using smaller devices, remotely controlled[22]. They provide data on the partial or complete extent of a territory, enhancing specific spatial and spectral characteristics. The detail is usually lower than that required for terrestrial acquisitions. For this reason it is good practice to integrate different models at various scales and resolution.

Since 1960, *aerial archaeology* is considered an important field for the interpretation of archaeological landscape, and not just for its representation. It uses a variety of techniques, according to the goal of the project and the kind of sensors (passive or active) mounted on board. It is characterized by two phases: the "observation and photography in or from the air" and the "interpretation of the images" (Bourgeois 2005: 15).

Analysis	**Aerial photo**	**Corona**	**Landsat**	**Spot**	**ASTER**	**QuickBird Ikonos**	**SRTM**
Visual interpretation	x	x	x	x	x	x	x
Contrast enhancement	x	x	x	x	x	x	
Georeferencing	x	x	x	x	x	x	
NDVI			x	x	x	x	
Classification			x	x	x	x	
Thresholding			x	x	x	x	
Principal Components Analysis			x	x	x	x	
Land Use	x	x	x	x	x		
DEM creation		x		x	x		x
Hyperspectral analysis					x		
Filtering			x	x	x	x	x

Table 3.4. Technique of geoimage analysis as referred to satellite imagery.
(source: Parcak 2009: 82)

Passive sensors, such as cameras, can be used both for vertical and oblique photography. *Vertical acquisitions*, usually taken with cameras pointing straight down at the ground and fitted inside an aircraft, are used to produce orthographic images that may be useful for many archaeological purposes, such as topography (Wilson 2000: 32; Picarreta: 1987: xi). Unfortunately, even if the photo is taken

[22] An historical overview is available in: Bourgeois 2005. A review of several techniques can be found in: Picarreta 1987; Bewley 2002.

with great care, it still retains some deformations. Usually what is acquired isn't a single picture, but a series of overlapping photographs. These can be used for any photogrammetric purpose, such as the creation of three-dimensional models of the landscape. Models like these reproduce what is visible in the aerial images and at the same resolution, that is to say: the terrain and all the structures on it, such as trees, buildings, etc. Various measurements can be achieved: from single-point measurements up to a regular terrain model, such as DSM, Digital Surface Model (Kasser – Egels 2002: 169–190).

Oblique photography is very useful for landscape interpretation and is much more used directly by archaeologists. It is a well known technique enabling you to recognize patterns on the ground which are otherwise impossible to see from the ground. Although in fact it gives a "distorted" representation of the features (perspective deformation), it is employed by archaeologists in the interpretation process. Through photo-interpretation, in fact, it has been possible to identify several archaeological sites, networks of tracks, fields and settlements, all over Europe, and of many historical periods, from the Neolithic onwards. An example of the use of this technique is the identification and reconstruction of an Iron Age fort at Bloodgate Hill, South Creake in North Norfolk (*Fig. 3.5*)[23].

In photo-interpretation, most of the traces originally derived from excavated features, such as boundaries, pits or post holes, can be seen as soil marks (variations of colour and texture of the soil) or crop marks (differential crop growth: positive marks over a ditch or negative ones over wall or stone foundations). More consistent remains on the ground can be recognized as earthworks. From the air, these features appear as dots or lines or areas of differently coloured crops and soil. Since these traces cannot be easily dated, it is necessary to verify them on the ground and integrate as much information as possible: some crop marks, in fact, do not belong to archaeological features, but are formed, for example, by geological features or modern agricultural practices (Wilson 2000: 163–209). Another problem is correcting those images to draw the feature in the GIS, as vector layer. Although there are several softwares that can perform such transformations, two specific programs have been developed: Aerial and AirPhoto, included in the Bonn Archaeological Software Package (BASP)[24].

[23] Wade-Martins, P. (ed.), 1997. Norfolk from the Air, plates 12–15. And: http://www.norfarchtrust.org.uk/bloodgate/index.htm

[24] To download the software: http://www.uni-koeln.de/~al001/airdown.html

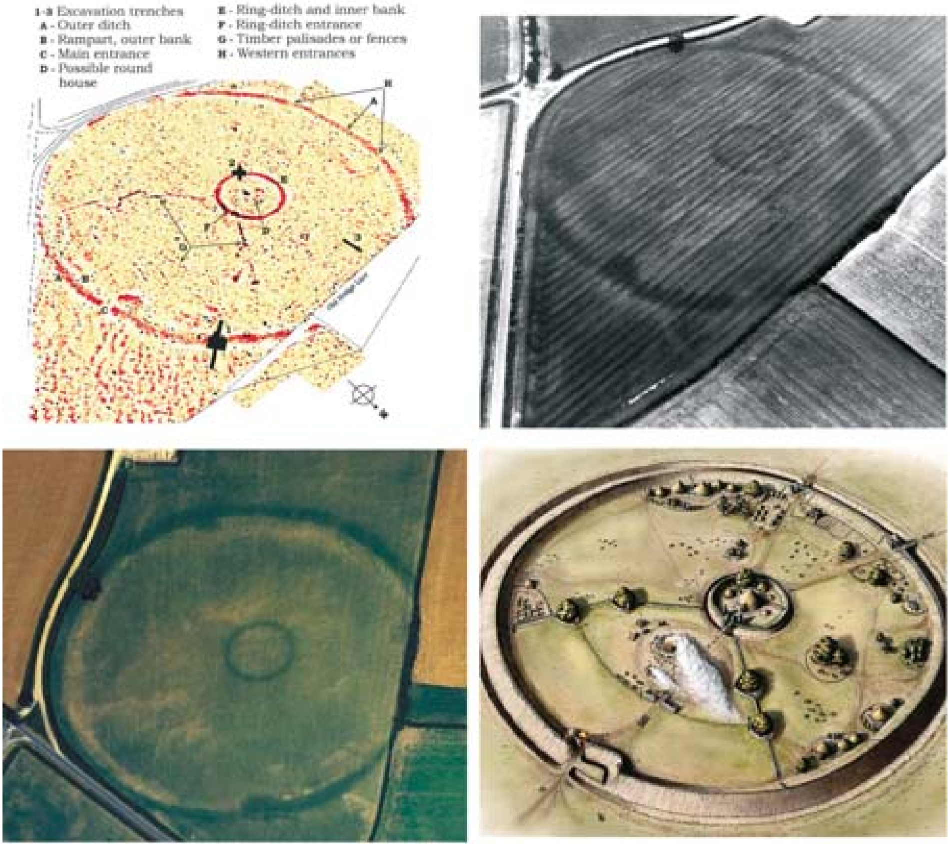

Fig. 3.5. Bloodgate. Left: Air photo of the fort showing as soil marks and crop marks; Right: Geophysics prospections and Artist's Reconstruction of the Fort Interior. (http://www.norfarchtrust.org.uk/bloodgate/cropmarks.htm and /reconstruction.htm)

In many countries there are accessible aerial archives, such as the atlas of oblique photos of the University of Siena in Italy[25]; the Austrian archive[26]; several archives in the UK, Scotland and Wales[27], etc.

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25 http://shaq.archeo.unisi.it/oblique/

26 http://www.univie.ac.at/Luftbildarchiv/archiv/aa_ent.htm

27 Collection at Cambridge University (http://www.uflm.cam.ac.uk), the National Library of Aerial Photographs (http://www.english-heritage.org.uk), the RCAHMS in Scotland (http://www.rcahms.gov.uk), the RCAHMW in Wales (http://www.rcahmw.org.uk), the Aerial Reconnaissance Archives of the University of Keele with several RAF World War 2 photographs (http://www.evidenceincamera.co.uk).

Active sensors can be mounted on aeroplanes or satellites. An example of these sensors are those used for *airborne laser scanners*. Lidar (Light Detection and Ranging or Laser Imaging Detection and Ranging) is a well-known technology, and although not so widely used, it has gained general acceptance as an accurate and rapid method for three-dimensional surveying of the Earth's surface[28]. The Lidar system has several advantages, such as the ability to view subtle landscape changes and high resolution feature detection (resolution of 3 cm). It can be combined with vertical survey cameras or airborne digital sensors, to record the entire landscape. Its main disadvantage, on the other hand, is its high cost, together with the fact that it is quite impossible to fly in every place or country (Parcak 2009: 76–77). Another problem of aerial laser scanning, as mentioned for terrestrial acquisitions, is the way data are acquired, in a "monolithic" way. The entire visible information is captured and stored without distinguishing vegetation, buildings, etc. This often means a long post-processing work to clean up, divide up and sometimes re-model part of the final 3d mesh. New algorithms and approaches to this problem are currently debated in specialized conferences.

There are other airborne sensors used in archaeology, such as the *RadarSat, AirSar (Synthetic Aperture Radar)* or *thermal radiometry*. It can acquire at a resolution of up to 3 meters and identify, no matter the weather conditions or darkness, pathways or sites even under dense vegetation. Unfortunately even this system is quite expensive[29]. Hyperspectral acquisitions are quite useful in various landscape applications, for example in the definition of natural features, such as vegetation (the classification and mapping of species). They are used, in combination with fieldwork and ground analysis, for the identification of culture characteristics (density, humidity, etc.), the analysis of relations between vegetation and geomorphology, and the monitoring of parks. In landscape archaeology they have been used to identify palaeo-channels or structures hidden under the ground or even to characterize superficial materials.

3.2 Invisible landscapes

Excavations aren't the only way to define what has been preserved under the ground. There are several techniques that can help us to analyse ancient natural or

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28 A tutorial can be found at: http://home.iitk.ac.in/~blohani/LiDAR_Tutorial/Airborne_AltimetricLidar_Tutorial.htm

29 http://www.space.gc.ca/asc/eng/satellites/radarsat1

anthropic remains. Geophysics offers several methods to obtain information from underground (Campana – Piro 2008).

Geoarchaeology can also be successfully employed to identify the geological, lithological, and geomorphological characteristics of a territory and to understand how or when its shape (geomorphology) has changed through time (Cremaschi – Baroni 2000; Goldberg – Macphail 2006; Panizza 2005).

Another field that has been integrating increasingly into landscape reconstruction is *Paleobotany*. Vegetation biologists can analyse, within specific required conditions (such as the presence of water, or sediments), the remains of seeds or pollen and thus identify plant species, crop cultivation or deforestation, in a certain area and over a certain period of time (*Table 3.5*).

Type of remain	Type of sediment	Obtainable knowledge
Soil	All	Type and environmental characteristic of the deposit
Pollen	Buried surfaces, deposits with traces of water	Vegetation, land use
Phytolith	All	Vegetation, land use
Bacillariophyta	Submersed deposits	Level of water salinity and pollution
Vegetable not burnt remain	Dry and drenched	Vegetation, diet, natural material used in constructions
Vegetable burnt remain	All	Vegetation, diet, natural material used in constructions
Wood	Dry and drenched	Dendrochronology, climate, materials and building techniques

Table 3.5. (from: Renfrew – Bahn 1991: 223).

The first invisible landscape is the one that cannot be seen. Fortunately in recent decades detectors have been developed to see for us, where we ourselves can't see. This is the subject of the *Remote Sensing* field[30]. These detectors can be mounted on aeroplanes, satellites or other devices, but also used for terrain applications. The basic principle is well known: the earth reflects the spectrum

30 Wiseman, J. – El-Baz, F., *Remote Sensing in Archaeology*, Springer, 2007; Williamson, A. – Nickens, P. R., *Science and technology in historic preservation*, Ed. Springer, 2000; Miller W. F. – Sever T. L. – Lee D. (1991). *Applications of ecological concepts and remote sensing technologies in archaeological site reconnaissance*. In: Behrens, C. – Sever, T. (Eds.) Applications of space-age technology in archaeological site reconnaissance 121–136. A good tutorial can be found in http://www.cnr.berkeley.edu/~gong/textbook/

of sunlight, providing us with a lot of information about the composition of this surface, and revealing also traces of past human activities. The surface is made up, in fact, of elements which emit heat at various levels, visible to sensors such as *multi-spectral scanners*. Differences in the soil or in vegetation can be detected by variation in temperature. The analysis of infra-red radiation at a variety of wavelengths, for instance, can help in identifying pathways in the landscape, irrigation ditches, buried stone walls (stone can absorb more heat with respect to its surroundings). Moreover, analysis through radar sensors allows us to study the ground even if it is covered by clouds or canopies or hidden by darkness. Several commercial softwares have developed features to manage these analyses, identifying distinctive "signatures" characterizing specific features[31].

The basic work one can do on satellite images is *band combination* (*Tables 3.2* and *3.3*). Each image, in fact, is characterized by several bands, each one representing a range of the electromagnetic spectrum (Aster: 15, Landsat ETM+: 8; Spot: 4, etc.). We should in fact consider various parameters when we plan to buy geoimagery, such as: spatial resolution, spectral bands, program history, image surface area, price and licensing. If we want to obtain, from a Landsat image, a true-colour or visible image, we should for instance combine bands 3, 2 and 1, assigning respectively a Red, Green and Blue value. The combinations of these bands enables us to distinguish vegetation, water or geological features better. These distinctions can also give interesting inputs to identifying archaeological features, often related to changes or discontinuities. Some useful combinations (Landsat imagery) in archaeology are:

- bands 3, 2, 1 (RGB): visible image, useful to identify details;
- bands 4, 3, 2 (RGB): false-colour image (pixel values not representing the true colour photo) where vegetation is enhanced, appearing in red;
- bands 5, 4, 3 (MIR, NIR, Red) to highlight differences between areas with or without vegetation;
- bands 4, 5, 6 (RGB): useful to identify hills, barrows etc.;
- bands 4, 7, 5 have been used to identify, for instance, rammed earth;
- IHS Fuse of Bands 5,4,3: used to incorporate Band 8 of a Landsat TM image (15 m Panchromatic) to obtain a 'false' colour image of a 15 m resolution.

[31] ErMapper, GRASS, etc. (Appendix B)..

Other remote sensing analyses useful for archaeological landscape reconstruction are (Parcak 2009: 91–99):

– *Normalized Difference Vegetation Index* (NDVI): used to measure, in different images for different times of the year, the health of vegetation possibly affected by buried archaeological remains, or the outline of a settlement, or a ditch. This has been used, for instance in the Jure Vetere (*Fig. 1.1*).
– *Classifications*: to identify land cover or other kinds of clusters. It can use "Supervised" (human-assisted) and "Unsupervised" techniques. The former requires the control and identification on the ground of "training regions", that are then reported in digital classification in order to define different cells better. "Unsupervised" classification, on the other hand, creates clusters of multispectral images, each one representing similarities in the spectral space (Forte 2003b: 85).
– *Thresholding image segmentation*: classification in which it is possible to specify parts of image values that remain visible.
– *Principal Component Analysis* (PCA): helps in clarifying classifications and band combinations. It has been used in archaeology for better feature recognition.
– *Land Use Land Cover Changes* (LULC): land use variation analysis as observed in different time periods.
– *DTM modelling:* obtained from SRTM data, stereo-pair SPOT, ASTER or stereo CORONA images.
– *Hyperspectral analysis:* useful in case the spectral signature of a specific material (such as stone) is known. Hyperspectral satellites datasets are needed, such as OMIS (Optical Monitor Imaging Spectrometer) sensors.
– *Radar analysis*: SAR or LIDAR techniques.

In the Aksum project, directed by the Oriental University of Naples and Boston University, with the cooperation of CNR ITABC, remote sensing analysis was employed to identify archaeological features (Forte 2003b: 81–93; Bard *et al.* 2007). This project aimed at the reconstruction of the archaeological landscape of Aksum (Ethiopia), the capital of one of the most powerful Red Sea kingdoms during the 1st millennium AD, and at its visualisation in a Desktop Virtual Reality (DVR) application. The aim was achieved thanks to an integration of fieldwork, ethno-anthropological investigations, paleo-environmental analysis, aerial photo interpretation and remote sensing. Thanks to the multispectral classifications of a Spot XS image, various thematic maps (soil use, vegetation, geomorphology, and archaeology) were obtained, and an interpretative map was developed. This was used in the reconstruction of the archaeological landscape which was used to build a VR environment (*Fig. 3.6*).

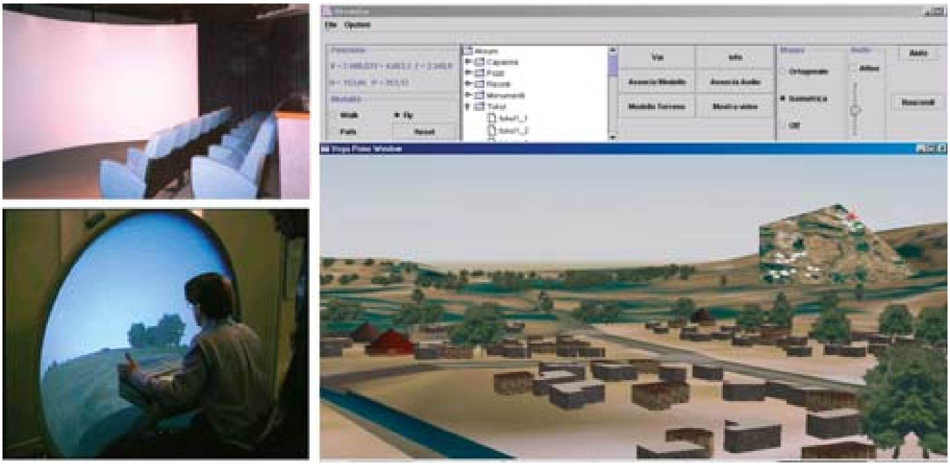

Fig. 3.6. Aksum: Photo of the territory – Remote Sensing analysis (supervised classification) – Archaeological Landscape Reconstructed.

3.3 Post-processing

At this point, acquired spatial data needs to be further processed (*Table 1.2*). The goal in fact is to manage and visualize them, developing a model of the archaeological landscape, made up of its anthropic and natural features, but also of the interpretative analysis carried out. This model will also be the reference point for any *interpretation layer* emerging out of the post-processing work. At the end of the process, in fact, on top of the reconstructed archaeological landscape, a "*mapscape*" will be created. It will represent all the interpreted features, identified after remote sensing analysis or aerial photo interpretation, and will be the basic source of potential ancient landscape reconstruction.

Since all datasets should be considered in their spatial dimension, every reconstruction process starts by building a GIS project, which will be the reference point for all activities, continuously updated.

Geographical Information Systems (GIS) are tools, or rather sets of instruments, initially developed by and for the army, for spatial dataset management. They are now considered essential also in archaeology, since they are used for many activities: archiving, analysing, querying, or just as reference and middleware. They have been described as “ the most powerful technological tool to be applied to archaeology, since the invention of Radiocarbon dating” (Maris – Te Boekhorst 1996, cited in Conolly – Lake 2006: 5). GIS describes space in terms of location and attribute. Each element inside a GIS needs two descriptors, which indicate what it represents (attribute) and where it is located (location), as referred to a space, either absolute or relative (Conolly – Lake 2006: 3–4). There is an extensive bibliography specifically regarding the use of GIS in archaeology (Wheatley – Gillings 2002; Lock 2003; Lock – Stančič 1995).

GIS is also basic during the reconstruction of archaeological and past landscapes. It can manage to overlay various pieces of information and, most importantly, it enables to compare data and carry out calculations on different parameters (grid calculations, vector analysis, etc.). In Appendix B there are specific GIS analyses, described in detail. The entire reconstructive process is based on GIS analysis, as described in Chapter 4.

WebGIS are commonly considered as Internet “extensions” of traditional GIS, although they often do not have the same analytic potential, but are used as digital on line archives dedicated to geo-spatial data, such as archaeological maps, digital images, grids and vector data. New projects are under way whose goal is precisely to extend GIS potentiality, mainly boosting editing and analysis capabilities. The MapServer Open Source platform, for instance, has several projects of tools specifically thought out for these purposes[32]. A project such as Fasti on Line is a webGIS, built on MapServer technology. It derives from *Fasti Archaeologici (*1946–1987) edited by AIAC. It allows registered archaeologists autonomously to add references to, and the location of, archaeological excavations in Italy, Albany, Bulgaria, Macedonia, Malta, Morocco, Romania and Serbia[33]. Other Open Source projects, whose evolution could offer interesting applications to landscape reconstruction, are: *Ka-Map*, an application Server Open Source[34]; *Embrio*, a web interface which combines map interactive visualisation, and PyWPS, enabling GRASS and QGis integration and real time analysis, such as Viewshed, Slope, and Cost Distance[35]; *OpenLayers*, a javascript tool which enables the use of dynamic maps and layered dataset, located in distributed

32 http:// www.mapserver.org
33 http:// www.fastionline.org
34 http:// ka-map.maptools.org
35 http:// pywps.ominiverdi.org/demo/embrio/ka-map/htdocs/index_wps_qgis.html

servers and loaded "under" personal geographical data[36]. This last example, as in the case of GoogleMaps, opens up several possibilities in the field of landscape reconstruction, since it allows the sharing of various data, without actually "moving" them, but maintaining them in original servers.

GIS or webGIS are used to store a variety of spatial information during its process (raster, DTM, vector), to perform analysis, and finally to export spatial dataset to be used in the 3d modelling process. As mentioned, a basic spatial dataset is made up of at least one geo-referenced raster image and one digital elevation model of the terrain.

Generally, architecture or object modelling is carried on separately from terrain modelling. This is mainly due to the differences in the required computing work, and of elementary ontologies.

We have already described the way a monument, a site or archaeological remains can be modelled: mainly by measurement techniques, as in the case of a 3d scanner (Range Based Modelling) or photogrammetry (Image Based Modelling), and by non-measurement techniques, as in the case of computer graphics. Which technique is worth adopting is a question of the aim of the project, the required post-processing time and level of expertise and, last but not least, the available budget. No matter which technology is used, the crucial issue is *if* and *how* to integrate the models into the landscape.

As mentioned in chapter 2, the best place to test hypotheses and theory is a 3d virtual environment, made up of virtual ecosystems. Here the third dimension gets back to interpretation, and inter-relations and dynamics can be seen. A VR environment can get across communication in a more direct and simple way, turning a lesson into an experience, a study into a hyper-research. We should therefore handle not only GIS datasets in landscape reconstruction, but also integrate 3d models.

The most problematic (and still open) question is *how* to integrate those models in the landscape. A first decision to be taken concerns the use of the reconstructed environment as a whole: for real time purposes, or not? Real time applications, in fact, require great care in model optimization, polygon lowering, levels of detail, and paging generation. Various optimization techniques are continuously under development. Computer graphic rendering and animation, on the other hand, can handle much more complicated and realistic scenarios, using (relatively) less effort in optimization. Another question concerns the development of *on line* or *off*

[36] http://openlayers.org

line applications. Even in this case, bandwidth requirements for on line projects play a central role in the definition of the dimension of objects. In any case, when we decide to work with 3d models, the entire team should take responsibility for their geographical spatial dimension and location. This is usually done inside the GIS, mainly in two ways: creating a vector layer representing their planimetry (polygons) or their centre (0,0 axis coordinate). In this way it is easy to locate the models on the ground automatically. With large models, some software may provide algorithms to level and smooth the terrain, in order to avoid a "flying" effect, an operation that can be also done in the GIS, although it requires a modification of the original DTM. A better solution is normally to avoid saving and using big models, preferring their subdivision into smaller pieces. With non real-time applications concerning smaller areas, modellers usually prefer to work in computer-graphic software[37] with a single file, integrating models directly in the terrain, to provide better control in rendering the effects of the entire scene.

Terrain modelling, on the other hand, requires specific software to be performed, as well as tools that can handle its complexity, maintaining its spatial characteristics at the same time, and potentially enabling a final interactive exploration. It usually follows three steps: 3d terrain generation (from geoimage and dem), culture generation (both natural and anthropic characteristics) and 3d models integration. The first programs were created for the army to train soldiers to fly and hit a target (flight simulators), or drive a tank without losing direction. Reality-based reconstructions were essential, such as the geo-referencing of the digital scenario. Software for developing these kinds of applications were quite expensive at the beginning[38]. A complete review of available programs is published every year by the U.S. Army Topographic Engineering Center (Survey of Terrain Visualisation Software) and made available on line[39]. The goal of such a survey is clearly identified in the premise: "to provide the U.S. Army and DoD with more effective methods of merging, visualizing and analyzing battlefield terrain and environmental information."

In the usual procedure[40] (*Fig. 3.7*), acquired data are processed in a GIS software to obtain a geoimage, or mosaic of images, a DTM (or more than one), and vector datasets representing landscape characteristics (rivers, lakes, roads,

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37 3d Studio Max, Maya, Blender, Cinema 4D, etc. (Appendix B).

38 Principal software have been Multigen Creator Terrain Studio (CTS) and Terrex Terravista.

39 http://www.tec.army.mil/research/software/TD/tvd/survey/index.html

40 In Chapter 7 is reported an example of this procedure.

sites, plans, vegetation areas or plants, monument locations, etc.). At this point a Terrain Generator is required, a software that can import spatial dataset and produce a fully 3d terrain. Terrain complexity (both in terms of geometry and texture) is treated with the following techniques: Different Levels of Detail (LOD), paging and tiling. The final result, the *Terrain Database (TD)*, has a hierarchical structure, with a "master file" that usually opens all the tiles-files. *Paging* capability, which means that it is possible to tile together any number of terrains to make extremely large worlds, is important especially in the case of on line publications (Luebke 2003: 187). A *tile* is a rectangular portion of the grid used to organise the TD. Each tile has several *LODs*, which represent polygon density: less detail for distant visualisation and more detail for near and steep visualisation.

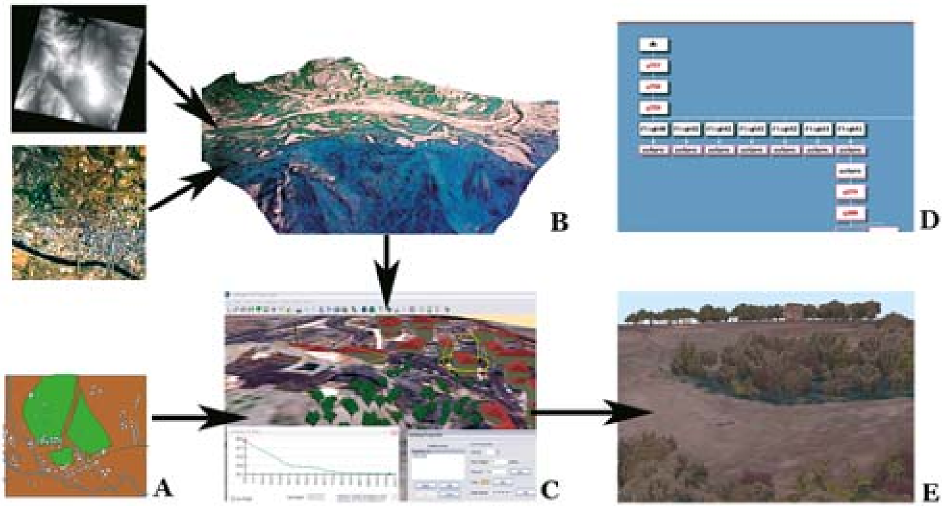

Fig. 3.7. Schematic representation of the entire process of terrain generation (B) cultures integration (C) and landscape publication in VR application (E).

Known terrain generators, which automatically produce TD with these characteristics, are: Terravista, Creator Terrain Studio and, on the Open Source side, OpenScengraph OSGdem[41]. Open Scene Graph is a graphic toolkit to develop graphic applications such as a flight simulator, scientific visualisation, or augmented reality environments. It is based on OpenGL. It has several features such as: crossplatform, Real Time optimisation, a wide range of input format

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[41] Other tools which support terrain paging are: Demeter.

support (flt, 3ds, obj, osg), extensibility through-plug-in architecture, built-in support of paged LOD terrain generation and navigation. OSG already provides both a tool to generate hierarchical paged terrains (OSGdem) and a network loader capable of providing the browsing of such hierarchies with reasonable bandwidth requirements (.NET).

While OSGdem is very essential, most advanced products can obtain direct DTM modifications in accordance with vector layers (river beds, road pavements, automatic bridge generation over rivers, etc.).

Other products, such as Visual Nature Studio, allow to process spatial datasets: adding effects and modifiers, managing complex ecosystem generation, adding 3d models; to create renderings and animation; to export the final landscape in formats (*Table 3.6*) useful for: direct real-time visualisation (such as OpenFlight), computer-graphics manipulation (i.e. 3D Studio) or processed GIS datasets, ready to be further implemented with a Terrain Generator.

Elevation data	DTED (levels 0,1,2); USGS 1:250k; Arc Info BIL; ESRI Grid Ascii; ESRI Grid Float; GeoTIFF (as 16 bit elevation data); BitMap (as 8 bit elevation data); etc.
Imagery	GeoTiff; TIFF + Tfw; GIF; BMP; JPEG; etc.
Vector data	DFAD (all levels); Shape (import & export); DXF; etc.
Textures	SGI .rgb .rgba; TIFF; GIF; BMP; PNG; etc. (OpenGL usually requires power of 2 dimension: 256, 512, 1024, 2048 pixel)
3D models	(OpenFlight) FLT, 3DS, DXF, OBJ, WRL, Collada, X3D, OSG/IVE; etc.
Tiled Terrain DB	OpenFlight; Terrapage; OSG/IVE; Quantum3D VT; ViewTec Web Streaming TVW; etc.

Table 3.6. Landscape generation process file formats.

The final terrain can be now visualised with a *3d viewer*. Most of the terrain generators offer their viewer, which can normally open proprietary files but sometimes also other formats. OpenSceneGraph, for example, has the OSGviewer tool that enables you to explore OSG/IVE files in real-time. Another interesting open project is *Virtual Terrain*, that developed several tools for terrain handling, such as Enviro, for spatial datasets interactive exploration, with some interesting editing functionalities[42].

[42] http://www.vterrain.org

In some cases the work isn't finished, but requires a further *integration* of 3d models, vegetation characteristics, environmental maps, behaviour and interactivity such as: link to external databases and other media, avatars, environmental effects, reference maps in overlay, etc.

In the Delta Po River project, Terrex Terravista was used to generate the large TD representing the archaeological landscape. The 3d reconstruction was also used as a sort of 3d interface, where further GIS datasets were overlaid, becoming a simulation space, to study the evolution of the coastline during four different periods: the Roman age, and the 14th, 17th and 21st Centuries (*Fig. 3.8*). Two archaeological sites, with excavated Roman villas, were then modelled in detail and added to the landscape, developing a second level of walk-through exploration behaviour (Guidazzoli *et al.* 2004).

Fig. 3.8. Delta Po River VR application: the progress of the coastline.

3.4 Data integration: problems and solution

As we have seen, we are moving towards a massive integration of many different ontologies. Let's start to consider some possible solutions to the commonest problems. Integration can be considered mainly from two perspectives: the so-called Layer Fragmentation (LF), and Zonal Fragmentation (ZF). LF concerns elements belonging to various categories (i.e. a DTM and a 3d model), while ZF refers to the same feature class but with different characteristics (two DTMs not perfectly overlapping or at different resolutions, but also parts of a monument) (Laurini 1998; Agugiaro – Kolbe 2009).

How can we embed high resolution objects, such as monuments or archaeological remains, in a generally low resolution Digital Terrain Model? How can we merge together DTMs of different resolution? More in general, how can we integrate acquisitions made at different resolution in a single visualisation and management platform? Integration can in fact generate errors or misunderstanding.

LF is still an open field. In real time applications a variety of solutions have usually been developed to integrate 3d models in a 3d scene. The more complex the scene the more care should be taken with respect to polygon numbers. Although model simplification seems to be a good solution, if exaggerated it can lead to the elimination of important detail. Usually other systems are used to avoid this problem, such as multiresolution techniques. A final solution is always a balance between target user/hardware/purpose, in order to obtain scenes as realistic as possible (complex, highly detailed), but also through rapid (sometimes interactive) rendering. The goal of multiresolution is to extract the necessary details from complex models and get rid of unnecessary ones[43].

Recently CINECA Visit Lab has developed an integrated solution to enable the modeller to integrate high resolution 3d models into the terrain database. It is composed of a plug-in for 3D Studio Max (OSGexp) and a PostProcessing tool. The basic concept is that every modeller who works for realtime applications, can be limited in terms of file-dimension (geometry and texture). He can still obtain a complex and high resolution 3d model by subdividing the object into several separate files, each one with different LODs. In this way, the real time exploration

[43] The commonest multires techniques are: image pyramids, volumetric methods, vertex decimation, vertex clustering, edge contraction (mesh optimisation, progressive meshes), simplification envelopes, wavelet methods, etc. Although not updated, a good reference point is: http://www.cs.cmu.edu/afs/cs/user/garland/www/multires/bib.html

can fit the actual perceptive capability of the users and also their interest in a specific area, whose details can be downloaded sequentially (Pescarin *et al.* 2008). It might also be possible to connect terrain LODs with 3d models LODs, so as to give a better feeling of continuity during visualisation, and to avoid dramatic resolution differences (*Fig. 3.9*).

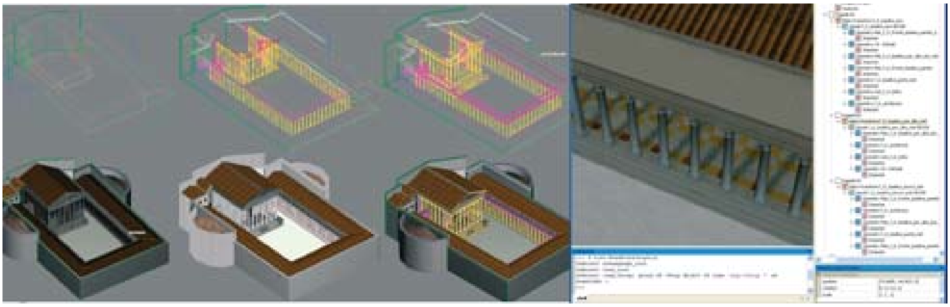

Fig. 3.9. Multires models of the Virtual Rome project.
Courtesy of S. Imboden (CINECA) and M. di Ioia (CNR ITABC).

Various solutions have been proposed concerning ZF, such as the enhancement of a part of a DTM (Karel – Kraus 2006), or of the entire DTM, taking information from a 2D vector dataset of known features and parameters (roads, rivers), thus increasing the number of known elevation data; in the same way, others have suggested increasing elevation information by capturing it from building planimetries. Multiple DTMs are currently supported in many landscape applications, such as CityGML (Groger *et al.* 2008) and OSGdem, and successfully applied in projects such as Virtual Rome (Calori *et al.* 2009) (*Fig. 3.10*).

Fig. 3.10. Different resolution DTMs integrated in Virtual Rome project.

Recently Agugiaro and Kolbe have attempted to solve the problem of integrating laser scanner high resolution and low resolution DTMs in more detail; the solution presented is addressed to the creation of a correct and clean "*transition surface*", influenced by local parameters of both terrain models. This surface is generated in order to create a smooth transition in terms of geometry, precision and density (Agugiaro – Kolbe 2009).

Chapter 4

Potential Landscape Reconstruction

In the previous chapters, I have described methods and techniques which offer a contribution to landscape interpretation and the reconstruction of archaeological landscape. In this chapter, I put forward some reflections on the reconstruction of ancient potential landscape. As I have already indicated, it should be considered a reference for ancient landscape reconstruction and, moreover, an open process, where input data resulting from the inter-medium steps we have described can change together with the final visual result. Unfortunately, there are several problems in this approach, due to data incompatibility, unawareness on specific fields, professionals incommunicability, etc. Archaeologists, for instance, rarely know the landscape as a geologists do, but, on the other side, an earth science specialist often doesn't undestand time and method of archaeology. The contact point is *dynamics*. Shape and soil are results of dynamic process determined by different forces: they are the apparently static result of a dynamic process. How fast a landscape has changed? Which are main territorial characteristics that have been modified? Which kind of data, therefore, we need and how do we have to treat them as to obtain a reconstruction of a potential landscape? Geomorphology, soil and hydrography are sufficient characteristics?

Man has always modified his territory and its natural equilibrium to a varying extent, especially after the introduction first of agricultural and later industrial activities. The way this impact has been expressed has changed over the centuries. But the idea that ancient societies were living in peace and harmony with nature, in their landscapes, is usually a misleading one. In antiquity human territory was exploited, sometimes even intensively. Nevertheless, the relationship between man and his environment used to be more balanced than it is today in most western countries (Chiusoli 1985). After the introduction of agriculture, the soil has been intensively used for a variety of purposes and at various levels, while urban and industrial expansion has assumed a growing importance. Ancient communities have modified the environment while carrying on various activities. The study of these activities might help in the reconstruction of ancient landscape: the use of fire, hydrographic operations, practice of horticulture or other cultivations. Traces of these modifications can be recognized in remains of channels, terracing, drainage ditches, boundary walls, fields subdivisions, etc. Archaeological excavations can identify ploughing tracks or cast analysis. Also instruments, ovens, flour mills, winepresses or oilmills eventually founds can contribute at indicating the type of farming. Pollen analysis and the study of the wood employed in structures can help to identify forests management activities, as pollarding, cutting, extensive cut, fires, etc. (Renfrew – Bahn 1991: 223).

While studying the territory, scholars in the field of earth sciences have developed tools which can help us to understand what might have been the original natural environment, with particular emphasis on its potential vegetational characteristics, on common characteristics of similar areas or Land Unit (uniform combination of soils, of climates, of morphology) and on their potential use (Giordano 1999: 312). The most advanced tools are represented by Landscape Units Maps, whose goal is to study and describe a territory, subdividing it into various areas and assigning to each area a potential use (Arnoldus-Huyzendveld – Pozzuto 2009: 16). They are based on Landscape Evaluation, a well-established method, developed in the '70s by FAO, the Food and Agriculture Organisation of the United Nations, and addressed to the analysis of the terrain when it is used for a specific purpose, including different studies on contemporary cultivations, on plants specific needs, etc.

Most of the known classification and analysis insists on the subdivision of a landscape into different *Land Units* (LU). A Landscape Unit is a *homogeneous territorial area, with specific unitary characteristics and/or qualities* (FAO 1976). A *characteristic* is a measurable attribute, such as slope angle, rainfall, soil texture, available water capacity, the biomass of the vegetation, etc. *Qualities* are analog measures expressed with reference to productivity or management (*Table 4.1*) (FAO 1976; Giordano 1999: 312).

In archaeology, it is common to work with material remains, whereas the ancient environment is much less well known (or dealt with). Sometimes it is possible to obtain some pollen analysis or other botanical observations, or to find traces of ancient farming, with modern techniques of investigation: today there is in fact more focus on ecological observation, in comparison with past excavations (Musco *et al.* 2001). Nevertheless we never have a satisfactorily broad perspective on the natural environment, nor therefore on the connections and relations among sites and natural elements.

For this reason, the contribution of ecological studies is fundamental to the reconstruction of past landscapes. Moreover, the consideration of potential landscapes offers a more scientific and reliable approach to further reconstructive processes.

Qualities	Characteristics
PRODUCTIVITY (from crops or other plants)	Nutrient availability; crop harvest; radiation energy; temperature regime; flooding hazard; workability of the land, etc.
ANIMAL PRODUCTIVITY	Productivity of grazing land; resistance to degradation of vegetation; availability of drinking water; climatic hardships affecting animals, etc.
FOREST PRODUCTIVITY	Types and quantities of indigenous timber species, etc.
MANAGEMENT & INPUTS	Terrain factors affecting the use of industrial techniques; terrain factors affecting accessibility (roads); size of potential management units (e.g. forest blocks, farms, fields); location in relation to markets and to supplies of inputs, etc.

Table 4.1. Land Units quality. In the right column attributes that can be used also in archaeology (Source: FAO 1976).

There are at least three main essential characteristics that we should taken into account in landscape reconstruction: geomorphology, soil and hydrology. In chapter 3 we have seen that mapping is the first activity of an archaeologist interested in reconstruction. But, how much can we use and rely on the earth, as it appears today? How long ago, we wouldn't have recognized the shape of the environment around us? Geological-lithological studies are focused on the deeper terrain strata, with less impact on vegetation structures in the landscape, which have a stronger relation to the upper strata: the soil. The soil is a fundamental element to be considered also for ancient potential land evaluation. Although, in fact, it is a dynamic system, continuously modificating, "an evolving entity maintained in the midst of a stream of geologic, biologic, hydrologic, and meteorologic material" (Buol *et al.* 1973), characterized by energy exchange, it is also in a time-indipendent steady state. "A steady state soil, or soil component, is one which remains roughly the same, even though matter and energy may move in or out, be produced or be consumed. […] Soil depth remains virtually constant" (Bridges – Davidson 1982: 133). Soil and geomorphology are strictly connected and their development, in cycle of erosion and growth, is therefore interlinked in the soil-landscape system. How does this development work is an interesting matter for ancient landscape reconstruction. Soil and landscape develop in "an episodic way, with periods of geomorphic stability, during which pedogenesis takes place, alterning periods of erosion and deposition which may modify all or part of the land surface". The ground surface changes differently in different zones and each zone has a different history. "Summits and shoulders remain relatively unmodified by erosion; hillslopes become progressively truncated upslope by erosion; part of the debris eroded from the hillslopes may be temporarily stored as valley fill, before being removed by a stream or […] the eroded debris remains in the slope position"(Bridges – Davidson 1982: 140).

The soil is central to the reconstruction of ancient potential landscapes. For instance, soil map was used to reconstruct the ancient potential landscape of Rome in imperial times, in the "via Flaminia" project (Appendix A).

In order to extend the general concept of potentiality to all historical periods, we should start from *Land Evaluation* studies and then consider different parameters as reference, defining new categories and classes, based on acquired and processed data. The use of Land Evaluation in archaeology has been recently experimented in Italy and Holland, thanks also to a conference held in Gröningen in 2000 (Van Joolen 2003; Arnoldus-Huyzendveld – Volpe 2004: 177–233; Arnoldus-Huyzendveld 2007: 41–60; Attema *et al.* 2002).

In order to determine the potential use of past landscapes for ancient land uses (Attema *et al.* 2002: 186), we should start from the elements useful in ancient landscape reconstruction. *Soil* characteristics, such as drainage, slope, depth, texture, etc. are connected to productivity: plant productivity (growing and renewing), and hence food, energy and garment production. The landscape, its potentiality and natural aspect, has consistently affected the evolution of human settlements.

A starting point in the reconstruction of landscape potentiality is "*terrain ecological attitude*", i.e. the condition a terrain gets into when the environment is preserved in a certain period and at a certain latitude (Blasi 2000). Terrains can be divided into principal categories, such as wooded or agricultural terrains, that should be considered as reference points in landscape reconstruction.

4.1 Potential Land Evaluation in archaeology

Land Evaluation (LE) concerns the analysis of land and of its uses. It has been defined as "the process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation" (FAO 1976). LE usually requires several activities, since it is based on *climate*, *type of soils* and *vegetation surveys*, etc. Not all values are considered, but only those relevant for "physical, economic and social context" (FAO 1976). It might be approached through the *Land Capacity Classification* (LCC) and the *Land Suitability Evaluation* (LSE).

In both cases the first step is *observation*. The territory under investigation should be studied and analysed in relation to its shape (morphology), clivometric aspects, orogenesis, lithology, hydrography, and so on.

In Land Capacity Classification, terrains are classified with reference to general agro-wood-pastoral systems, with no specific reference to one agricultural activity, nor to the soil's physical properties (Klingebiel – Montgomery 1961). LCC considers how far a terrain's usage is limited to a generic agricultural activity, and this analysis is based on soil quality and contextual environment characteristics (Loomis – Connor 1992). For example, a territory with productivity limitations due to chemical values, is placed in relation to some landscape requirements, such as morphology, climate, vegetation, etc. This relation can change the intensity of the original limitation, to greater or lesser extent when compared with slope, aridity, vegetation degradation, etc.

Fundamental criteria for land capability are: the relation to permanent physical limits; reference to general agricultural activities undertaken in that territory and not to specific cultures. Capability classes are indicated in *Table 4.2*. LCC has two main *distinctions* and eight different *classes*. Each class has several *sub-classes*, which further define the usage limitation typology (Cremaschi – Rodolfi 1991) (*Table 4.2*). Although LCC offers an useful method, this approach seems to be quite problematic, due to the lack of clear application criteria for the assignation of classes and subclasses, and, most of all, due to the specific qualitative character of the method. Application therefore varies, according to region and country.

In the second approach, the LSE, *terrains are assessed in accordance with a specific use* (i.e. terrain suitable for cereal or rice etc.). LSE studies the actual land usage, the vegetation, climate, soils and other aspects, also to identify possible alternative usages. The method consists in the definition of *Land Units* and in their comparison, in terms of quality, with each single "potential" usage, including technological and economic capacities (FAO 1976). LSE is structured into *Orders* (suitable with no risk, not suitable due to some preclusions), *Classes* (highly, moderately, marginally suitable and currently or permanently not suitable), *Sub-classes* (defined by kinds of limitation) and *Units*, while different usages aren't classified *a priori*, but taken into account each time a new LSE is arranged. The classification can be expressed *qualitatively* (physical criteria), *quantitatively* (economic criteria) and can be referred to *current* or *potential* suitability. The result includes a description of land utilization types, maps and tables showing the degree of suitability, economic and social analysis and information on the reliability of the suitability estimates (FAO 1976). Essential information comes also from specific characteristics of each potential cultivated plant: what kind of terrain it prefers, exposition, depth, etc.

	Capability class	Description as referred to limitations
Suitable for agriculture	Class 1	Soils have slight limitations that restrict their use
	Class 2	Soils have moderate limitations that restrict the choice of plants or that require moderate conservation practices
	Class 3	Soils have severe limitations that restrict the choice of plants or that require special conservation practices
	Class 4	Soils have very severe limitations that restrict the choice of plants or that require very careful management or both
Not suitable for agriculture	Class 5	Soils are subject to little or no erosion but have other limitations, impractical to remove, that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat
	Class 6	Soils have severe limitations that make them generally unsuitable for cultivation and that restrict their use mainly to pasture, rangeland, forestland, or wildlife habitat
	Class 7	Soils have very severe limitations that make them generally unsuitable for cultivation and that restrict their use mainly to grazing, forestland, or wildlife habitat
	Class 8	Soils and miscellaneous areas have limitations that preclude commercial plant production and that restrict their use to recreational purposes, wildlife habitat, aesthetic purposes

Table 4.2. Land Capability Classification: main distinctions and Land Capacity Classes.

Potentiality can be applied to *Archaeological Land Evaluation*. In order to successfully adapt *LCC* even *to Archaeology,* it is important to start with the definition of actual Land Evaluation (or to take into account Land Evaluation carried out for modern territories), and then proceeding in the reclassification of those terrains, applying different criteria, valid in different historical periods.

Soil maps, with the application of LCC analysis, can be taken as reference points and then modified in accordance with historical parameters, decisive in landscape modifications. Unfortunately it is quite difficult to define unequivocally what the relevant parameters are. In *Table 4.3* there is a list of possible parameters that might be taken into account in potential landscape reconstruction.

Geomorphology may be locally different: different clivometric values might determine slightly different choices in agriculture. *Hydrology* was often different from now, developed to a greater or lesser extent, with an evident impact on settlement and farming limitations. Vegetation now might be dissimilar to that of the past: some of the original natural species are now completely lost or modified, while others were introduced in different historical periods. In this case it is very important to define *original and potential species,* typical during a certain historical period. A graphic library of plants can then be developed for this purpose and updated.

Historical Parameters of aLE (Archaeological Landscape Evaluation)	
Geomorphological modifications	*Changes for earthquakes or other phenomena that could impact on the territory; anthropic modifications for industrial (caves, etc.) or residential purposes*
Hydrological modifications	*Changes in natural river beds or due to anthropic modifications or to other phenomena connected to rain (floods) etc.; new rivers, lakes, basins or channels due to anthropic modifications, modification in rivers, springs capacity*
Soil modifications	*Changes due to erosion, deposition, etc. of the soil*
Climate modifications	*Changes in climate*
Geological modifications	*Changes for volcanic activity and other phenomena with impact on the territory, such as neotectonics*
Coast Line modifications	*Coast line modifications (land modifications or sea level modifications)*
Vegetation modifications	*Natural species and newly introduced species*
Technological advances	*Use of machines in agriculture; animals; slaves; etc.*
Cultural and perceptive aspects	*Dimension and subdivision of fields; pasture usage and its eventual modification to the territory; woodland usage; proximity or distance to sites such as industrial or residential places; religious belief; etc.*
Economic and Energetic aspects	*Political and economic aspects; energetic issues; widespread commerce or other form of contacts – presence of not original cultures; etc.*

Table 4.3. Parameters of Ancient Landscape Reconstruction.

There is another aspect to consider. We are discussing *digital* reconstructions, so we need to take into account their level of detail and resolution, since they are intimately connected to the scale of representation and of available input and interpreted data. We can start the reconstruction work with a general scale, detailing it increasingly in specific areas.

A re-classification of Usage Classes based on the above mentioned parameters (*Table 4.3*) might be assigned to each Archaeological Landscape Unit (aLU). One or more classes will be assigned to each aLU, according to the available detailed archaeological, geomorphological, botanical, and topographic information of the territory. In the assignments we should consider also the level of detail, its accuracy and reliability (Dramstad *et al.* 1996).

Landscape Suitability Evaluation defines the suitability of a Land Unit for a specific purpose. When we apply it to archaeology, we need to define firstly how many and which land utilization types we can distinguish in a specific historical period and latitude.

Evaluation type	Characteristics
Land Capacity Classification (LCC)	Main distinctions (agricultural soils – pasture and wood soils – not agricultural nor wooden or pasture soils) > classes (soils good for one or any cultivations, with some limitations, with bad limitations, with very bad limitations) > sub-classes (further limitations)
Land Suitability Evaluation (LSE)	Land Units > orders (suitable, not suitable), classes (highly, moderately, marginally suitable), sub-classes (defined by limitations), units
Archaeological Land Evaluation (aLE)	Historical and environmental parameters > Land Utilization Typologies (LUT) > Ancient Land Units (aLU) > usage classes (potential suitability); soil/plans matching > sub-classes (defined by level of limitation)

Table 4.4. Comparisons of evaluation criteria.

As economic criteria are often difficult to evaluate in past societies, the LSE *qualitative potential method* is a good starting point, as it takes into account only the potential physical productivity of the land.

The use of LSE for ancient landscape reconstruction requires the following activities:

1. definition of the context: historical and environmental parameters,
2. definition of historical Land Utilization Typologies (LUT) (FAO 1976: ch. 2.3.1),
3. definition of ancient Land Units (aLU),
4. economic and social analysis for better aLU definition and identification of possible limitations,
5. comparison between defined LUTs and aLU and definition of archaeological Land Suitability Units obtained with LSE methodology (aLSU), and production of suitability maps and tables (FAO 1976: 3.4),
6. description of sources used and estimated reliability level,
7. model development.

4.1.1 Definition of the context: sources and resources

Mandatory to any further evaluation is the study of the context of the case-study area. Parameters to consider are: location and accessibility; climate; orography; the basis of the economy; the economic infrastructure (e.g. roads, rivers, other services); the size of farms or other residential and productive structures; the land management system and the political system. Was the territory we want to reconstruct located in a rural area? What was its geomorphology like? Was there any road system? Are there rivers nearby? What was the climate like in that period? Were there farms or other structures and what can we say about their management? To which horizon did the territory belong to (Di Fidio 1990: 222–223)? And how can we answer all these questions?

Written sources, useful for the reconstruction of historical periods, are ancient authors, sometimes not very reliable since their work may be conditioned by an ideal and/or a political position (Traina 1990). In Roman times, there were writers who specifically focused on agriculture, such as Varro, Cato, Columella or Pliny[44]. Other authors mentioned aspects of landscape and living conditions during Roman and Greek times (Fedeli 1990)[45]. Some of them reported previous traditions regarding more ancient periods. An example is what authors reported on the early territory of Rome: they tell of a landscape consisting of forests, navigable marshes, high settlements, pastoral farming and a variable hydrography which caused a good deal of flooding[46].

In more recent times, ancient documents and manuscripts or cadastrial maps can be very useful in the reconstruction of a territory and in the definition of ancient Land Use Maps. Nevertheless, we should be very careful in the consideration of these sources, since they cannot simply be *reproduced* visually, and even in those cases in which the situation seems to be quite evident, it is still necessary to be severe and weigh up descriptions or representations. Although not specifically related to the landscape, a good example of reconstruction through historical sources is the NuME project. It is a virtual museum dedicated to the reconstruction of the city of Bologna, in Italy, in different historical periods, obtained analysing documentary and iconographic sources, organised in relational databases (*Fig.*

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[44] Cato, *De agricultura;* Columella, *De Re Rustica;* Plinius, *Naturalis Historiae;* Varro, *Res Rusticae.*

[45] See the Appendix B for a list of the authors.

[46] Hesiod, Teog. v.1013; Sal., Catil. 6.1; Varro 1.14.4, 1.20.2, Ling. 5.43; Lucretius, 5, 1241; Livy, 1.4.6, 1.7.4, 1.4.5, 5.53.9; Cicero, De Re Pub., 2.6.11.

4.1). Historians and computer scientists have then created a final model of the territory and made it explorable in real time developing a VR on line application[47].

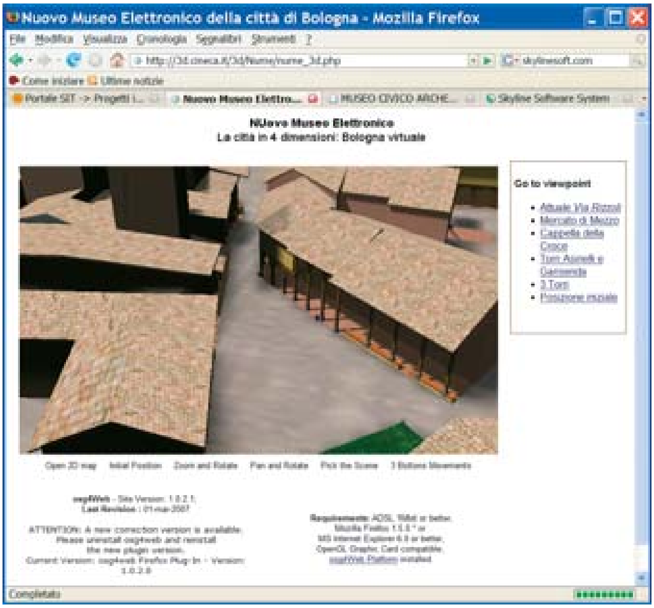

Fig. 4.1. NuME project. The reconstructed medieval town of Bologna.

There are several studies that analyse ancient sources and summarize their positions and vision of their territory[48]. These studies can contribute to the reconstruction of ancient landscapes, but also of *mindscapes* (Forte 2000)*,* which in some cases becomes *dreamscapes* (Keith 2000: 35). What authors usually describe, in fact, is their *idea* of the landscape or the idea of the dominant class. So the resulting reconstruction can offer a subjectively perceived landscape, a territory as it was observed and reported by the ancients.

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[47] Bocchi, F., *Medieval metropolises Metropoli medievali. Proceedings of the congress of the Atlas working group, International Commission for the history of towns, Bologna, 8–10 maggio 1997*, Grafis, Bologna 1999. http://www.storiaeinformatica.it/nume/english/ntitolo_eng.html

[48] Fedeli 1990; Traina 1990; Pavlovskis, Z., *Man in an artificial landscape: The marvels of civilization in imperial Roman literature*, Brill Archive, 1973; Welch, T.S. *The elegiac cityscape: Propertius and the meaning of Roman monuments*, Ohio State University Press, 2005; Morris, I. *Classical Greece: ancient histories and modern archaeologies*, Cambridge University Press, 1994: 137.

Another example regards the Via Flaminia project. In the reconstruction of the territory around the villa of Livia, we have taken into account Roman frescos, especially for the characterization of the gardens. Specifically, the famous fresco of the so-called summer *triclinium* of the villa, conserved at the Roman National Museum at Palazzo Massimo in Rome, depicts an entire series of plants (*Fig. 4.2*).

Good references for the definition of the general context are also the researches

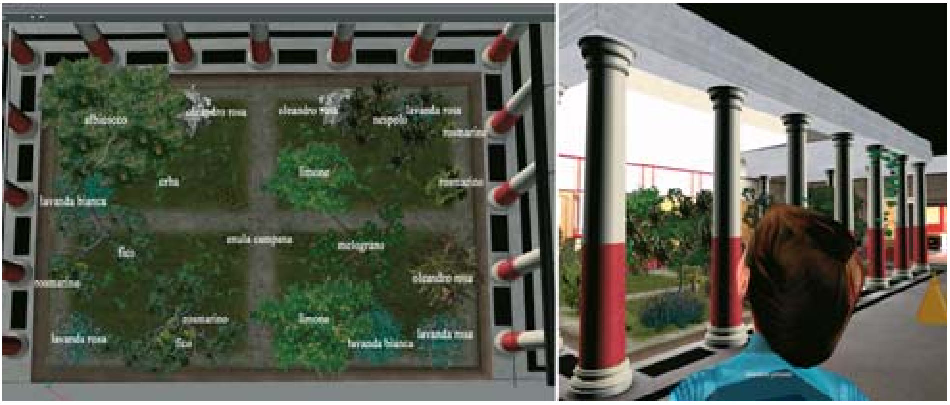

Fig. 4.2. Reconstruction of the Republican Garden at the Villa of Livia, Rome.

which have developed the concept of "potential vegetation" and of "typical local landscape". An example is the work of Tomaselli, who in the '70s published the Map of Potential Vegetation (Tomaselli 1970). In this map, the Italian territory was divided into four different *ecosystems*, called *horizons,* based on latitude and altitude, each one distinguished by a specific set of plants:

1. Mediterranean horizon
2. Sub-Mediterranean horizon
3. Mountain horizon
4. Alps and sub-Alps horizon

Apart from latitude (where the territory is located) and altitude (minimum and maximum elevation), another parameter to consider is *climate*, since it could have changed over the centuries.

All this information identifies the natural "*Typical Local Landscape*" (TLL). In Italy scholars have identified 7 different TLL (Blasi *et al.* 2000; Di Fidio 1990: 222–223; Giacomini – Fenaroli 1958; Pignatti 1979):

- Oleaster and carob tree landscapes: typical of southern warm and arid regions
- Holm-oak (*ilex*) and olive tree landscapes: typical of Mediterranean climate and of regions warm during the summer
- Downy oak (*quercus pubescens*) landscapes: typical of colder climates
- Turkey oak and chestnut landscapes: typical of valleys and mountains with a temperate climate
- Beech (*fagus*) and fir (*abies*) landscapes
- Red fir and larch (*larix*) landscapes
- Trees and contorted bushes landscapes

4.1.2 Land Utilization Typologies (LUT)

Land Utilization Type (LUT) consists of a set of technical specifications in a given physical, economic and social setting (FAO 1976: ch. 2.3.1). An example is “farming based on cereals by smallholders with low capital resources, with cattle drawn farm, with high labour intensity with many slaves, freehold farms of 2 ha”.

The types of land usage are specified at the beginning of the evaluation procedure. Each usage characteristic can be described, with requirements and limitations. Each LUT has specific *agronomic demands* which have a general validity, such as growing period, radiation, temperature and water requirements. It also has management requirements, which have a validity referring to specific historical periods and cultures: field locations (closeness to markets, access to water, travel – transport accessibility), water application, pre-harvest, harvest and post-harvest necessities (FAO 1985)[49]. LUT description may also include information about the size and shape of farms, historical cultivation practices and land tenure, density of plants, etc. An example is the territory management and subdivision Romans used to undertake, especially in lowlands: *centuriatio* and *limitatio*. An example of LUT in relation to the Romans is *viticulture* (Gioia – Volpe 2004).

[49] A complete list of agronomic requirements (growing cycle and period, radiation, temperature, water quantity and quality, nutrients, salinity, sodicity, diseases and weed, flood, storm, wind and frost) and management requirements (location, water application management, pre-harvest farm management; harvest and post-harvest conditions; mechanization) can be found in Appendix of the FAO soils bulletin 55, published in 1985.

Each LUT description will contribute to the creation of a Virtual Ecosystem, characterized by its principal vegetation, secondary vegetation, density, shape of the cultivation (in the case of rows), etc.

4.1.3 Ancient Land Units (aLU)

The identification of modern Land Units is particularly useful for "recent" reconstructions. After the necessary study and observation of the territory, LU definition requires analysis and survey carried on by specialists. Today these analyses consist of physical surveys of the soil, and aerial or satellite photo interpretation, etc. After this work, LU *boundaries* are defined. They are also outlined by the study of landforms, soils and vegetation (FAO 1976: ch. 4). The necessary activities, based on GIS platform, can be summed up as follow: analysis of base and thematic cartography (hydrography, pedology, morphology, elevation and slope, road maps, etc.), definition of the legend, direct observation and reliability verification through field analysis (slope control, rockiness of the soil, drainage, useful depth for plants rooting, colour of the soil, acidity, etc.) data processing, aerial photo interpretation and land evaluation (Arnoldus-Huyzendvel – Pozzuto 2009: 21). The result of this work is a *Land Units Map*. In this map the various units are associated with their potential agricultural usage. This result is obtained considering also agronomy studies to define *requirements* of land uses in comparison to soils characteristics (*Table 4.5*).

Type of cultivations	**Soils requirements**
Cereals or other sowable	Arable land, easily accessible, not very stony
Orchard	Accessible terrain, moderately deep and with no water-bearing layer
Vineyard	Rather deep terrain ploughable, not calcareous and with no late frost risk
Olive-yard	Accessible terrain, slightly deep, with no water-baring layer
Pasture	All terrains not too much stony or rocky
Coppice-wood and chestnut grove	Terrain not too steep, with minimum depth and with no water-baring layer

Table 4.5. (from: Arnoldus-Huyzendvel – Pozzuto 2009: 29).

In order to obtain a more useful map, for the development of models of the ancient territory, we better re-consider the process. The analysis of aerial and satellite images can be successfully integrated in the process: photo interpretation can be essential in the identification of archaeological features, agricultural traces, etc. Previous knowledge of archaeological sites location (archaeological maps, surveys, etc.) should be also considered at this point. In some cases, although not always relevant, a modified Digital Terrain Model should be taken into account and used as a new reference for the definition of aLU *boundaries*. However, among various modifications occurred to a territory, what definitively should be taken into account is hydrographic modifications, due to natural and most of all anthropic reasons (movement of river beds, cut of new channels, consequent movement of soils, etc.), since they represent the more conspicuous agricultural landscapes transformation in the past. This is quite a new history chapter that it is slowly starting to be written (Musco *et al.* 2001: 271). Moreover the use of *site catchment* analysis to identify a depending territory around an archaeological feature, can be also useful (Arnoldus-Huyzendvel – Pozzuto 2009: 21). This catchment area can be used as secondary weighted boundary.

The study of ancient agricultural techniques, activities and cultivated species in antiquity can be useful to better specify the relation plants/soil proposed in *Table 4.5*[50]. Terrain quality can be maintained in the case of slight modification of the soil strata, or modified considering the stratigraphic analysis or specific descriptions in written sources. In the end an ancient *potential Land Unit Map* is created, representing the territory divided into areas, each one sharing the same characteristics in terms of type of soil, soil depth, geomorphology, etc.

4.1.4 Economic and social analysis

Economic and social analysis includes the study of land tenure systems, labour potential, government development objectives, etc. The analysis of the demand also gives an idea of how far a land usage could have been pushed, due to central (political) requirements. An example is the first Roman imperial period, where the landscape assumed a hegemonic model, connected to political demands and to the rules for field division (*agrimensura)* (Traina 1990: 49). Moreover, the reconstruction of an anthropic landscape should take into account factors

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[50] White, K. D. *Roman Farming*, Cornell University Press, 1970; Garfinkel, Y. *Dancing at the dawn of agriculture*, University of Texas Press, 2003; Capogrossi, L. Colognesi, *L'agricoltura romana. Guida storia e critica*, ed. Laterza, Roma-Bari 1980; Carlsen, J. *et al.. Landuse in the Roman Empire*, L'Erma Di Bretschneider, Roma 1994; Mazoyer, M. *et al. A history of world agriculture: from the neolithic age to the current crisis*, Earthscan, 2006; Forni, G. Marcone, A. *Storia dell'agricoltura italiana*. Vol.1 and Vol. 2, Patron Ed., Bologna, 2003.

which might have determined the preference for a specific place, such as water proximity, strategic position, religious preferences, sun exposition or other kind of orientation, proximity to roads or other villages, etc. (Renfrew – Bahn 1991: 223).

4.1.5 Comparison between aLUT and aLU, archaeological Land Suitability Units, Suitability maps and tables

The identified potential land usages (aLUT) are then combined with the characteristics of each land unit (aLU). If we do not have any economic observations we can use the *qualitative potential method*, focusing the evaluation on the physical parameters of the identified land units. Every unit will, in the end, be *suitable or unsuitable for a specific use*, in a certain time and place. The definition and final control of LSE should be carried out by different specialists, including natural scientists and archaeologists.

The results of the classification can be summed up in a table, a simple and immediate way to present the work. In this way the potential presence of more than one cultivation typology is maintained.

Land Units	**Kinds of land use:**			
	Spelt	**Fruits**	**Vineyard**	**Olive trees**
aLU 1	S1	S2	N1	N2
aLU 2	N1	N2	S1	S1
aLU 3	S4	S2	S2	S3
aLU 4	N1	N1	S3	S2
...				

Table 4.6. Example of tabular representation of Roman agricultural usages suitability (FAO 1976: ch.3.2).

In *Table 4.6* there is a representation of a territory in tabular format, with a different aLUT suitability level (spelt, vineyards, etc.) in each aLU. The level is codified in this way:

- S1: highly suitable. Benefits justify inputs, without unacceptable risk
- S2: moderately suitable. Land with limitations that require input. Overall advantage inferior to expected
- S3: marginally suitable. Land with severe limitations for sustained use of the considered culture. Expense and effort only marginally justified

– N1: currently not suitable. Some characteristics of the land preclude the sustained use of the cultivation under consideration
– N2: permanently unsuitable

In order to process these data, it is important to produce *suitability maps* as georeferenced maps, made up of polygons or raster grid. Usually we will have as many suitability maps as the identified aLUT. In most cases, in GIS, it is convenient to transform the polygonal vector layers, probably drawn on top of topographic maps or aerial images, into raster grids, to simplify the subsequent analysis, which can be carried out comparing cells and making calculations on grids (aLU and aLUT/suitability maps).

The final evaluation of the ancient landscape will therefore produce several maps, tables and descriptions. In a study carried on recently in Tuscany by Arnoldus-Huyzendveld and Pozzuto the Land Unit Map obtained through land evaluation analysis has been superimposed to an archaeological map (*Fig. 4.3*). The result of this work has determined how Etruscans have been devoted to forest

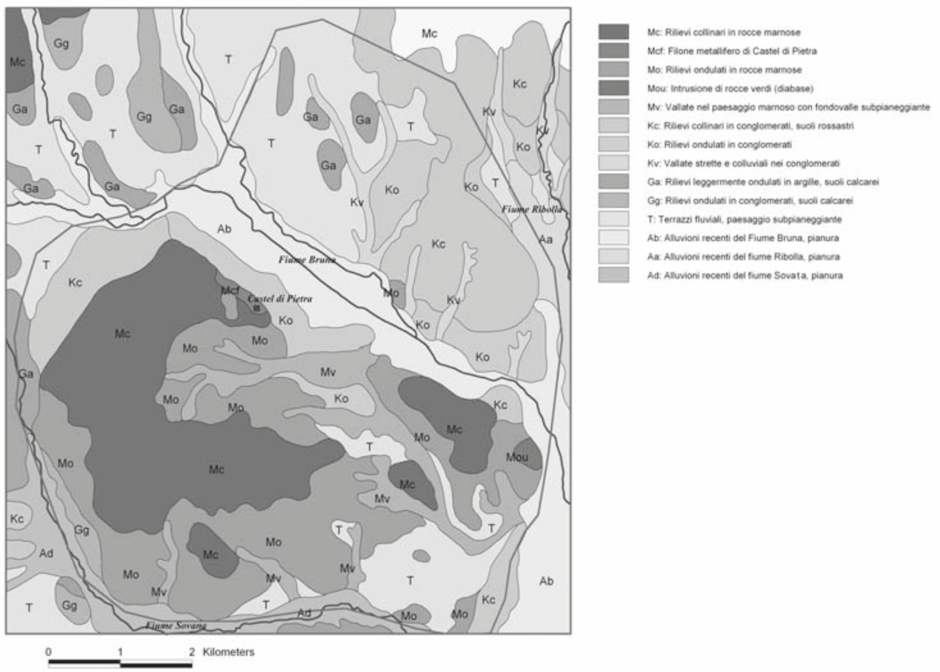

Fig. 4.3. Example of Land Units Map created for Castel di Pietra Medieval site in Tuscany (Courtesy of A. Arnoldus-Huyzendvel. In: Arnoldus-Huyzendvel – Pozzuto 2009).

exploitation and pastoral farming, while Romans to cereal and leguminous growing. An index of productivity of the different cultures is also discussed: cereals during Roman times have a production efficency of 11–13 quintals per hectar (110–130 kg of flour), in Medieval times 4–8 q/ha (40–80 kg flour), while currently FAO calculates 40–60 q/ha. We can, consequently, propose considerations on the number of people who can be fed, assuming that the needed quantity, per head, of flour per year is 400 kg (Arnoldus-Huyzendveld – Pozzuto 2009: 31–37).

If we could represent at this point the potential landscape we would need to use a *multi-dimensional* and *multi-layered map.* The final visualised reconstruction will be one of the several possibilities, in accordance with archaeological or historical knwoledge of the territory. At the same time, it will be *ambiguous*, describing general characteristics of the territory, or constants (chapter 2). Reliability maps might be created to represent the level of suitability of the final reconstruction and, therefore, its level of uncertainty.

Fig. 4.4. Potential ecosystem map of Rome in early imperial times.

4.1.6 Description of sources used and estimated reliability level

Each source, used to define the different usages, to combine them with the Land Units of the studied territory, to a produce suitability map, etc. should be described and archived, if possible in a database and connected spatially to categories. Other information which can be stored is the level of reliability of aLU, as it is commonly done for 3d models.

4.2 An example: Roman landscape reconstruction

The following example describes the entire digital pipeline developed to reconstruct Roman potential landscape, without available actual soil maps or land use maps and with little archaeological information. This work was carried out within the "Virtual Museum of Ancient via Flaminia" project (Appendix A).

The initial input was whether it might be possible to define a *general methodology* to reconstruct a potential landscape, that is to say how a territory could have appeared in a certain historical time and at a certain latitude, applying the methods developed for Land Suitability purposes.

Ancient landscape is the result of many different inter-connected factors: potential landscape (ecological disposition) and anthropic landscape (material and cultural traces.

Ancient Landscape (AL) = Potential Landscape (PL) + Anthropic Landscape (HL)

As we have seen in previous chapters, what we actually reconstruct and define as ancient landscape isn't related to its "reality", but to our interpretation. The way a territory existed in its physical reality is not the territory we reconstruct, basing our assumptions on observation, analysis and deductions (Renfrew 1994:10). Our interpretation is conditioned by our identity, by cultural, social and political elements, by effectively available data, by technological advances and also by unpredictable factors: a mix of imagination, intuition and deduction capabilities. Also ancient authors, e.g. Latin or Greek writers, reported their own personal vision of the landscape, a mediated landscape consisting of many cultural, social and political factors.

The final step requires the definition of a model representing the ancient potential landscape.

The various steps of potential landscape reconstruction are:

a. analysis of the reconstructed archaeological landscape (the observed landscape is a basis of interpretation and reconstruction);
b. definition of the general territory's *ecological attitude,* with no consideration of human interference;
c. consideration of anthropic and cultural aspects and landscape modifications;
d. definition of ancient Landscape Units (aLU) and of ancient Land Usage Typologies (aLUT);

e. reconstruction of suitability maps;
f. reconstruction of ancient potential landscape.

Every analytical process regarding a territory should take into account spatial dimension data and should start “mapping the space”, reconstructing the archaeological landscape (Chapter 3).

The reconstruction of the ecological attitude of the Roman landscape aims at reconstructing three main distinctions or categories, and their sub-categories: agricultural or pasture lands (cereals, vineyard, orchard, etc.), woodlands (natural or cultivated forests, long-stemmed plants) and lands not suitable for woodland or agriculture/pasture (Di Fidio 1990: 215; Volpe – Arnoldus-Huyzendveld 2005; Dramstad *et al.* 1996; Chiusoli 1999).

In order to obtain these distinctions, spatial analysis is performed on diverse raster maps. At the end of the process we obtain vector themes, that might be further modified or corrected, and in part directly used as input in the terrain and ecosystem generator software (Chapter 3).

In the end, we obtain a model of a generic potential landscape but with no fundamental elements, the last stage in landscape formation in a specific historical period. We need in fact to integrate other anthropic factors, adding archaeological and geomorphological data and information.

In the application of this evaluation method in northern Rome, several units were identified, as follows:

– Cereal Land Utilization Type: flat lands, not too far from water resources, from Roman roads or residential structures (villas), belonging to one of the following lithostratigraphic classes: valley incisions, fluvial thalweg, and volcanic plateau.
– Vineyard and olive tree cultivation units: gentle slope areas, not far from villas, belonging to volcanic terrains.

The territory located in northern Rome belongs to the category of “*Holm oak and olive tree landscapes*” (Di Fidio 1990: 222–223; Giacomini – Fenaroli 1958). It is naturally characterized by Mediterranean vegetation with forests and evergreen bushes, with Holm oak (*quercus ilex)* woods, strawberry trees (*arbutus unedo)* and mastics (*pistacia lentiscus)*. There were probably also cork oaks (*quercus suber*), maritime pines (*pinus pinaster*), and Italian stone pines (*pinus pinea*) in the area. Potential suitable agricultural uses of the land, confirmed by Latin authors, could have been: olive tree cultivation, vines and cereals. In the upper limits, there could also have been manna ash (*fraxinus ornus*) and downy oak (*quercus*) woods, while in mixed deciduous forests there could have been pedunculate oak, carpine, ash, downy oak and oak trees. Of each *species* a database can be created, to store information about names, average and maximum height and one or more digital images. Botanical references and paleo-botanist consultancy should be taken into account at this stage. The experiment we carried out, in accordance with the visualisation application we were developing, required the creation of a simple *Archive of Roman Potential Vegetation:* an **.xml* file built up with VTP software[51] (*Table 4.7*).

```
<?xml version=”1.0” encoding=”utf-8”?>
<species-file file-format-version=”1.0”
        <species id=”60” name=”60_cornus_mas_512.png” max_height=”5.00”>
                <common name Lat=”Cornus Mas” />
                <common name En=”.... />
                <appearance type=”1” filename=”cornus_mas_512_Fol.png” width=”10.0” height=”5.0”
/>
        </species>
```

```
<species id=”61” name=”61_Fagus sylvatica01.png” max_height=”45.00”>
                <common name Lat=”Fagus Sylvatica” />
                <common name En=”.... />
                <appearance type=”1” filename=”Fagus sylvatica01_Fol.png” width=”15”
                        height=”25.0” />
</species>
```

```
<species id=”63” name=”63_fraxinus_ornus_1_512.png” max_height=”25.00”>
                <common name Lat=”Fraxinus Ornus” />
                <common name En=”.... />
                <appearance type=”1” filename=”fraxinus_ornus_1_512_Fol.png”
                        width=”12” height=”15” />
</species>
        <....>
</species-file>
```

Table 4.7.

Having acquired the available data, further analysis is required to define a valid pipeline and to obtain a potential natural visualisation of the territory: actual DTM, historical maps with ancient river systems, litho-stratigraphic regional maps, geological regional maps, vegetation maps, archaeological maps and information from archaeological surveys. It is now necessary to modify the archaeological landscape dataset previously created. The first step would be to modify the actual DTM, trying to reconstruct the Roman geomorphology. The new DTM is obtained by data interpolation, and for this reason has a level of uncertainty and reliability very closely connected to the available data and its distribution

[51] http://www.vterrain.org

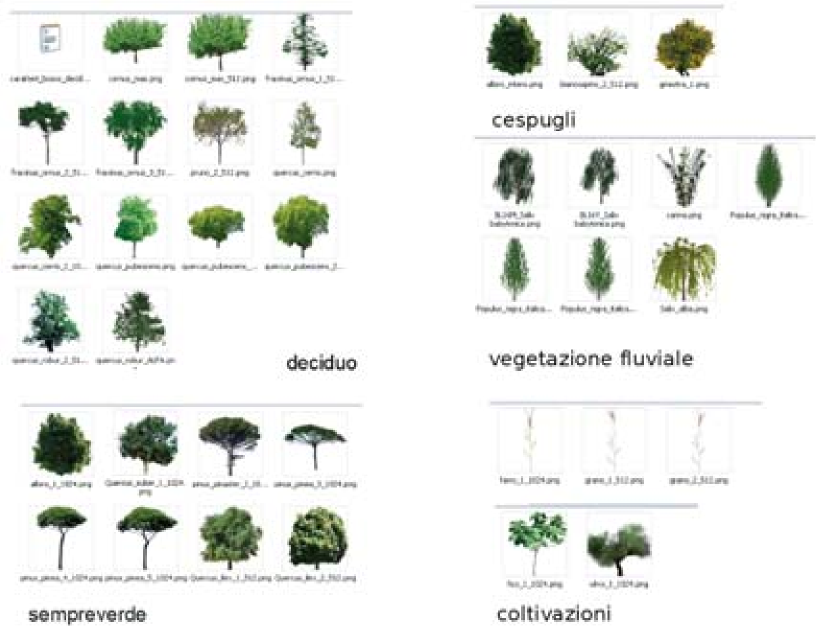

Fig. 4.5. Roman potential vegetation digital library.

over the territory. Useful sources are: archaeological excavations, or known modern morphological modifications such as caves, etc. For this reason, it can be accompanied by a *reliability and distribution map*, indicating the most and least reliable areas (Pescarin 2000: 155–158; Cardarelli *et al.* 2000: 200–210). Natural characteristics, taken from historical, archaeological maps and environmental indications are added to obtain the Roman hydrography. We can then calculate Potential Landscape Units, through the comparison with lithostratigraphy, slope and terrain depth. The slope grid can have several Orographic Classes assigned to it (an example is reported in *Table 4.8*).

The Slope grid, reclassified depending on Orographic Classes, is then used in combination with Lithostratigraphic Classes, previously combined with terrain depth information (Volpe – Arnoldus-Huyzendveld 2005), as reported in *Tables 4.8* and *4.9*. This operation is performed through calculation among grids of the same resolution. At the end we obtain Potential Landscape Units.

To each unit is assigned more than one LUT. If we use a matrix to describe each unit, we can see that in one cell more than one potential cultivation can be found. If we observe the first cell (C/P/F), we have plain and alluvial terrains with potential cereal or pasture usage.

Slope Values	**Orographic Classes**	
0–1% (0%)	Plateau: thalweg; Flat landscape	S1
0–3% (2%)	Very gentle slope: agricultural terrain; Sub-Flat landscape	S2
1–8% (4%)	Gentle slope: heavier agriculture; slightly wavy landscape	S3
4–16% (10%)	Moderate slope, sloping; wavy landscape	S4
10–30% (20%)	Moderately elevated slope: difficult agricultural activities; Hilly landscape	S5
25–60% (35%)	High slope; steep landscape	S6
> 45% /60%)	Very High slope: deciduous forest limit	S7
Depth Values	**Classes**	
< 25 cm (15 cm)	Extremely limited depth	D1
25–50 cm (40 cm)	Very limited depth	D2
50–100 cm (70 cm)	Limited depth (moderately deep)	D3
100–150 cm (120 cm)	Deep soils	D4
> 150 cm	Very deep soils	D5

Table 4.8. Land Slope and Soil Depth Classes (in Arnoldus-Huyzendveld *2009: 23).*

Type of terrain		Deep Soil	Mod. deep soil	Shallow soil
Alluvial terrain	***L1***	L1a	**L1b**	L1c
Volcanic Tuff	***L2***	**L2a**	**L2b**	**L2c**
Gravelly terrain	*L3*	L3a	**L3b**	L3c
Schistose terrain	*L4*	L4a	**L4b**	L4c
Tufaceous terrain	***L5***	**L5a**	**L5b**	**L5c**
Arenaceous terrain	*L6*	L6a	L6b	L6c

*Table 4.9. (*Volpe – Arnoldus-Huyzendveld *2005).*

	L1b	**L2a**	**L2b**	**L2c**	**L3b**	**L4b**	**L5a**	**L5b**	**L5c**
S1	C/P/F	C/V/O	C/F	C	P	C	C/V/O	C/F/P	C
S2	C	V/O/W	P	C	P	P	V/O/W	P	C
S3	W/P	W/P	W/P	C/W/P	W/P	W/P	W/P	W/P	C/W/P
S4	W/P	W/P	W/P	W/P	W/P	W/P	W/P	W/P	W/P
S5	P	P	P	P	P	P	P	P	P

Table 4.10. Example of Roman Potential Landscape Units matrix:
Terrain potentially suitable for forest (W), pasture (P) or, in grey, agricultural activities (cereals: C, olive trees: O, vines: V, fruit: F).

Further useful indications, in possibility reduction, come from ancient authors like Cato, Varro and Columella (appendix B). From their writings it is possible to gain a better understanding of the use of the territory around Rome, where cereals were not extensively cultivated. So some of these land units could be left as pastoral farming.

From the social, cultural and economic analysis, it is possible to add a further variable of agricultural land units: these units in fact were divided into smaller parcels of land based on the agriculture subdivision methods used *(limitatio* or *centuriatio)*. Old aerial photographs can come in very useful in the identification of such traces. In the case of the Via Flaminia project a trace was found in a 1944 frame, which was useful to improve definition of the orientation and size of these parcels of land (*Fig. 4.6*).

Fig. 4.6. A 1944 aerial photograph with a trace of ancient parcelling (courtesy of V. Vassallo).

When we add anthropic characteristics, such as the Roman roads system, Roman villas or farm locations, etc. we can further define the correct usage of each Landscape Unit.

The presence of a villa with remains of grain deposits may be a probable indication of cereal activities in that area. Furthermore Roman roads were often flanked by trees, such as elms (*ulmus*). Main consular roads, especially those near cities, paved with basalt stones (*basolatae*), would have been better taken care of. Along these roads, funerary monuments that in some cases can still be seen were built as great memorials to Roman families (*Fig. 4.7*). No agricultural activities

Fig. 4.7. The Roman road: via Appia with funerary monuments (photo B. Trabassi).

Fig. 4.8. Potential Roman landscape of the northern area of Rome.

in these areas could be undertaken, so a buffer can be calculated and subtracted from previous classes.

Also "cultural" information, such as the use of keeping a safe, uncultivated area around most important rivers, such as the Tiber (mainly to avoid floods), can be useful to indicate a certain type of vegetation.

Fig. 4.9. Potential Roman landscape of the villa.

Residential and productive structures are then added. Through a GIS analysis, "Thiessen polygon" (Appendix B), the extension of competence territory can be calculated. This analysis should also take into account the importance of the site and its distance from rivers, roads or other kinds of boundary, and therefore how far it was suitable for viability and hydrography (Clarke 1977a; Di Gennaro *et al.* 2005). Another useful spatial analysis is "catchment analysis", that can serve to identify farming or pasture areas, taking into account also natural springs and other water sources.

At the end of the process three main distinctions were made: cultivated and uncultivated terrain, and woodland, while Roman potential vegetation was divided into 7 classes as explained in *Table 4.11*.

Cultivated terrains	Agricultural terrains for cereal usage
	Agricultural terrains for vine or olive trees
	Agricultural terrains for fruits
Not cultivated terrains	Pasture, bushes
Woods	Forests

Table 4.11.

At the end of the process, after the reconstruction of the Roman potential environment, 3d models of the archaeological sites were added, with two different approaches: monuments with enough information were completely reconstructed, while the others were treated in 3d as simple evocative symbolic monuments (a model for each category) (*Fig. 4.10*).

Fig. 4.10. The ancient landscape reconstructed with its monuments.

Unfortunately many questions will remain open and unsolved. But the theoretical approach does allow integration of input data and as a result the re-processing of potential landscape.

When we compute such models we often find land units of irregular shape, quite unrecognizable as natural norms. It is useful for this reason to use a grid or mesh simplification. Several mesh simplification algorithms have been developed in recent years to eliminate some points of a mesh, within a certain value (Luebke *et al.* 2002; Cohen *et al.* 1996; Agugiaro – Kolbe 2009). These algorithms use several techniques, oriented to point decimation, edge collapse or triangle collapse, keeping some variable approximation to preserve details.

Chapter 5

Communicating the Landscape

This chapter presents specific techniques used to visualize landscape reconstructions, from a twofold perspective: research and dissemination. Although we often consider "communication" as a final, non-scientific and not even essential step, we need to reconsider this assumption. Most of the time the word "communication" is used instead of "dissemination". There can be no real distinction, in fact, between research and communication, since we need to communicate while we develop our research and while we disseminate its results.

Dissemination regards the diffusion of scientific results to both a restricted and broad-based community, the circulation of acquired knowledge. It uses various communicative languages and media, such as publications, drawings, movies, interactive applications, etc. It can be directed toward a heterogeneous audience, with the goal of making the information on our past landscape accessible. In order to be as effective as possible, it requires specific technologies and techniques, adequate to the kind of communicable information and to public access and understanding.

Technologies for *research* regard a more limited group of people, the scientific community, whose interests are closely connected to the research subject and its aims, within a multidisciplinary framework. Communication, as previously mentioned, is part of the research process. It makes use mainly of *visualisation* and natural languages – often in combination – during data acquisition, interpretation, analysis, model development, simulation and cross-networking.

5.1 Dissemination

5.1.1 Drawings

Images are commonly used in science to present data. There is still some debate about what image type should be used, whether 2d-digital or 3d-digital or hand-drawing. Archaeological drawings of human artefacts, such as stone tools, are sometimes still preferred to photographs. The human drawing system, in fact, is an *observational tool.* Drawings are synthetic representations of selected characteristics. When we consider the innumerable scientific images we can see a systematic connection between (1) image types, (2) purposes, and (3) contexts of use (Adkins 1989; Piggott 1978).

Professional drawers have produced wonderful artistic reconstructions of past landscapes. The best, along with their artistic skills, often work together with archaeologists and palaeo-environmental experts. These experts in fact provide exact references and information which enable correct representation, which is, nonetheless, a personal vision developed by combining the perspectives of the archaeologist, the artist and the naturalist.

If we follow the career of these professionals we find very impressive reconstructions of ancient landscapes. A well known historical reconstruction artist is Alan Sorrell (1904–1974), who travelled England and Wales, bringing vividly to life ancient monuments from the prehistoric up to those of relatively recent times. The Imperial Rome drawn by Gilles Chaillet or the Egyptian landscapes by Jean-Claude Golvin are other examples of amazing visualisations (Harris – Fairchild Ruggles 2007; Golvin 1999, 2007).

These drawings, thanks to their pictorial technique, help create emotional reconstructions. Their main limitations lie in the bi-dimensionality of the media and, most of all, in the static nature of the representations. The effort put into redrawing, whenever new data or interpretations appear, create a serious problem of updatability in some cases.

Today, artists and designers use a mixed technique. The drawing is first done with a traditional technique, on paper, and afterwards refined in various phases. 3D simple digital reconstructions of principle monuments are sometimes developed. They are used to gain different perspectives and therefore to choose striking viewpoints for the final version. This system permits a sort of "updatable" version of the drawing, which can be more easily re-drawn or repainted from the same viewpoint, changing just a few details. An example of this technique is used by Ink Link Studio[52].

5.1.2 Not interactive media

The film industry still represents the most mature media for cultural heritage dissemination, with its schools, experience, comparisons, feedbacks and success. And also a colossal market. Movies can create involvement, thanks to skilful shots, effects, sounds, plot and with a shrewd direction, creating in the spectator a sort

[52] http://www.inklink.it

of personal experience. With a movie, you can get the public to understand many concepts in a short time and with immediacy. Moreover, story-telling techniques, as used in film production, are richly communicative, obtaining good results in terms of public satisfaction and knowledge transfer. This technique employs a mix of video sequences, images of real places, ancient maps, drawings, computer animations, characters and digital effects.

Nevertheless, on the other hand films are *linear* media. This characteristic makes them immediate, but it is also their limitation, from a certain perspective. When we watch a film, i.e. a computer animation of a reconstructed territory, the realism of the reconstruction is taken as *reliability*. We trust in the accuracy of the director or the computer scientists. We cannot see what there is in the backstage, how the reconstruction is done, which sources are used, which detail and accuracy level is followed. In this sense, we end up in *complete passivity* in front of the screen (Turkle 1997). This doesn't mean we shouldn't make use of films, obviously. Videos are created, in fact, in almost every virtual archaeology project. Moreover virtually all TV programs on archaeology or history today use computer graphic animations and renderings. We just need to be aware of the risks as well as the benefits when we plan a communication project dedicated to a public.

In the *Imperial Forum Museum*, in Rome, the reconstruction of the territory is proposed in panels and in a video, composed using computer graphic renderings, traditional watercolour drawings and real photos (*Fig. 5.1*). Other examples are the videos created for the Seabed Project, commissioned by Wessex Archaeology, or the Stonehenge Landscape reconstructed from Lidar data[53]. Also in the *Ca' Tron project*, the entire work of reconstruction of 20,000 years of history was summarized in a short video (Appendix A). Photo-realistic reconstructions and videos have been developed by CNR IBAM within the *Jure Vetere project*, where spatial analysis was used to reconstruct the Medieval potential rural landscape (*Fig. 1.1*, Fonseca *et al.* 2007; Roubis *et al.* in print), or in the reconstruction of the territory of *Metaponto*, in Italy (*Fig. 5.2*).

In the Virtual Museum of Ancient Via Flaminia, accessible in Rome in the Roman National Museum at the Diocletian Thermal Baths, a mixed technique has been developed. Real time VR interaction, in fact, is mixed with videos on specific aspects of ancient landscape, characterized by a "scientific-descriptive"

53 http://video.google.com/videoplay?docid=1246762325049132604;
http://www.youtube.com/watch?v=pzYUx4l80m8

Fig. 5.1. Imperial Forums in Rome. In the exhibition of the museum different media (video/drawings) are used to make visitors understand how was the centre of Rome during Imperial Times (Sovraintendenza ai Beni Culturali of Rome. Museum of Imperial Fora-Scientific direction: Lucrezia Ungaro, graphic by InkLink Florence).

Fig. 5.2. Digital photorealistic reconstruction of Metaponto (F. Gabellone, CNR IBAM, commissioned by Basilicata Superintendency, 2006).

language and with other videos created with a different and more personal "story telling" style (Appendix A) (Forte *et al.* 2008; Forte *et al.* 2007). Story-telling, although a well tried research field, has recently been taken into account in a new interdisciplinary perspective: *virtual story telling*, the use of this collection of techniques in Virtual Reality applications[54].

5.1.3 Landscape Virtual Museums

How can we overcome passivity and opacity? How can we access "the dark side" of reconstructions? Through *interactivity*, *transparency* and *openness*.

Examples of a possible use of all these characteristics are *Landscape Virtual Museums*. They are Virtual Reality (interactive, real time) applications specifically for landscape exploration and public access. In the article written in 2006 with Maurizio Forte on "Virtual Museum of Landscape" we defined it in this way: "*A virtual museum of landscape regards, first of all, the process of virtualization of dynamic relations concerning the ecosystem, humans, animals, plants, soils, earth, water, etc. It is an artificial ecosystem, map and alphabet of the landscape itself*". Such a museum is "*focused on generating a holistic view of the environment, because without environment we cannot describe a landscape, and an ecological model*" (Forte – Pescarin 2006: 87).

If we want to communicate what a territory was like in the past, who used to live in it, or which archaeological monuments could be seen, we can visit the place (in this case the landscape will be the museum of itself), read a book or visit a "non-place", such as a virtual museum. Thanks to specific applications, the user can interactively interrogate elements, models, materials, becoming familiar with dynamic and static aspects. Through the creation of maps, it is possible to provide the user with interpretation instruments, which can help to decode something that no longer exists and is, therefore, very alien to our contemporary awareness. Without a code, in fact, we cannot achieve an interpretation. In a VR museum, the landscape is approached synchronically and diachronically. It becomes "*an open and evolving model, a scenario of simulation of artificial life, integrating different information ontologies*" (Forte – Pescarin in print: 87).

Landscape Virtual Museums consist of a variety of components:

1. Maps (ancient maps, cybermaps, etc.);
2. GIS (vector thematic layers);
3. Geoimagery;

[54] There is an annual international conference dedicated to interactive story telling (International Conference on Interactive Digital Storytelling): ICIDS 2008 Erfurt, Germany, November 26–29, 2008, Proceedings, Vol. 5334, Spierling; Szilas, Nicolas (Eds.), 2008.

4. Environmental information (soil maps, land use maps, geological maps, potential ecosystems etc.);
5. Anthropic information (archaeological map, cadastre, etc.);
6. Digital archives (databases, repositories, digital libraries);
7. Interactive behaviour (querying, walking, flying, picking, slicing, editing, etc.);
8. Viewpoints (the landscape seen from specific perspectives);
9. Places;
10. Relations;
11. Dynamic simulations;
12. Story telling (video, past literature or sources, contemporary stories and memories);
13. Artificial life.

How can we build a Landscape Virtual Museum? Unfortunately there are not many definitive answers or well-defined guidelines, also because available examples are in most cases the prerogative of restricted groups or scientific communities.

Nevertheless, many projects of the VHLab team at the National Research Council (CNR) or of other institutions and companies such as Visual Dimension, University of Foggia, University of Virginia, CINECA, etc. have demonstrated the potentiality of these VR museums: Aksum project (Forte 2003b), Certosa Virtual Museum (Guidazzoli *et al.* 2004), Narrative Museum of Archaeological Appia Park (Forte *et al.* 2005), Delta Po River VR museum (Guidazzoli *et al.* 2004), Virtual Bononia (Pescarin *et al.* 2007), Virtual Rome (Pescarin *et al.* 2008), Flaminia Virtual Museum (Forte *et al.* 2007), Ename TimeLine exhibition, Itinera Time Machine, Rome Reborn.

In the case of Aksum, the archaeological landscape was reconstructed by remote sensing analysis and ethnographic studies, collecting the results of ten years of excavations in Ethiopia carried out by Boston University, Naples Oriental University and CNR. The entire territory was generated in 3D, using Terravista simulation software[55], while models of the main archaeological structures were placed in relation to roads, rivers and geomorphology. A Desktop VR (DVR) application was developed using the VTree (CG2) OpenGL library and a Vision Station was used to visualise it, simulating a 360° real time immersive exploration

[55] http://www.terrex.com

of the territory (*Fig. 3.6*: bottom left). A "sound GIS" was also created in order to give a deeper *perception* of being immersed in the landscape: the sound of water near rivers, of wind on leaves and birds close to woods, the voices of rituals approaching the villages. The DVR application was shown during an exhibit on the history of cartography in 2002 in Rome (Bard *et al.* 2007; Forte 2003b). On the same dataset, another VR application was developed for a Virtual Theatre, an immersive space characterized by a big semicircular screen and stereo projection, specifically for researchers' interaction. This application, in fact, developed with Multigen Vega[56], was strongly oriented to database search and real time visualisation of DB results. For instance, it was possible to identify in the database all archaeological structures that shared similar characteristics or belonged to the same chronological period, and visualize them in 3D in the archaeological landscape, together with multimedia meta-information (*Fig. 3.6*: right)[57].

Another VR landscape museum was created more recently for the Delta Po river project. In this case the final application was used to create two interactive installations (kiosks) in small visitor centres of Rovigo province, in Italy. The landscape itself became the interface to access information on the archaeology of two Roman sites, and also the history of the evolution of the coastline over the centuries (Guidazzoli *et al.* 2004; Pescarin – Ruzza 2004).

In *Ename*, Belgium, a long lasting project has reconstructed the history of the village from the 11th century. The entire work has been exhibited in the local museum thanks to the *TimeLine* application (*Fig. 5.3*).

Another virtual environment dedicated to a scientific exploration of a territory is the *Itinera Time Machine* project. The system, developed in the Digital Archaeology Lab of the University of Foggia, in Italy, is based on the scientific and archaeological documentation acquired in the field from the site of Faragola (Ascoli Satriano, FG). The Time Machine brings the visitor and his avatar back in time to explore different hypothetical reconstructions of the site and of the stratigraphic process (*Fig. 5.4*). He can also watch the threshold between

[56] Vega Prime by Multigen Paradigm is a tool for the creation and deployment of visual simulation, urban simulation, and general visualization applications (www.multigen.com/products/runtime/vega_prime).

[57] The Virtual Museum of Aksumite landscape was developed by CNR ITABC, under the direction of Maurizio Forte, Aracnet (VTree library and Vision Station) and CINECA (Vega and Virtual Theater). More information on: www.vhlab.itabc.cnr.it/Projects_Aksum.htm. The exhibition took place in Rome at EUR during the annual conference of MondoGIS (22–24 May 2002).

archaeological reality and reconstructive imagination, through the visualisation of the inter-connections of stratigraphy and interpretative traces (De Felice *et al.* 2007).

An interactive space was recently opened at the Roman National Museum of the Diocletian Thermal Baths in Rome, dedicated to the virtual multi-user exploration of the ancient Via Flaminia (*Fig. 5.5*). In the Virtual Museum, located inside a real museum, visitors can choose one of four avatars and explore together the archaeological landscape, discovering its aspect during late Republican and early Imperial times, and also meeting historical figures, such as the emperor Augustus himself or his wife, Livia (Forte *et al.* 2006; Forte *et al.* 2007)[58].

An example of a Virtual Museum dedicated to an immersive exploration of the archaeological site of Sacred Angkor, in Cambodia, or dedicated to Place-Hampi in India, are those developed by Sarah Kenderdine and Jeffrey Shaw, with the Museum Victoria, Swinburne University, Royal Melbourne Institute of Technology (RMIT), Monash University and Adacel Technologies in Australia. The environment (stereographic panoramas of the temple complex) is visible in the Museum, thanks to a state-of-the-art display environment, a unique place for the visualisation of scientific and historical ideas, and associated objects[59].

Fig. 5.3. Ename archaeological site reconstructed in different phases 1020/1663 (right). Interactive application inside the local museum (left). (D. Pletinckx, Visual Dimension).

[58] http://www.vhlab.itabc.cnr.it/flaminia

[59] http://www.vroom.org.au, http://place-hampi.museum, http://www.vroom.org.au/pdf/kenderdine_avatars.pdf

Fig. 5.4. Itinera Time Machine project, Unversity of Foggia, IT (courtesy of Volpe and De Felice).

Fig. 5.5. Flaminia Virtual Museum.

5.1.4 Social network and Virtual Communities

In 2004, I followed the preparation of the Digicult Thematic Issue 5, dedicated to “Virtual Communities and Collaboration in the Heritage Sector” (Geser *et al.* 2004). This report divided Virtual Communities into two main typologies:

1. *Interest groups or discussion groups* (web-based discussions) focussed mainly on creating discussions or participation on specific topics, using mainly simple tools such as: newsletters, newsgroups, chat, IRC (Internet Relay Chat), Web-cam in real-time video conferencing meeting, groupware, MUD & MOOs.
2. *Multi User communities*, whose main goal is to create a *meeting experience* among participants, through advanced 3d tools. 3D environments are re-created and users are projected into the cyberspaces by means of an “avatar”, who represent themselves even while communicating. The first well-known platforms were Blaxxun, Second Life and ActiveWorlds[60].

Belonging to this second group, there is an interesting project Quest Atlantis. With its 200.000 students, QA was developed by Indiana University. In this project artificial three-dimensional worlds, as in the case of the OPEN Virtual Parks Project, are re-created with learning purposes to immerse children, ages 9–15, in educational tasks (quests) (*Fig. 5.6*). “Quest Atlantis leverages multi-user (online gaming) technologies to have QA students and their families virtually explore the rich histories and beautiful natural environments of National Parks. Through such engaging learning environments we hope more people will develop a greater appreciation of our shared global heritage”. The virtual experience inside the landscape enables young people to learn without really noticing that they are. Each one, in fact, is appointed to act as a specific character (the scientist, the ranger, the archaeologist), solving, alone or together with other students, impelling problems that even threaten the end of an ecosystem (Barab *et al.* 2007)[61].

Another example of the possible use of multi-user virtual communities comes from the University of California, Merced, where the reconstruction of the Roman Villa of Livia in Rome is used to teach undergraduate students, inside Second Life world, or in the case of the “Akragas doors project”, developed by No Real,

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[60] http://www.blaxxun.com; http://www.secondlife.com; http://www.activewolrds.com
[61] http://www.questatlantis.org

where visitors can also dress up as a Greek *hoplite* and take part in an attack, thus gaining understanding of the military tactics of 6th century BC Akragas, in the Valley of Temples near Agrigentum, Sicily (*Fig. 5.7*), or also in the case of the Digital Humanities island developed by King's College of London (Appendix B).

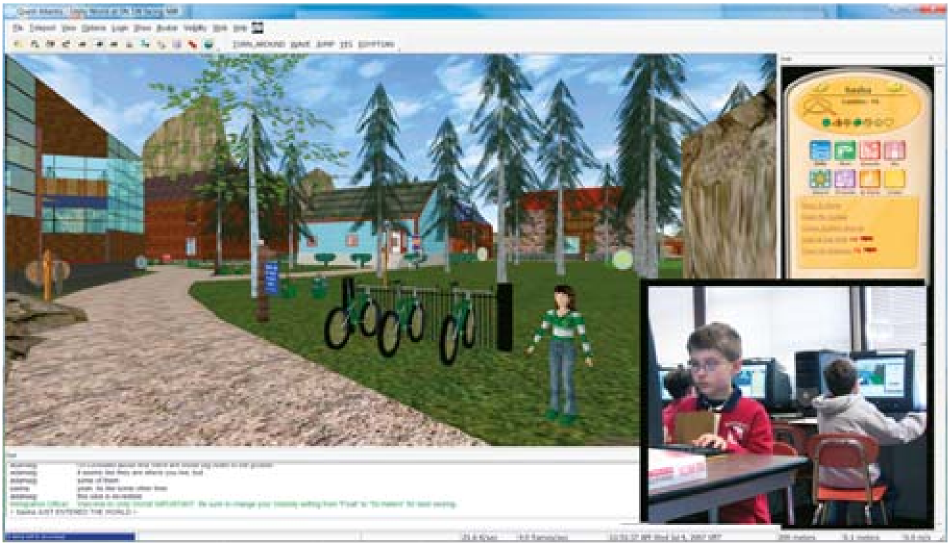

Fig. 5.6. Quest Atlantis on line educational experience for young students (www.questatlantis.org).

Fig. 5.7. The Second Life version (left) and a frame of the video in computer graphics (right) dedicated to the historical evolution of the defensive system of the ancient Agrigentum, during 6th AD. In Second Life (left) an ancient door has been reconstructed with minor realism but with a better focus on interactive potentiality of visitors to freely visit the space (D. Borra, No Real).

Key words of these communities are: communication, exchange, common interests, confidence, interaction, intermediation, authenticity, identity, and sustainability.

Apart from very few experiences, significant examples dedicated to ancient landscapes are lacking. 3D communities are commonly used as a sort of 3d chat room, as in most Second Life islands, where what people commonly do is just meet and talk.

Nevertheless, there are institutions which could be really interested in creating Landscape Virtual Communities. Museums of territories or Archaeological and Naturalistic Parks may obtain positive results in the creation of communities centred on e-learning or social communication and participation, as in the cases above mentioned. They can help to create common interests and new synergies between public and institutions, also with the exchange of memories and stories. The creation of new landscape virtual communities, based on narration, can give importance also to social features, not just cultural, thus helping to produce new knowledge, public involvement and awareness through shared participation in cultural policies, within democratic contexts.

Through these cyberspaces, powerful learning and tourist tools, it might be possible to visit archaeological territories virtually, meeting other visitors or guides for a greater and more intense understanding of ancient landscapes. But it would also be possible to shift a traditional perspective, creating an "upside-down" view of cultural digital portals with participants interacting directly and adding, not only receiving, content and information. In Virtual Communities cyberspaces become places, not just tools, and the system is the people (Rheingold 1994).

If the communicative level of VR communities can be very high, there is a problematic aspect that should be taken into account: the geospatial dimension. They are more suitable for the creation of scenarios or small environments rather than landscape. These cyberspaces are focused, in fact, on exchange and experience much more than on the scientific value of the geographical dataset. In most cases, scenarios are really simplified, so as to enable a diffusion over the Internet, and sometimes they should be created inside the chosen platform (as in Second Life), since to directly import geographical data is not allowed.

Another problem of these projects is that their success depends strictly upon how much they are used. In sociological studies, it was shown how similar virtual communities are to real communities. To have success they need to have a goal, be limited to that goal, have fixed rules, build habits, and be based on the idea of sharing and exchanging. Unfortunately, it is difficult to obtain an "exchange" when institutions try to exert close control over the communities, limiting them just to a museum activity for visitors.

5.1.5 Mobile communication

We cannot talk about communication without touching on mobile technology. It was the first to be developed for environmental and tourist purposes with car navigators, thanks to the integration of commercial GPS in low cost devices. Today this field is rapidly evolving in terms of digital content, moving toward future generation devices, such as smart mobile phones. Archaeological sites can be explored while visiting the areas through systems that integrate geo-localisation of visitors and information provided directly on PDA or mobile phones. Precursors of these kinds of application were ArcheoGuide, an augmented reality systems developed to enable a virtual visit of archaeological sites such as Olympia in Greece.

Recently there are examples of interactive exploration of archaeological areas through integrated systems based on a centralized Multi-channel Service, as in the GITA project developed by Infobyte[62], which allows presentation of multimedia content on demand or automatically on mobile devices (mobile phones, PDA, SmartPhones) or immersive mobile displays (Augmented Reality devices for outdoor applications).

Another new and very promising field is 3d interactive content, such as educational games, available for smartPhones, like IPhone. This market, although at its very beginning, is already very surprisingly active. In the IPhone and IPod AppStore, at the end of April 2009 there were almost 1 million downloaded applications!

5.2 Research, communication and simulation

5.2.1 3D webGIS and VR webGIS

After the success of Geographical Information Systems in archaeology, and their increasing use over the web through webGIS applications, today there are new typologies of web-based geospatial applications, such as 3D webGIS and VR webGIS.

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62 http://www.infobyte.it

While GIS and webGIS are typically considered as 2d (or 2,5d) systems, 3D webGIS fully manage the third dimension, enabling at the same time geospatial data on line access. Thematic layers commonly used in GIS are wrapped on the 3d terrain (vectors, raster maps). In principle, 3D webGIS possess spatial analysis potentiality.

VR webGIS are applications which have attributes typical of Virtual Reality (real time 3d interaction behaviours), of web-based tools (networking, on line access) and also of GIS systems (geographical dimension, vector-raster data management). They can integrate different types of information such as: 3d terrains, vector layers, 3d models and metadata, vegetation, multimedia contents, etc. The landscape can be explored and queried through graphical interfaces. Chapter 7 is dedicated to these specific applications.

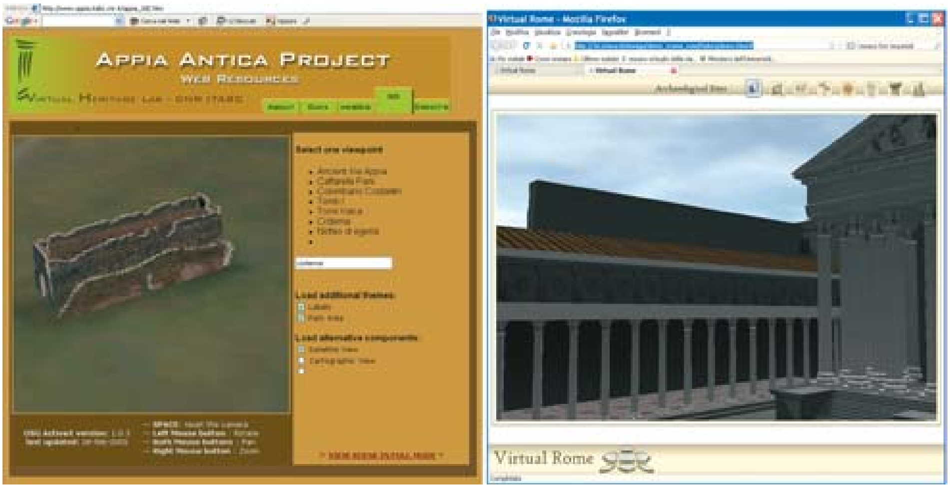

Fig. 5.8. Appia and Virtual Rome VR webGIS.
(www.appia.itabc.cnr.it; www.virtualrome.net)

Examples of VR webGIS were developed in the Appia and Virtual Rome projects (Appendix A). In these cases, the reconstructed archaeological and ancient landscapes were published in Internet, through a web plug-in, *osg4web*[63] which enhanced browser potentiality of 3d data exploration, querying and interaction. Users, no matter who and where they are, can access geospatial information and digital content through an interface, exploring the territory dynamically in

[63] http://3d.cineca.it/storage/demo_vrome_ajax/osg4web.html

different ways (flying, or walking on it), uploading other spatial dataset (2d, 3d, vectors, multimedia) on the landscape, to understand and analyse spatial relations better (*Fig. 5.8*).

5.2.2 Research Virtual Communities and Collaborative Environments

Landscape reconstruction is a multidisciplinary field which requires spatiality and interaction. For this reason, the emergence of interdisciplinary contexts is creating a need for research into a variety of fields. If interaction plays an important role in the dissemination of cultural information, this is even more important in VR applications for scientific communities, as in the case of Collaborative Virtual Environments (CVE). CVEs are a class of networking applications which support cooperation among remote users, through a common spatial environment and using 3d graphics; CVEs are updated so as to reflect the actions and the movements of the participants. In these communities, the exchange of information and data through the net, and the development of shared multidisciplinary interpretation sessions, based on scientific geospatial datasets, is essential. The future of the net itself seems to be connected with the future of community, democracy, education and science (Rheingold 1994). "A virtual community is a space where people can bring in their own objects and with these (digital) surrogates, their own interpretation [..] thus enriching shared knowledge" (Hazan 2004: 8).

Unfortunately, we don't have many examples of these specialized communities, focused on the sharing of specific knowledge and topics. But we shall be seeing several developments of these platforms in the near future.

The main characteristics of CVE are interaction, spatiality, inclusivity, editing, sharing, multi-disciplinarity, networking, and repository and library integration (*Table 5.1*). In these contexts researchers can exchange ideas and analysis, sharing the same dataset and environment as well, sometimes even the same perspective. Each participant can cooperate in the creation of the archive, in digital collection, and the creation of the virtual museum, bringing with him his own contribution (such as digital objects) and preserving those of others.

While in the modelling, design or military fields there are several examples of CVEs, there aren't as many examples in the Cultural Heritage field, and specifically in landscape archaeology. The causes may be mainly three: the cost of these solutions, their complexity and lack of flexibility, and also the lack of knowledge of their existence. Dealing with landscapes means having to manage a variety of data, such as: 3d models of different dimensions and resolution, detailed 3d terrains, high resolution geospecific images, vector thematic layers, vegetation, natural characteristics, etc. Each one has different attributes and might become a problem, when it is implemented into a VR system. MultiUser and On Line access amplify this problem.

Characteristics of VR museum for dissemination	**Characteristics of VR system for the scientific community**
Experience, story-telling	Research
Learning	Analysis, selection and comparison
Game	Openness and transparency
Interaction (natural)	Complex interactions
Perception	Cognition
Simplicity	Complexity
Involvement	Sharing
Interfaces	Flexibility
Design	Updatability
Realism	Reliability
Information	Data
Content	Metadata
Communication	Communication
Immersivity	3d geospatial dimension

Table 5.1. (Forte – Pescarin 2005).

There is also a fourth reason. Although there are still many technical problems in the development of such platforms, most complicated aspects aren't technical. As in the case of Landscape Virtual Communities, a successful CVE should be *used* by researchers. Unfortunately not everybody is interested in *sharing* information or data. Some might think that information de-contextualized and considered just as an exchange object is deprived of relevance, even dangerous (Hazan 2004: 9). We need to face the development of new CVEs also from a sociological point of view, to understand what interfaces and exchange mechanisms should be used.

In the research field, CVEs might be developed as fully editable environments or just as interactive spaces used to access complex scientific databases.

Recently, VHLab team at CNR ITABC has been involved in two projects, whose aim is the reconstruction of ancient landscape: a FIRB project on Robotics and Virtual Environments (Forte *et al.* 2008) and Virtual Rome (Pescarin *et al.* 2008; Calori *et al.* 2008). In these projects, as an archaeologist, I have been able to experience personally the complexity of a real multidisciplinary approach. For this reason, we have been pushed to experiment a more efficient approach, testing and developing examples of low-cost on line Cooperative Virtual Environments, based on Open Source and Commercial platforms. The FIRB project has developed a multiuser cooperative environment, available on line, which enables researchers to work together in the reconstruction of archaeological sites. It is based on VirTools Dev[64] and is available on line, with a common Internet browser (Appendix A, *Fig. 5.9*). Virtual Rome, on the other hand, has developed an Open Source web VR application, based on geospecific data, 3d models and multimedia contents, with front-end and back-end on line solutions, for the interpretation, reconstruction and 3d exploration of Roman landscapes (*Fig. 7.13*).

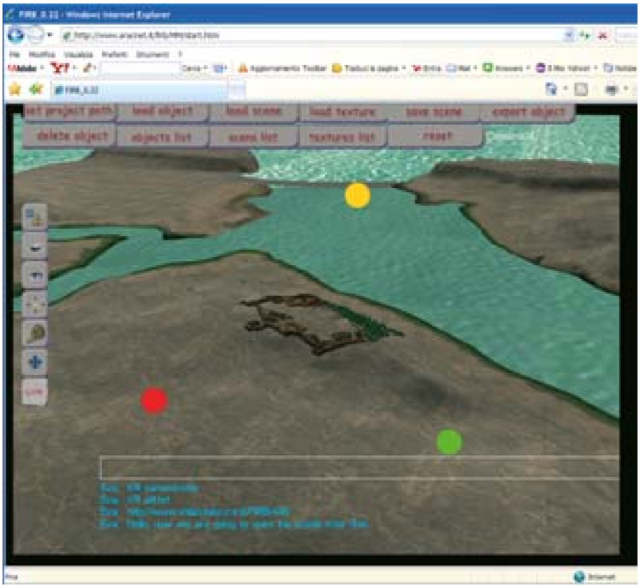

Fig. 5.9. Virtual Collaborative Environments for the research: Egyptian landscape reconstructed by CNR ITABC (E. Pietroni, CNR ITABC, Scuola Sant'Anna, University of Pisa).

5.2.3 Simulation models

Reconstructions can be used also as simulation spaces. This is quite a widespread application field in the hard sciences, such as chemistry, physics, etc. but is still not very diffused in landscape archaeology. Nevertheless, in architecture it is a well known practice, even when dealing with ancient monument reconstruction.

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64 http://a2.media.3ds.com/products/3dvia/3dvia-virtools/

An example is provided by a project of the University of Caen, in France, directed by Philippe Fleury, where a 19th century plaster of about 70 square metres representing Rome and made by the architect Paul Bigot is being scanned and completely reconstructed in 3D, becoming an interactive laboratory on Roman architecture (*Fig. 5.10*)[65]. A similar project was carried out by UCLA, Virginia Universiy and the Politecnico of Milan, on the plaster conserved in the Museum of Roman Civilization in Rome and representing this city in the 4th century AD, when Constantine was emperor. The result of the complex 3d scanning was post-processed and used in various media, also for communication and educational purposes (Guidi *et al.* 2005).

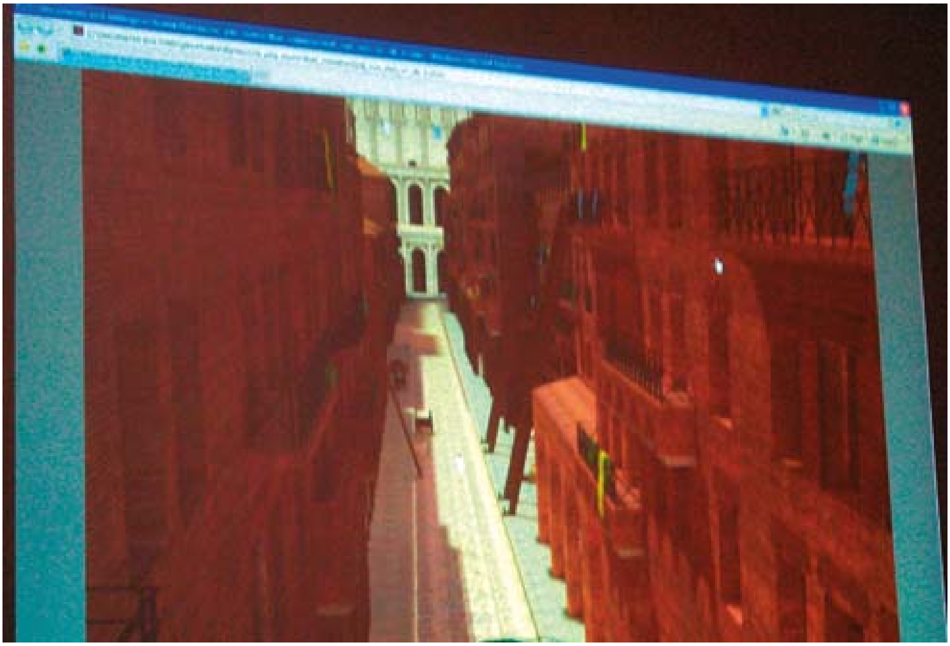

Fig. 5.10. Photo taken during CAA2008, during a real time session in the Plan de Rome virtual reality project (P. Fleury, S. Madeleine, Univ. Caen).

A simulation of landscape dynamics was developed in the *Exploris* project, on the eruption of the Vesuvius volcano in Italy. In this case, a mathematical model of the eruption temperature surface was calculated by supercomputers and

[65] Fleury, P. Madeleine, S. Réalité virtuelle et restitution de la Rome antique du IVe siècle après J.-C., in *Histoire urbaine. Société française d'histoire urbaine*, vol. 18, 2007: 157–165; http://doc.ocim.fr/LO/LO044/LO.44(6)-pp.20–23.pdf

visualised in a VR application. The territory around the volcano was reconstructed in 3D and connected to dynamic databases, containing e.g. population density. The result of the simulation was then visualised in real-time and connected to a time display, so as to analyse the effects of the eruption on the territory (*Fig. 5.11*)[66]. The same simulation could be performed also on the Roman landscape, reconstructing the original volcano's shape, as it probably was before 79 AD.

These simulations can go beyond the field of research: they can be successfully applied also in environmental services, for cultural policy evaluations and preventive archaeology.

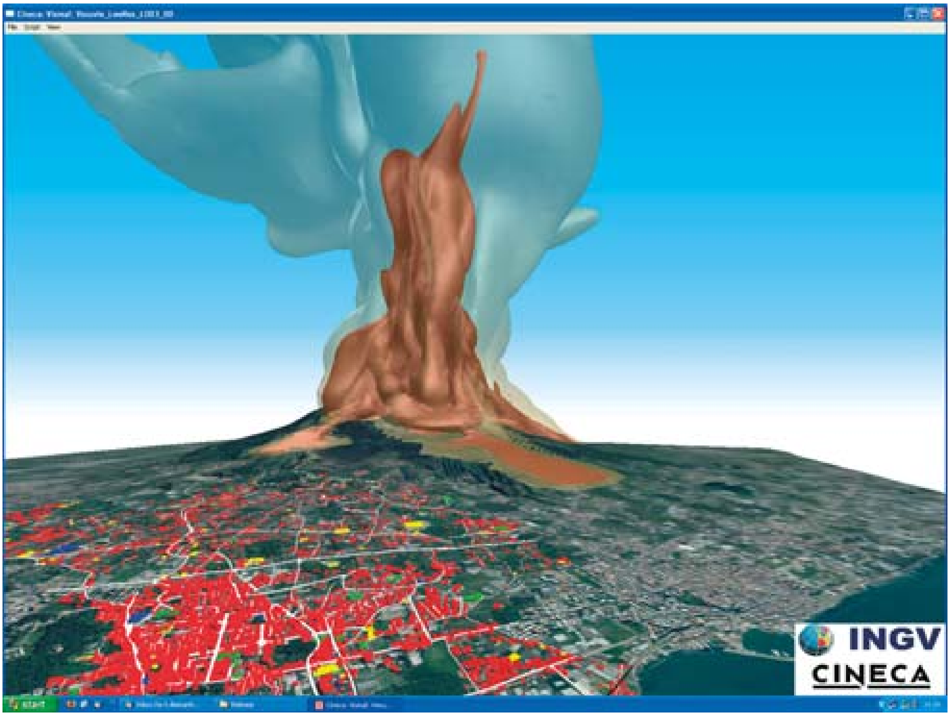

Fig. 5.11. Exploris project and the simulation of the eruption of Vesuvius volcano, with analysis of effects on the nearby Ercolano (courtesy of CINECA).

[66] http://exploris.pi.ingv.it/, Macedonio G., Costa A., Longo A. 2005, A computer model for volcanic ash fallout and assessment of subsequent hazard. In *Computer & Geosciences*, 31, N.7, 837–845.

5.2.4 Preventive and predictive archaeology

The use and application of *preventive archaeology*, changes significantly from country to country. In some cases, even within the same country, as in Italy, the rules change in accordance with individual regional regulations, due to the lack of clear central directives and effective coordination. From a theoretical point of view, preventive archaeology should be carried out by archaeologists and environmental experts in close cooperation with the administrators in charge of urban planning (Pescarin in print b; Cardarelli *et al.* 2004). The results in fact should be used, for example, in the definition of the archaeological *risk* or of building restrictions for patrimony preservation, while their use for *predictive archaeology* is still quite controversial. An archaeological map, in fact, is a necessary and reliable tool since it is based on real-based knowledge, acquired during scientific investigations. Unfortunately, it is not enough to define portions of the territory potentially rich in remains. Predictive archaeology is, rather, based on theoretical models provided by environmental, cultural and geographical observation.

In the United Kingdom the general application of preventive archaeology is defined by governmental rules, since 1990, through the PPG-16 (Planning Policy Guide)[67]. The results of archaeological investigations are then implemented in the Site and Monument Record, an on line archive of known or potential remains. This information has also a public level of visibility, through the on line ADS ArchSearch[68]. It gives the exact location of archaeological sites, visible also on google maps embedded in the page, as well as basic information and other connected resources such as historical maps[69], road maps and aerial images[70].

Also in France preventive archaeology is a well established practice. Early examples date back to the 70s. There is a national institute in charge of these kinds of investigation: INRAP, the Institute National de Recherches Archeologiques Preventive[71]. It contributes to the creation of the National Archaeological Map prepared by following clear rules, a document used by the State itself for urban and environmental planning.

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67 http://www.communities.gov.uk/index.asp?id=1144057
68 http://ahds.ac.uk/archaeology
69 http:// old-maps.co.uk
70 http://www.multimap.com
71 http://www.inrap.fr

Another example in this field is from Italy. CART (Carta Archeologica del Rischio Territoriale) is the territorial management tool, developed by the Institute of Artistic Cultural and Natural Heritage (IBC) in cooperation with Emilia-Romagna Archaelogical Superintendency and several public administrations. It is used as a tool for the knowledge and safeguard of our heritage and as a support for the planning of territorial interventions. CART is a GIS-based system connected with a geographical relational database, accessible on line for registered users. CART enables to add to and search archive information on the basis of various factors such as depth or location; to insert digitized excavations, researches or just traces recognized in historical maps or aerial images; to georeference data; to add geophysical and paleo-botanical analysis; to carry on spatial analysis for quantitative evaluation and simulation of potential reconstruction; virtual reality reconstructions; open access through on line interface at various levels; archaeological potentiality simulation for urban planning (depth or density simulation of possible archaeological findings).

The systematic classification and digitalization of all known archaeological data of a territory, in a geospatial system with editing, analysis and querying functionalities, is fundamental for several reasons: research, reorganization, standardization, availability of information and revision based on spatial analysis. The goal is to build a knowledge instrument on the state of the art of archaeological discoveries (archaeological maps), and a predictive instrument (risk map) useful to reconstruct ancient landscape dynamics in various historical periods. In this case, the reconstruction process produces preventive maps which can be used to support preservation, and our collective memory, for a better, more aware urban and territorial development.

Chapter 6

OpenLand: Open Source and Landscape Archaeology

6.1 Introduction

In 2001, in his famous book “The Cathedral and the Bazaar”, Raymond wrote that the style of the Linux community looked like a confusing bazaar, full of projects with different approaches. Although it would seem that only a miracle could bring about a stable and coherent system, this style works. The development of an open source project was compared by Raymond to a bazaar because it was different from a centralized approach like the common software development style. His objection referred to the need for a centralized approach, in relation to projects with a high level of complexity. In these cases, the traditional approach was directed at leaving the entire work of software development to individual genius or small bands of wizards, without any intermediate version available (Raymond 2000: 19–20). But the history of Linux and of some open source projects has indicated a valid alternative approach. The considerations that originally referred to software development might be of interest also to the archaeological field. Landscape reconstruction process could be inspired by some developments of Open Source tools.

In Cultural Heritage, projects do not have always a “linear” development, for several reasons, such as the continuous lack of substantial funding or the difficulties over sharing, or the way new data are found. This means that the “natural” development of a project is often subverted by more urgent priorities. Sometimes the projects themselves have a certain vagueness to allow for a necessary flexibility. If on the other hand we compare its approach to the one adopted in industrial and commercial fields, as in all those areas with a more pronounced economic impact, we can see the latter follows a “vertical management”, from the initial construction phase of a project to the hierarchical management of human resources. Several business models based on this approach have been analysed by economists for adoption by the humanities.

There is another reason why we can associate open movement and virtual heritage: the social aspect. The archaeological landscape, sites, parks, and historical monuments are heritage properties belonging to the worldwide community.

Researchers, scholars, and curators also have a social and public mission. This mission regards the study and conservation of our heritage to enable it to be transmitted to future memory.

Scientific research itself has a public dimension, in the creation of studies of our collective heritage and cultural landscapes, and also in the communication of such studies.

What is often underestimated is that progress in research is also founded on information sharing criteria. This will be increasingly clear in Europe, where, in a sort of "global competition", will emerge those who can get access to knowledge. The extension of an open source approach to the field of archaeological landscape may open up new horizons, in terms of available tools used and methodologies to be applied to sustainable projects, as EU projects such as Epoch[72] have demonstrated. The question, whether a "conversion" to open source and a rediscovery of a real public dimension of research in the actual economic panorama is really possible, is still open (Laser 2005). We could think about a softer approach, directed at the adoption of alternative possibilities to already available commercial products.

Although the Open Source movement started from software development, there is perhaps a lesson to be learnt also by cultural heritage (Stallmann – Lawrence 2002; Torvalds – Diamond 2001): "visiting a bazaar" might produce good results in terms of research's global (not just individual) growth. Open Source therefore can represent a possible alternative to commercial software and offer different models of project development and of business (AA.VV. 1999).

Open Source concerns the way a software is distributed, together with its code. It doesn't just mean access to the source code, as stated by the Open Source Initiative[73], but should satisfy the following requirements:

- free re-distribution;
- source code availability;
- opportunity for modifications and derived works;
- integrity of the author's source code;
- no discrimination against persons or groups or against fields of endeavor;
- continuity in the distribution of licenses;
- no license specificity for a product;
- no restrictions for other software;
- neutral development of technology.

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[72] http://www.epoch-net.org

[73] http:// www.opensource.org

In archaeology, we can treat Open Source as a movement that offers open (and often free) software, but we can also use it as a reference methodology for the development of a project or an application.

As we have seen in chapters 1 and 2, transparency in the reconstruction process is crucial. As a method, open source can offer several solutions to maintain transparency in the results.

In the next sections, I will try to describe its pros and cons, comparing a typical Open Source project with one belonging to landscape archaeology.

At the beginning, programmers freely shared the software they were developing, together with the source code. The result of this practice is described as an incredibly rapid development of the field, with many consequent positive effects on final users. At the end of the 80s this development started to slow down, perhaps in part due to the introduction of software patents, thus giving only binary programs to final users. This commercial strategy led to the creation of probably more stable, robust and documented software, but it also blocked the creation of new algorithms and tools. In 1984 those programmers who believed in a different philosophy decided to join the Free Software Foundation and the Open Source Initiative (Stallman – Lawrence 2002). Those who subscribe to the initiative and decide to publish their tools under a public license (such as GPL or LGPL[74]) believe that this can contribute to the creation of better software and to its rapid evolution. For an end-user, it means that it is possible to download and use tools (binaries or precompiled versions), modifying them (or asking for modifications) and adding new functionalities, appropriate for a specific purpose. It is also possible to continuously access new releases or updates and participate in the international community, as users, with requests and suggestions.

6.2 Open Source and Landscape Archaeology

While Information Technology is related to software and hardware, landscape archaeology concerns cultural and environmental information. Researchers in the former field are involved mostly in software development, while the interpretation process absorbs archaeologists, anthropologists and environmental experts. What I propose here is that this field can probably benefit from the application of an open approach. To what extent?

[74] For a description of most common licenses: http://www.gnu.org/licenses/

As described in the previous section, *participation* is a key element, typical of an open project, and connected to any further potential sustainable development. A project in fact can be maintained by the scientific community itself, if it is a research project, or by a users community, in the case of knowledge dissemination and communication. Involving people and taking them *into* the projects makes them aware of the scientific cognitive process or memory, enabling an easier continuous updating, preventing obsolescence. An open approach institutes a dynamic involvement process between players, encouraging a wider participation of the entire working group. Some analysts think that a new way, based on sharing and exchange, is slowly emerging, beside the typical private industrial economics, price-driven (Benkler 2005). Other studies have underlined that the use of technologies in various fields, such as in archaeology, involves a continuous state of tension between a "working-together" and a "working-apart" philosophy (Surman – Reilly 2003[75]). This dichotomy emerges even more clearly, when we consider the research that uses the network or that are web-based. In these cases, four main approaches can be identified: formal, informal, distributed and centralized (*Table 6.1*). Each approach tends to use different applications and tools, making a different use of reconstructions.

	FORMAL		
DISTRIBUTED	Research Networks, Collaborative Environments, Repositories	Traditional Media (web page, drawing, movie, broadcasting products), Intranets	CENTRALIZED
	Social Networks, Wikis, Blogs, P2P, MuDs	Alternative Media (Interactive Kiosks, Virtual Museums), mailing lists, games	
	INFORMAL		

Table 6.1. Schematic approach in cultural heritage.

Institutions, such as museums, universities, government bodies, etc. tend to have a more formal centralized approach, controlling information and communication, in a top-down perspective, through "linear" systems such as traditional media. In a few cases, there are experiments regarding a more

[75] On line version of the report is available at: http://programs.ssrc.org/itic/publications/knowledge_report/final_entire_surman_reilly.pdf

informal and interactive use, for example with Virtual Museums. They use mainly commercial products. The scientific community follows a more formal-distributed approach and employs some commercial tools, but also many open projects. The communication in this case, one-to-many, when directed at a public, or many-to-many, in the case of working environments, can in the future benefit from the diffusion of an open approach. In fact the construction of open systems which allow the exchange of data and information and the sharing of ideas inside multidisciplinary groups, can trigger a virtuous cycle, encouraging "working-together" initiatives, to the disadvantage of "working-apart". Interdisciplinary activities, in fact, are essential in the development of innovative and useful projects. In its initial phases, a project should involve a variety of people and experts, to indicate knowledge bases, necessities, interests and requirements. The definition of a common language is another requirement, the premise for and the consequence of this approach.

An open project of landscape reconstruction should therefore be characterized by an exchange and sharing practice, from its beginning distinguishing what the general development plan requires from the software development/use plan. The use of exchange tools (repositories, content management systems, etc.) and media (Internet) makes it really feasible (Luke *et al.* 2004).

6.3 Open networks

The use of a *network* is a fundamental requirement of an open and multidisciplinary approach.

The Internet is increasingly becoming a *working* environment and not only a communication media, useful to publish, often marginally, the results of research.

The network, thanks to the widespread development of physical infrastructures and the widespread availability of broadband connections in many countries, is today one of the most powerful media to access and diffuse information and knowledge.

The possibility of integrating different data, thanks to the network, increases *validation and criticism* of the research itself, preventing wasted effort and resources duplication. Moreover, it enables rapid development through sharing. The Internet is therefore an instrument for knowledge, communication and dissemination, but also for study and research (Surman – Reilly 2003).

Available tools are: on line database, Content Management Systems (CMS), on line multimedia repositories, webGIS, VRwebGIS and, in the future, also Collaborative Virtual Environments (Chapter 7).

6.4 Open tools for ancient landscape reconstruction

There are several open source tools already in use or potentially useful in archaeology, either as alternatives to commercial software or as starting points in the development of new applications specifically orientated to the field.

How can open tools be found? One of the principal sources is SourceForge[76], with its 100.000 projects and one million registered users. It is a space dedicated to open source projects, where programmers can exchange source codes and users can access binary software. It is considered the largest repository of available codes and applications. It is a public and open resource where it is possible to publish projects and share their codes or information on them, working together through the net. The use of this kind of shared space strengthens the quality of delivered applications, because they are also open spaces, where other skillful developers belonging to a broad worldwide community, can freely express criticisms. The idea itself of putting forward a project in such a "glass case", with tremendous visibility, represents a further motivation in producing products that are stable, robust, and error free.

It was said above that open source software is developed by several programmers contemporaneously, working on the same program (code), or who add sub-programs to the main one. Within this structure, the only way to produce reasonable results is to align and keep track of various versions, merging them, but preserving, at the same time, a history of the project. For this purpose, programmers use Software Configuration Management tools (SCM), such as CVS (Current Versions System[77]), Subversion (SVN) or Tortoise[78]. These softwares are exactly designed to control different versions and align them. Also in the landscape reconstruction process there are several researchers working on the same territory or on the same site or even model. Sometimes it can be very difficult to cooperate, avoiding wasted effort or duplication. A simple example of this approach is the shared writing of a document through an on-line management system, such as GoogleDocs. In 3d modeling this can already be seen. When

[76] This repository is available at: http://www.sourceforge.net
[77] http://www.nongnu.org/cvs/
[78] http://subversion.tigris.org, http://tortoisesvn.tigris.org/

different modelers have to work, for instance, on the same monument, but concentrating on different parts, it is quite helpful to use tools which can help to align them to the resulting merged model, keeping track of the different versions. An experiment in this approach was made during the Virtual Rome project, with the OSG Post Processing tool (*Fig. 6.1*) (Pescarin *et al.* 2008). Unfortunately there are no relevant examples in the "terrain" field, although this could be really challenging. Recently, there are some interesting initiatives that can provide stimulating suggestions for the scientific community. One of these is the Open Archaeology initiative, which hosts a number of sub-projects dedicated to tools specifically designed for archaeology, such as StereoPhotogrammetry, Digisite, and so on[79]. Another one is the Virtual Terrain Project, probably the most complete review web-site regarding terrain generation and visualization.

The complexity of landscape reconstruction makes acquisition and post-processing activities quite problematic. The risk is to create huge monographic

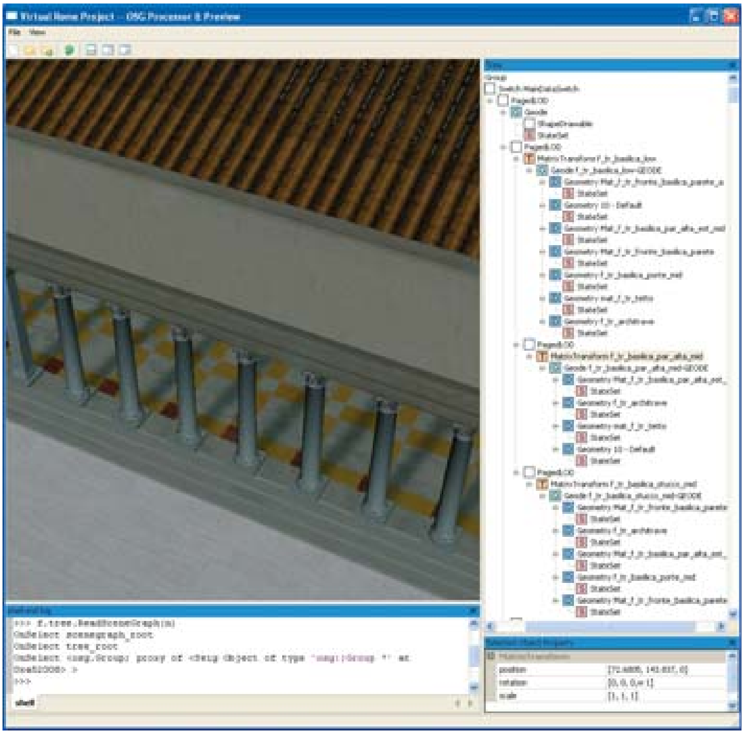

Fig. 6.1. The OSG Post Processing Tools (developed by CINECA, S. Imboden).

[79] https://launchpad.net/openarchaeology

studies, far from the spatial or temporal context, or which cannot be integrated into other research on the same topic. Integration is another central issue in data processing; it can be obtained by working inside a single digital “framework”, collecting and connecting data, procedures, technologies, formats, and methodologies, from different disciplines. In this way greater care is taken over exchange formats more than on standards, or on the methodological approach rather than on software lists. The more we use open exchange formats, the more researchers can be free to choose tools better suited to their uses. Projects and data can therefore be more easily updated and moved from one platform to another[80]. Users dependency on the software company in the case of commercial products is very great and makes for insecurity. If it fails, or decides not to produce a specific software we are using any more, we will no longer be able to read our data.

In Table 6.2 there is a schematic list of the most common open source tools, useful for landscape reconstruction, together with their commercial references. In the Appendix there is a more detailed description of most of these tools.

Category	Commercial tools	Open Source tools
Operative System	Windows, Mac	Linux, (CygWin)
Server	Microsoft IIS	Apache
Suite Office	Microsoft Office	OpenOffice, KOffice
Web browser	MSExplorer, Safari, Opera	Mozilla Firefox, Konqueror
Desktop Publishing	Macromedia Freehand, Xpress, FrameMaker	Inkscape, Scribus
Image Processing	Photoshop	Gimp
CMS (Content Management System)	Oracle	Mambo, Joomla, Drupal, PHP-Nuke, MediaWiki
CAD	AutoCad	Qcad, BRLcad
Panorama Tools	QuickTime, PhotoVista	PanoramaTool, PanoTools, PTStitcher OpenQuickTime (Linux), Hugin
GIS	ESRI ARCGIS, ARCpad	GRASS, QGis
webGIS		MapServer
VR webGIS and 3D webGIS	Skyline	OSG4WEB
Virtual Reality CG libraries, development toolkits	VirTools, Vtree, Unity3D	OpenSceneGraph, OpenSG, Delta 3D
Game Engine	Torque	OGRE

[80] On open formats: Open-document Standard Initiative (http://www.oasis-open.org/specs).

Terrain generator and Ecosystem generator	Terravista, Multigen Creator Terrain Studio, Visual Nature Studio, Bryce	OSGdem, Demeter, VTP
GPS software	SkyPro	OpenSourceGPS, GPStoolkit,
3d modeling	3D Studio Max, Maya	Blender, Art of Illusion, Wings 3d
Laser Scanner (acquisition, processing)	Cyclone, RapidForm	Grass, MeshLab, Scanalyze, MeshAlign, PointShop
3d viewer and web 3d viewer		
Software Configuration Management tools		CVS, Turtoise, SVN

Table 6.2.

Landscape reconstruction requires the contribution of various disciplines, as we have explained, in a dynamic process. An open approach contributes therefore to creating a *research network*, through which various and distant working groups could cooperate, using Internet. Moreover, the entire digital pipeline described in chapter 2 can be successfully designed on Open Source software, as can be seen in the proposed scheme (*Fig. 6.2*).

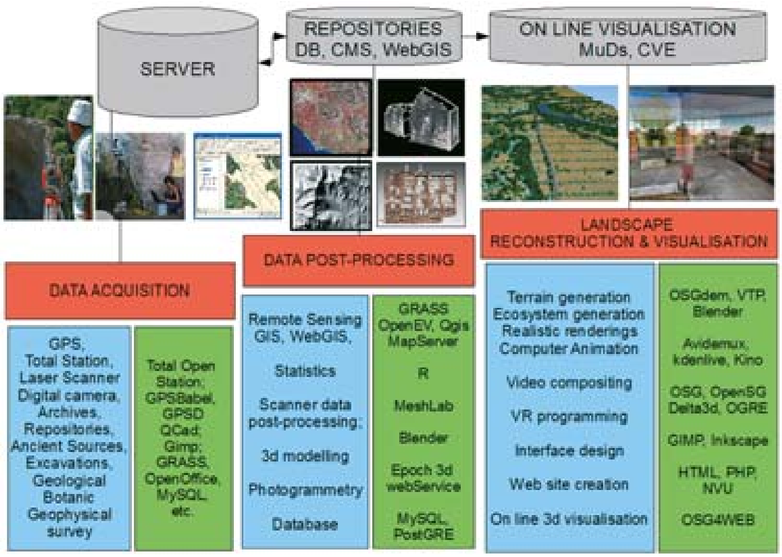

Fig. 6.2. The digital pipeline described by open source tools.

Data acquired in the field, with GPS, Laser Total Station or Laser Scanner, are initially treated with specific software provided by the instruments. Almost all hardware companies, in fact, do not let their users freely access the source code of the accompanying software. Nevertheless, there are some projects which are developing tools to process raw data captured by instruments. Raw data may be initially uploaded on a server, in order to store the original data's accuracy and resolution.

After the acquisition, raw data are processed in the lab with various software categories. For 3d modeling processing, tools might be used such as Scanalyze[81], MeshLab[82] or, although not open but free, the ARC3D webservice (Automatic Reconstruction Conduit)[83], and in the following phase a computer graphic software more oriented towards realistic rendering and computer animation, such as Blender[84]. For terrain generation, the first step requires the use of GIS and Remote Sensing tools. The most famous and mature GIS package is GRASS[85], that can be used both for vector and raster data. It also has powerful algorithms for remote sensing analysis. To generate 3d terrains and to create entire ecosystems consisting of forests, monuments and other objects, there is for example the Virtual Terrain Project or OSGdem, a tool that belongs to the OpenSceneGraph library[86]. Metadata and other textual information can be stored in a database such as MySQL or, in the case of spatial data, PostGRE SQL.

Processed data can be uploaded in a structured repository, built on a geographical database, and accessible to non-programmers through a web-based interface. A Content Management System, based on various connected on line databases, can be successfully used in order to let users access repositories and add their contents (3d, 2d, multimedia, text), or modify those already uploaded. Although the majority of CMS are dedicated to text or image content, some experiments are actually in progress to enable a user to access and edit also 3d or 2d-geospecific data, embedding or integrating plug-ins for 3d visualization, such as OSG4WEB-backend,[87] or webGIS editing, such as ARK[88]. Through these systems data can be visualized, edited, dynamically modified, and connected to other repositories or database. Other useful tools for shared work are Wikis[89]. The

[81] http://graphics.stanford.edu/software/scanalyze/
[82] http://meshlab.sourceforge.net/
[83] http://www.arc3d.be/
[84] http://www.blender.org
[85] http://grass.itc.it/
[86] http://www.openscenegraph.org/projects/osg/wiki/Support/UserGuides/osgdem
[87] See Virtual Rome project: http://www.virtualrome.net
[88] See http://ark.lparchaeology.com/
[89] There are several open source Wikis (http://en.wikipedia.org/wiki/Wiki), such as MediaWiki (http://www.mediawiki.org)

entire set of processed information will be integrated in shared repositories, which can be successfully used in the following reconstructive phases (archaeological, interpreted and potential landscapes). The reconstruction work can be configured as a collective process, developed on shared resources inside 2d or 3d geospatial environments.

The digital pipeline ends with the landscape reconstruction and with its visualization on line or off-line, through an interactive real-time system (VR – AR) or through a non-interactive visualization (video, digital image). The creation of a Virtual Reality application, where users can dynamically explore the reconstructed landscapes activating various behaviors, requires significant programming activity, especially in the Open Source domain. 3D platforms dedicated to VR, such as OpenSceneGraph[90] or OpenSG[91], or game and simulation engines, such as OGRE, Crystal Space[92] or Delta3D[93], although very powerful, often do not offer development and deployment utilities. VR (web)GIS and 3d (web)GIS represent a good compromise for those who need to visualize geographical dataset and 3d models simultaneously and interactively, although open source solutions are still under development. One example is the OSG4WEB plug-in developed by Italian CNR and CINECA Visit Lab (Calori *et al.* 2008). OSG4WEB provides a framework for in-browser openGL-based application wrapping. The framework allows the development of OpenGL and OSG based applications embedded in the browsers, allowing JavaScript bidirectional interaction with surrounding page elements. It is particularly suited to landscape visualization over the web, since it supports paged LOD terrains (Chapter 7).

Realistic rendering, animations and video compositing are still quite problematic, in both non-open and open communities. Landscape characteristics, in fact, make the management of large territories inside traditional Computer Graphics software such as 3D Studio Max or Blender, very difficult. One solution is to use a game or simulation engine that supports terrain rendering, or import terrain generation outputs.

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90 http://www.openscengraph.org
91 http://opensg.vrsource.org/trac
92 OGRE game engine: http://www.ogre.org; Crystal Space: http://www.crystalspace3d.org
93 Delta3D is a simulation engine that manages geospatial information: http://www.delta3d.org/

A full and updated review of the most common open source tools is available also in the Wikipedia, divided into categories[94].

6.5 Other open case studies

During the annual CAA (Computer Application in Archaeology) international conference held in Prato in 2004, some colleagues and I organized a workshop for the first time on open source and free ware in archaeology ("Open Source and free ware applications to archaeological research"). During the workshop the increasing tendency of the worldwide community to try out this relatively new approach emerged quite clearly. Some of the projects presented on that occasion are still maintained and developed, demonstrating that in the near future more and more users will start using and developing open source solutions for archaeology.

The following case studies represent interesting examples:

ArcheOS, developed by the ArcTeam, offers archaeologists the chance to have a Linux distribution which includes fundamental specialized tools for CAD drawing, GIS, database creation, GPS, Scanner Laser, statistics, stereo-photogrammetry, image processing and computer-graphic[95].

I have already mentioned GRASS (Geographic Resources Analysis Support System), a powerful GIS and remote sensing tool at one and the same time, continuously maintained and updated by its main developer community based in Trento, Italy. This software was initially developed for the US Army in 1982 by CERL (Construction Engineering Research Laboratory). In 1997 it was released to the worldwide community open and free. Since that moment, this project, now available also under Windows, has created new functionalities for terrain creation and visualization, for GPS and Laser Scanner data management[96]. Now it is part of a wider framework, OSGeo. In the field of VR application dedicated to terrain interactive exploration we should also mention the VISMAN project, a software framework for Managing Virtual Scenarios. It is currently developed at CINECA Visit laboratory and is mainly devoted to cultural heritage. It is written in C++ and

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94 Open Source software: http://en.wikipedia.org/wiki/List_of_open_source_software_packages

95 http://www.arc-team.com/archeos/wiki/doku.php?id=home

96 Useful references can be found in the FOSS4G conferences or in the GRASS users conferences, such as http://www.ing.unitn.it/~grass/conferences/GRASS2002/proceedings/proceedings/pdfs/Brovelli_Maria_Antonia.pdf

uses the wxWidgets and OpenSceneGraph libraries, so it relies on open-source software only. It is available on Windows and Linux systems, being scalable from an average PC to a virtual theater with stereo capabilities. It has been used to develop advanced systems within virtual cultural environments, as in the case of the simulation of the results of a possible new eruption of the Vesuvius volcano[97] (*Fig. 5.11*). The same simulation might be used to recreate the 79 AD eruption in Pompeii. Visman's goal is directed to the integrated fruition of complex 3D and multimedia contents on multi-platform technologies and in various contexts. The 3d virtual worlds become starting points for a straightforward interaction with complex environments that can be navigated, modified and queried through the link to more than one relational Data Base at a time (GIS, Multimedia, etc.), becoming an interface for accessing multiple information[98].

6.6 Conclusions and future perspectives

Today software and contents are more and more integrating into advanced systems, available on line. The creation of programs, through an open approach, dedicated to the specific needs of the discipline, enables the creation of sustainable projects and the rapid evolution of the research itself.

We are slowly moving toward a shared on-line cyberspace, where inter-disciplinary exchanges can happen and allow new ideas and methodologies to emerge. New cooperation agreements in the field of archaeology, computer science, psychology and the environment should be created.

The archaeologist's role itself is changing, and it will change all the faster when they are involved inside (open) collaborative environments, where a more efficient and pragmatic perspective will assure more reliable results.

Archaeologists will still occupy a very important position in these projects even if they are not computer experts. Their perspective can help in addressing and testing applications and software development.

From this viewpoint, open source should not be intended only as a collection of softwares, but as a project that is also a network of people, methods, and technologies, adaptable to the various applicative contexts. Landscape reconstruction will be a pre-eminent field in the development of new applications

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97 http://exploris.pi.ingv.it

98 http://www.cineca.it/resources/files/visman_en.pdf; to download the software: http://www.cineca.it/resources/files/visman.zip

web-based and GIS oriented, if it follows a few basic rules in the development of the actual project:

1. get your data out, perfection will come later;
2. avoid locking your data in proprietary formats;
3. prefer free and open source software for data editing and storage.

Chapter 7

Webscapes

7.1 Internet connections

Internet is the most widely used planetary inter-connection system. If we examine the evolution of the Internet landscape (the webscape) over the last 10 years on a map, we will be very surprised[99].

Although it started as an intra-net to connect leading research institutions[100], its wide diffusion is mainly due to the use that has been made of it by ordinary people at home. In the 80's, the world began to be transferred from the outside to the inside. In this sort of "Escher" game, the perception of *time* and *space* changed. *Near* or *now* are today much more expanded concepts than they were in the previous era.

The Internet is now giving new meaning to concepts of equity, of impact (also in terms of politics), of trust through collaboration processes, and sustainability (economic impact) (Surman – Reilly 2003).

Internet has also exasperated the way information is sought. Interaction is on the increase through hyperlinks and windows interfaces. Understanding doesn't just depend on analysis, but also on navigation and on the creation of new personal paths.

In this new era these are also new risks: the risk of limiting our approach to surface explorations, to rapid navigation, losing our capacity to concentrate and analyse; the risk of dealing with the world as a collection of signifiers without a signified; the risk of being manipulated by simulations (Turkle 1997: 121–140). This Internet era is in fact the era of simulations and of new freedoms, which become merely apparent and superficial, if we don't achieve greater awareness through the creation of critical instruments, tools to increase our potential for memorization and understanding. On the one hand opacity does enable us to deal with a higher level of complexity, and to create connections, which would otherwise be impossible. Internet is a parallel world, a new type of organism; new

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99 Map of connections: http://www.telegeography.com/products/map_internet

100 Further information and links at: http://en.wikipedia.org/wiki/Internet

objects live in its connections, "life on the screen" (Turkle 1997: 42). While we work studying and simulating the landscape we are part of a complex system of relations and connections (*Fig. 7.1*).

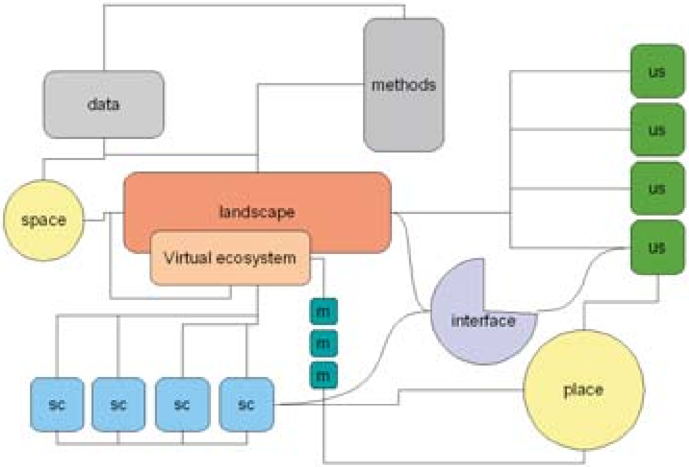

Fig. 7.1. A representation of the connections and relations which characterize the net within the landscape reconstruction process.

Internet *is* everywhere in most of the world, it is part of us, and it will be a persistent aspect of everyday life more and more in the future. It is not a matter of *if* we want to use it in or for our research. The question is whether we want to be connected, or isolated and left apart, whether we want to dialogue, to disseminate, to measure the merits and results of our studies. Internet *is* today a medium of science, beside traditional scientific publications.

In terms of social change and global scientific development, it is necessary for new concepts to be diffused as far as possible. In some cases a capillary diffusion isn't necessarily connected to content validity, but to the way these concepts are diffused and the medium used. The way parallel programming (PDP) started to be so widely diffused was due to the free distribution of software to be tried out on floppy disks, in conformity with the successful model "try it, play it, modify it" (Turkle 1997: 163–164).

The use and further development of web applications in this new and complex field of ancient landscape reconstruction depends, therefore, on social dynamics. From a certain perspective, the resistance to reconstruction activities we still experience in much of the Cultural Heritage field is a positive factor, part of the cultural impact of a new approach. This resistance tries to separate emotions and aesthetics from cognition and logic, returning our attention to essential characteristics, creating a distance between virtuality and the reality of ancient landscape.

What can be done for landscape reconstruction through or with Internet? There is no simple answer to this question. In this book we have analysed the various aspects of the field: *people* (scientists and the worldwide community, teachers and learners, etc.), *data* (geographical, spatial, bi- or three-dimensional, multimedia, ecosystems, etc.), *processes* (visualisation, interpretation, transparency, interaction, exchange, cooperation, land evaluation, data acquisition, post-processing, etc.) and *systems* (simulation and communication systems, interaction, virtual reality, complex systems, etc.). I'll try to answer the question above by taking as reference this distinction, indicating a few general categories, analysing problems and state of the art, and finally proposing some solutions. *Table 7.1* proposes a summary.

Category	**Type**	**Examples**
People	Social Networks	Facebook
	Virtual Communities	FIRB
	E-learning	Quest Atlantis, Akragas doors in Second Life
Data	Online repositories	Global Land Cover Facility, Open Street Map, etc.
	Online Content Management Systems	Virtual Rome
	Digital Libraries	Roman vegetation library; 3d model libraries
	webGIS	ECAI TimeMap; ADS; Fasti On Line; CART
	3D webGIS	SkyLine, Nasa WoldWind, Google Earth (Rome Reborn)
Processes	Cooperative Virtual Environments	FIRB, Virtual Rome, City Cluster
	3d web services	Epoch 3d web service
	Wiki	Media wiki,
Systems	Online virtual museums	Donald Sanders; Clarke, Flaminia on line virtual museum
	VR webGIS	Appia VR webGIS, Salerno archaeological district, Virtual Rome
	Online computer games	Rome

Table 7.1.

7.2 Webscapes

7.2.1 People

Social networks represent an interesting possible evolution for scientific communities to exchange ideas and results. As described in chapter 5, these networks aren't necessarily visual environments. In most cases they are places where people can exchange information, through text-base tools, and multimedia data, such as pictures or videos. One of the most famous social networks is *facebook*. With millions of members, its owes its success to its structure. First, it was designed for college students, *by* college students. Second, it allows information to spread widely but also protects *privacy*: you can *trust* it. Third, it emphasises *clusters* (socio-economic) and groups, thanks also to low-involvement communication; and last but not least, it offers *simplicity* and *speed*. It can be used by people interested in specific topics, such as ancient landscape. In fact the success of a social network depends to a great extent on having many users. It works when it creates social aggregations with people joining public discussions and forming personal relationships in the cyberspace (Rheingold 1994).

Virtual Communities are more focused on the concept of experience (Chapter 5). They include 3d visual environments at different levels. The user participates in the VR community through a digital alter-ego or an avatar, employed also to create a relation and an involvement with other users. A virtual community is based on the same concept as the social network, from a certain perspective: the creation of relations among people. In a Virtual Community the cyberspace becomes place.

In these cases, the language used, the interfaces, and the levels of interaction are crucial. Virtual reconstructions of ancient landscapes will be interesting for a wider community of humanists when developed applications start to speak the language of the humanities, and for a community of scientists when it starts to speak the language of logic and mathematics. As Sherry Turkle observed in her "Life on the Screen", sometimes it is necessary to create a Trojan horse to enable some ideas or approaches to be introduced into "enemy territories" (Turkle 1997: 169).

E-Learning applications are commonly used for online education at various levels. They involve teachers/students in learning activities. Although in most cases they are used as the simple re-production of academic lectures, they could go much beyond the simple lesson, when they become an *experience*. They often are based on VR online platforms, such as Second Life or ActiveWorlds, but they are carefully put together by teachers. These 3d online e-learning platforms can be particularly successful, as in the Quest Atlantis described in the following section, since they personally involve students in the solution of problems, helping them to get to know and understand the basic or specific information they require.

7.2.2 Data

On Line repositories are particularly useful for landscape reconstruction, since they enable us to access basic shared resources, such as geoimages (like the Global Land Cover Facility), digital elevation models, 3d models, vector files, etc. They can be simply FTP spaces, accessible widely or restricted to registered users, or they can be accessed through more advanced and structured interfaces, and included in digital libraries and WCMS.

Digital Libraries are structured typological archives of digital content, as in the case of Roman vegetation library or 3d terrains or 3d architectonic parts library. They are based on online database structures (like MySql or Oracle), geo-based in the case of geographical datasets (such as PostGreSQL). They are used in content management systems.

A web content management system (WCMS or Web CMS) is a content management system (CMS) software, usually implemented as a Web application, for creating and managing HTML content and connecting html pages dynamically to digital libraries and online repositories. It is used to manage and control a large, dynamic collection of Web material. It facilitates content creation, editing and maintenance. There are many available CMS platforms (like Joomla, etc.). Usually this software provides authoring tools designed to allow users to easily create and manage contents. The most advanced WCMS can include 3d visualisation and DB visual editing functionalities, embedding 3d plug-ins.

Other well known and fundamental tools for landscape online visualisation are *webGIS.* They started as web extensions of GIS software, used to manage cartography online, but they are more widely used now and have broader communicative attitude. A webGIS is used to disseminate geo-spatial information, but also to archive and share archaeological and environmental information with other users. In some advanced cases, they have a higher interaction level, including editing functionalities which more closely involve a variety of professionals, e.g. in public administration, higher education, tourist operators, etc.

An evolution of webGIS is *3D webGIS.* They enable on line 3d visualisation of geographical information with basic functionalities such as interactive exploration and in some cases questioning or problem raising. The first 3D webGIS platform was Skyline, an Israeli company which first believed in this promising field as early as 1997. Nevertheless, Google Earth is surely the most well-known application. Its developments are leading to a further development of this project directed at VR functionalities creation (VR webGIS).

7.2.3 Processes

There aren't many applications or examples which handle geo-spatial processes. This specific field, although at its very beginning, is very promising.

A recent tool, used also by specialists to exchange information or share specific knowledge (such as software development or program use), is *Wiki.* The best known example is the *wikipedia*, but Wikis can be successfully integrated in the process of landscape reconstruction since they enable the scientific community to share, edit, modify, or correct textual information, integrating images or videos and referring to other tools, such as digital libraries or online repositories. They are also commonly used in the cooperative work of project development.

Less familiar applications are *cooperative environments,* also known as CVEs (Collaborative Virtual Environments). They are still at a very experimental stage. CVEs are a class of networking applications that support collaboration between remote users, through a common spatial environment and using 3d graphics; CVEs are updated so as to reflect the actions and the movements of each of the participants. They are based on the concept of data and knowledge sharing, and on editing and validating functionalities. They include 3d and real time characteristics, typical of virtual reality applications, and communication paradigms of VR communities. In the near future they could be very promising applications, useful to reconstruct and represent potential Roman landscape, through the integration of different sources, the definition of models to be loaded and the identification of content connected to 3d models. The entire process can be completely updatable and editable. Some attempts have been made in this direction, enabling 3d editing, apart from the 3d terrain that needs to be pre-processed to be handled online as paged. There are also inspired examples that have explored the possibilities of exchanging digital information in a sort of virtual reality networking matrix, as in the case of City Cluster (*Fig. 7.10*).

Another interesting field for landscape reconstruction is *3d web service*. This includes a variety of services, from the distribution of stitched pictures, and geographical data on demand, including also post-processed remote sensing data, to the digital publication of scientific works. Recently there are some interesting new developments in the creation of 3d digital models online, from a series of pictures provided by users. This service, described below, is based on computer vision technology. Although not yet available, in the future there will be more and more of this kind of service, dedicated to 3d digital modelling or also to 3d terrain modelling, on demand. The success and diffusion of such complex projects will probably depend upon the service itself and the source code being (initially) freely and openly available.

7.2.4 Systems

In chapter 5, I dedicated some space to the description of Landscape Virtual Museums. One of the most promising communication systems, in terms of potential diffusion, of knowledge dissemination and cognitive impact are *online Virtual Museums*. If virtual museums, despite being known about and used since the early 90s, are still considered at an embryonic stage, this is even more true for online VR museums. In the inclusive Internet dimension, where anything can be accessed with a click, it is essential to avoid hyper-information, which in the end may turn out to be no information. These applications should therefore provide the careful design of behaviour, the differentiation of levels of access to information, a well planned storyboard and well constructed storytelling.

Online *computer games* are surely more mature applications. The powerful role that they are playing in culture and society cannot be denied, as well as the issues that may be raised about the boundaries between the ‘real’ and the ‘virtual’. It doesn’t simply involve a “migration” of previous board games into digital online format, but has a wider social impact. Games have also gained a place at the academic level today, with thousands of courses held on the subject throughout the world. One specific type of game is the so-called MMORPG, an acronym for “Massively Multiplayer Online Role-Playing Game”. In a MMORPG, thousands of players exist in the same game world at the same time. They play a role game together in a 3d environment. World of Warcraft is one of the best known MMORPGs. It enables thousands of players to come together online and battle against the world and each other. Players from across the globe can leave the real world behind and undertake quests and heroic exploits in a land of fantastic adventure. It allows players to play the game at their own pace; it offers interesting quests with story elements, and dynamic events. There are several game engines which can be used to create interactive 3d experiences, even on line[101]. Most of them are costly and proprietary, but rich in available behaviours, such as physics management, multi-user functionalities or artificial life implementation. Although a few of them are dedicated to geographical simulation, the majority aren't focused on the treatment of "real-based" spatial datasets. In order to maintain a high level of speed (frame rate) and interactivity, especially on line, they use specific techniques to visualise and create texture and geometry (procedural modelling, procedural texture creation, normal maps, shaders and similar effects).

While computer-games aren't usually based on geo-spatial scientific datasets, there is a type of application which includes some aspects typical of Virtual Reality systems and others of GIS: *VR webGIS*. These applications can be used to visualise large territories online, interactively, to explore sites in an intra-site and inter-site dynamic, to add to and query elements of the environment, to create personal interpretation paths, and to test simulation models, including artificial life evolution. They are spatial geographical applications and for this reason they can be successfully used by the scientific community as working tools. They can be developed through a cooperative virtual environment or a Web Content Management System (WCMS). Unfortunately, there aren't many examples of them, and a lot still needs to be done. In the panorama of 3d applications rendering platforms "browser embedded" there is no clear leader of the market, or even generally accepted standard. This panorama is currently led by game applications, which have also influenced its development (hardware and software), driven mainly by the high budget that characterizes these "productions". This has implied the development of various hardware and software platforms and the creation of privately owned and expensive development systems, often customized to specific devices so as to obtain very high performance. On the other hand, Internet tends to define a different mode to access content, an open standardized one (e.g. html, Javascript, Xml, etc.). Open Source and cross platform projects are therefore fostered (see the Firefox project). For this reason, joining these two worlds (of 3d interactive and of web access) isn't easy, and there are still no consolidated approaches or standard technologies to use as reference (*Fig. 7.2*).

[101] A complete list is available at http://en.wikipedia.org/wiki/List_of_game_engines

One of the projects that will be described in the following section, Virtual Rome, has proposed a solution to this problem.

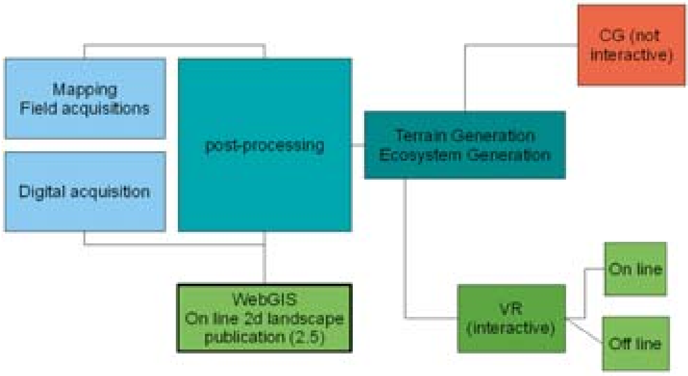

Fig. 7.2. Digital pipeline describing the process of territory processing and on line data publication.

We can subdivide available browser embedded systems into: VRML-X3D based systems, global earth geo-viewers, flash based systems and general purpose Scene Graph based systems (Calori *et al.* 2009).

As we have seen there are several available applications, some of them based on well-established technology, other on experimental high-end technologies. If we are interested in the online publication of a landscape, it is important to start assessing what is available. In order to evaluate a web project or application we should take into account communication potential, interaction, transparency, functionalities and also intuitiveness. The following parameters can be considered in the evaluation process:

- Web browser integration (applications embedded in the web browser or stand alone); technology used to develop applications (original software; VRML-X3D based systems; flash based systems and general purpose Scene Graph based systems; global earth geo-viewers; Java based applications or game engines based applications);
- Operative Systems and Browsers (Windows/ Explorer; Windows/ Explorer and Firefox; Windows and Linux/Explorer and Firefox; Windows, Linux and Mac/Explorer, Firefox and Safari; other); graphic card use (OpenGL; DirectX); interaction devices (mouse; graphic interface; keyboard; natural interaction; other); content that can be loaded in final application (GIS 2d or 3d data (DTM, geoimages, etc.); vector data; labels; 3d models; multimedia; metadata; avatars; other); type of loaded terrain (paged or

not paged); type of available behaviours (fly or walk functionalities; hyperlinks; reference maps; overlay of various layers; switching of layers, terrains, etc.; dynamic evolutions, simulations; animations; virtual communities; artificial life; etc.);
– type of licence (Open Source, commercial, application built on open libraries and released as freeware; other); type of downloading (streaming or complete download).

7.3 State of the art

This section is dedicated to examples, case studies, projects and web applications dedicated to the use of Internet for ancient landscape online publication and interaction. The most room is given to interactive 2d and 3d projects, whose utility has been extensively discussed in previous chapters.

Examples of online repositories dedicated to geographical or spatial information, such as the Global Land Cover Facility or the USGS Earth Explorer, are listed in Appendix B.

WebGIS is quite a stable and well-known technology. Specific applications, based on webGIS platforms, have been developed for ancient landscape visualisation or archaeological site location, at different levels of interaction. All these projects are browser-embedded and their portability depends on the software or library used. The three cases given below are based on three different tools.

ECAI, the Electronic Cultural Atlas Initiative, developed the *TimeMap*™ *Java* application. It is a set of tools created by Ian Johnson and Artem Osmakov[102]. It is now an Open Source project that enables the generation of complete interactive maps with a few lines of html. It’s easy for beginners, yet provides completely customisable power and distributed backend database connectivity for the expert. It’s free for personal use. The peculiarity of TimeMap is the time-based maps delivery system, that allows you to combine space and time dimensions, to visualise urban growth, environmental changes, etc. Several projects have been developed with TimeMap, such as the PHALMS or Ankor projects, demonstrating the potentiality of multi-temporal study with multiple datasets.

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[102] ECAI: http://ecai.org; TimeMap: http://www.timemap.net; the software is available at: http://sourceforge.net/projects/timemap.

Another already mentioned example is the *Fasti On Line* project[103]. Fasti was created by LP archaeology with the aim of continuing the "Fasti Archaeologici" publication, published by the International Association for Classical Archaeology (AIAC) between 1946 and 1987. It provides a list with the location of archaeological excavations since 2000. It is a database (MySQL) driven website, based on a MapServer Open Source library. PHP and *Mapserver*, on the server, connect to these data to produce the maps and the results pages[104] (*Fig. 7.3*).

Fig. 7.3. Fasti on line webGIS interface. (FASTI and LP archaeology).

CART is an example of webGIS and database developed and used by public administrations in order to archive, manage and also produce "risk-maps" for urban planning purposes. CART is a geodatabase built in 2000 and based on a (privately owned//commercial application (Highways) and on open standards (Xml, Html)). It enables a dynamic bi-directional connection with a desktop

103 http://www.fastionline.org

104 For technical references: http://www.fastionline.org/about.php?view=techsummary and on MapServer: http://mapserver.org/

GIS (ESRI ArcGIS) that is used by public employees at the local level. Data are archived online, through an Internet Explorer browser interface, as coordinates x,y,z (points, lines, polygons are described as sequences of coordinates). All this information can be exported as ascii open file[105].

A similar and more advanced webGIS system was created by the National Monument Record of English Heritage: the *Archaeology Data Service*. After the opening of the OASIS project (Online AccesS to the Index of archaeological investigationS), all archaeological data have been archived at national level in a unique geodatabase. The access to this database is possible at various levels. Institutions and professionals have user passwords, and they can query the entire archive or edit it to add new information on excavations, prospectings, etc. There is also a public and open access, through the ArchSearch interface[106], where the database can be queried in different ways and basic information is provided, together with the location of the archaeological sites visible on Google Maps. This archive is also connected to other online repositories, such as the old-maps archive[107].

There are some interesting developments of the webGIS application, aiming to make it a more interactive and editable environment.

Connected to MapServer library there are two interesting projects: KaMap and Open Layer. *KaMap* is an AJAX application that offers an intuitive web interface. It aims at providing a javascript API for developing highly interactive web-mapping interfaces using features such as interaction, continuous panning without reloading the page, keyboard navigation, optional layer control from the client's side, etc. These functionalities make this project really interesting for archaeological and environmental dataset visualisation and interaction[108]. *Open Layer* is dedicated to web dynamic mapping. It can display map tiles and markers loaded from any source. MetaCarta developed the initial version of OpenLayers and gave it to the public to further the use of geographical information of all kinds. It is free, Open Source JavaScript, released under a BSD-style License, and is part

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105 Guermandi, M. P. 2000. *Rischio archeologico: se lo conosci lo eviti* (IBC, Documenti/31). In Atti del Convegno di studi su cartografia archeologica e tutela del territorio, Ferrara 2000; D'Andrea – A. Guermandi, M. P. 2008. *Strumenti per L'Archeologia Preventiva. Esperienze, Normative, Tecnologie*, Archeolingua, Budapest 2008.

106 http://ads.ahds.ac.uk/catalogue/

107 http://www.old-maps.co.uk

108 Examples are available at: http://www.ominiverdi.org/index.php/kamap

of the Open Source Geospatial Foundation (OSGeo)[109]. It implements methods for geographical data access, such as the Web Mapping Service (WMS) and Web Feature Service (WFS) protocols[110]. Also the Italian Military Geographical Institute has developed its online repository based on Open Layer[111].

A specific multidisciplinary project on landscape archaeology has developed the *ArcheoServer PO-BASyN*, which intends to define a base for the experimentation of innovative solutions to exploit new conceptual tools, models, techniques and technologies to assist in the management of cultural resources. The choice of the context to experiment with this research approach is the study of the settlement dynamics of the Bronze Age in the Po river valley (northern Italy). It has experimented two online spatial analysis tools: settlements' spatial density tool (visualisation of the density in different Bronze Age phases) and sites' territorial tessellation (it calculates and represents a Thiessen polygon analysis on the sites: *Fig. 7.4*) [112].

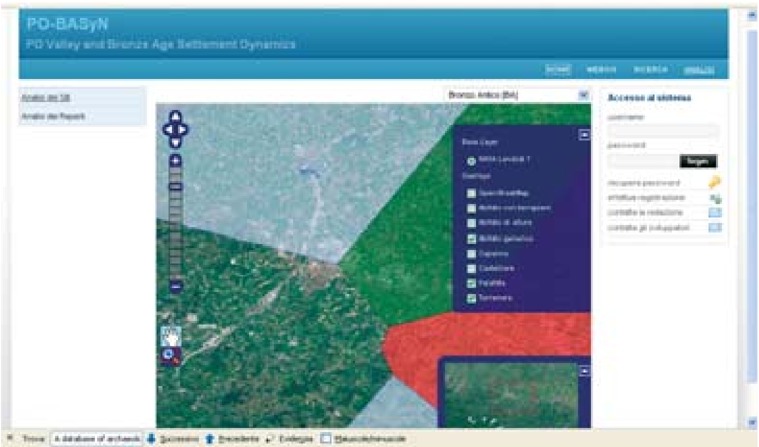

*Fig. 7.4. ArcheoServer PO-BASyN project (*Mantegari *et al. *in print).**

Just as GIS software 3d features began to be more widely used, also with webGIS new applications and platforms were developed so as to implement the 3d visualisation of geographical data. There are several categories of 3d applications,

[109] http://www.openlayers.org/; http://www.osgeo.org/
[110] WMS: http://www.opengeospatial.org/standards/wms;
WFS: http://www.opengeospatial.org/standards/wfs
[111] http://www.igmi.org/ware/
[112] http://www.archeoserver.it/pobasyn/webgis/index.php

divided into various categories. There are two important classifications: the first relates to geo-based or non geo-based spatial applications, the second refers to available behaviour and to the level of interactivity, also in terms of editing functionalities. Although these are not always easy to distinguish, we can recognize on line 3D webGIS, VR webGIS and VR applications, the latter including online games, virtual e-learning communities and collaborative environments (CVE). *3D webGIS* enables the interactive exploration of territories and of geospatial datasets, with limited behaviour and editing functionalities, while *VR webGIS* includes a higher level of interaction, typical of Virtual Reality systems, such as fly through and walk through navigation functionalities or interactive querying. They are both strongly based on geospatial datasets: geoimages, digital elevation models and vector layers. VR webGIS may include virtual ecosystems and 3d models. Global earth geo-viewers or Scene Graph based systems belong to these categories.

Although *Skyline* Software Systems Inc. developed one of the first earth geo-viewers, complete with authoring tool and server support[113], *Google Earth*, in its stand-alone version, is still the reference point for this sector[114]. It has been created and distributed since 2005. It is a stand-alone application which runs on Windows, Linux and Mac, based both on OpenGL and DirectX. It provides users with an immediate interface with various functionalities such as search panel, overview map, hide/show sidebar, placemarks, polygon or path inclusion on the scene, images in overlay, environments, navigation tools, etc.

An example of an archaeological project published using Google Earth is the reconstruction of 4th century Rome based on the Constantine plaster preserved at the Roman Civilization Museum in Rome (*Fig. 7.5*). It is the continuation of the *Rome Reborn* project, directed by Bernard Frischer (Guidi *et al.* 2005)[115].

Google Earth has also published a plug-in that has a JavaScript API which embeds the 3d Google Earth into the web pages. Using the API it is possible to draw markers and lines, drape images over the terrain, add 3d models, or load KML files[116]. An example is *Florence on Earth* project, where it is possible to access one century of archaeological excavation in Florence regarding four

113 http://www.skylinesoft.com
114 http://earth.google.it/
115 http://www.romereborn.virginia.edu/; http://earth.google.it/rome/
116 http://code.google.com/apis/earth/

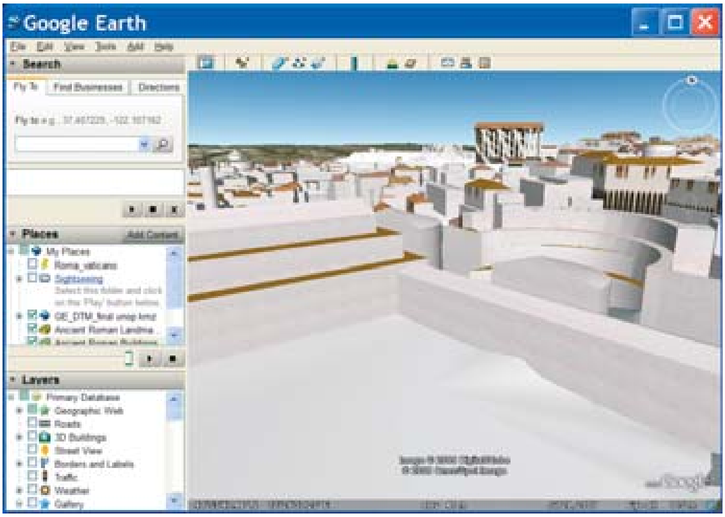

Fig. 7.5. Rome Reborn project inside Google Earth (project directed by B. Frischer).

periods: Roman, Late Roman, Early Medieval and Medieval. It is possible to explore also 3d reconstructions loaded on the 3d map[117].

There is another recent GoogleEarth project dedicated to an open source version of the plug-in, *O3D*, for creating rich, interactive 3d applications in the browser. This API is shared by a broader developer community interested in establishing an open web standard for 3D graphics. Google Earth enables urban building and architectural coverage, also supporting Collada[118].

Another global earth geo-viewer is *Nasa Worldwind*. It was developed in 2004 as an Open Source project by NASA, and is especially interesting as it permits the layered visualisation of scientific datasets. It is a stand-alone application, available as a full install under the terms of the NASA Open Source Agreement. It runs on Windows on PCs with a 3D Graphics Card with a fast Internet connection. It requires the .NET runtime environment and DirectX installed. It comes with some basic datasets (from NASA and TerraServer-USA of Microsoft Research), which are integrated and further downloaded after a certain point, during the navigation. Through Nasa Worldwind it is possible to explore datasets such as: Blue Marble, Landsat imagery, SRTM, NASA SVS dedicated to hurricane dynamics, MODIS (Moderate Resolution Imaging Spectro-radiometer) catalogue of fires, floods, dust, smoke, storms and volcanic activity, GLOBE with earth

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117 http://florenceonearth.com/

118 http://code.google.com/intl/it-IT/apis/o3d/

temperature dataset, country boundaries and place names, and a visual tool for latitude and longitude (*Fig. 7.6*). The latest version of WorldWind is Java based with better cross platform support[119].

Fig. 7.6. Rome exploration with NasaWorldWind.

In 2007 Microsoft also created its own 3d earth-viewer: *Virtual Earth 3D*. It is a stand-alone application that runs only on Windows and mainly on Internet Explorer, and is based on DirectX[120]. The Virtual Earth platform consists of two interfaces: Virtual Earth Map Control that lets users make requests via JavaScript to an AJAX map object and a MapPoint Web Service API using SOAP XML to communicate with other applications. Recently there is a new version of VE embeddable in browsers with sound Javascript SDK. Both NASA WorldWind and Microsoft VE unfortunately do not allow user 3d model insertion.

Virtual Reality applications are mainly not based on geographic datasets, although in some cases they start from geospecific data. Their characteristic is the complexity of available behaviour that extends the simple exploration of a 3d geographical viewer to a real cognitive experience, to the creation of collaborative spaces, and socially dynamic environments. They can be based on various technologies, although for those embedded in web browsers they are commonly VRML-X3D or Flash based, or even game-engine based systems. In some cases there are some experimental projects, scene graph based, that try to

[119] http://worldwind.arc.nasa.gov/features.html
[120] http://www.microsoft.com/virtualearth/

combine 3D webGIS (geospatial dataset in input, large 3d territories processing, etc.), with VR characteristics (interactivity, inclusivity, simulation, exchange, sharing, dynamics). I've called these applications *VR webGIS*.

Several projects, especially in the past, were developed on VRML, whose current improved version is X3D. *NuME*, the New Electonic Museum of the city of Bologna, was initially created with VRML and Javascript, although it moved to Performer and then to OpenSceneGraph libraries[121] (Guidazzoli – Bonfigli 1999). Other interesting projects using the same technology, relative to archaeological sites' virtual exploration and interaction, have been created by Learning Sites Inc., as in the case of the reconstruction of the prehistoric settlements at ancient Nemea (*Fig. 7.7*). Unfortunately X3D doesn't appear to be adopted sufficiently widely nor considered as a standard, lacking performance in world database paging (Calori *et al.* 2009).

Fig. 7.7. Reconstruction of the prehistoric settlements at ancient Nemea (D. Sanders and Learning Sites Inc.).

The use of a Flash-Shockwave based application has the undoubted advantage of widespread availability and good browser integration. Examples of geodatabase are the Italian *Pagine Gialle Visual* and the *GeoMind* products (3DIMap technology)[122].

[121] http://3d.cineca.it/3d/Nume/nume_3d.php
[122] http://www.visual.paginegialle.it/3d; http://www.geomind.it

A different case, based on Skyline technology, is *Bologna 3d*, a three-dimensional interactive version of the city developed by Bologna City Council itself. To explore the city it is necessary to download the plug-in, Terra-Explorer, a stand-alone application that runs on Windows, or can also be used as an integrated ActiveX component. It features automatic download and installation for web users, efficient streaming for terrain and overlays over the net an auto-pilot feature allowing pre-defined routes to be replayed automatically, easy navigation and "fly-to-location" using the information panel, a 2d map orientation synchronized with the 3d terrain, control speed, altitude and viewing angle via the mouse, keyboard, joystick, control panel, view of objects, symbols or geo-referenced information layers created within TerraExplorer Pro or TerraBuilder, web content integration, tools to measure distances and areas in the 3d world, and a saver of screenshots[123].

The Sardinia region has created a 3d stand-alone version of the entire island fully explorable in 3D, thanks to CRS4 research Institute in cooperation with CORE. This project is part of the Regional GIS[124]. The software is based on the BDAM technology, efficient for large terrain visualisation and developed by CRS4, in cooperation with CNR ISTI. Sardegna 3d runs on Windows, Linux and Mac, on 3d graphic cards, and it enables mouse or interface command panel interaction. It allows to calculate distances and paths, to locate a site through a layer-menu and to place a marker to remember a specific location, as well as to access the archive of aerial photographs taken over the years. Recently CRS4 has released as open source *RATMAN*, a framework for terrain streaming and rendering**,** a real-time terrain rendering framework able to asynchronously access terrain information from remote servers. It contains a simplified version of our BDAM technology[125].

Another example of VR viewer has been developed by the Scuola Sant'Anna of Pisa: the *XVR* player. Based on this technology is the project dedicated to *Piazza dei Miracoli in Pisa* (*Fig. 7.8*). It is a browser embedded application where users can walk in time and space in the city. It is an ActiveX plug-in (only on Windows and Explorer), based on OpenGL. Models are completely downloaded on the client PC before starting the VR session. XVR imports 3d models from 3DSMax, including animations, and it has script language, vertex and pixel shaders support, real-time physics using the Tokamak(TM) physics

[123] http://www.skylinesoft.com

[124] http://www.sardegna3d.it/

[125] The source code is available as open source from http://ratman.sourceforge.net

engine, HTML pages interaction using Javascript or VBScript, video textures and audio (also 3d audio) support[126].

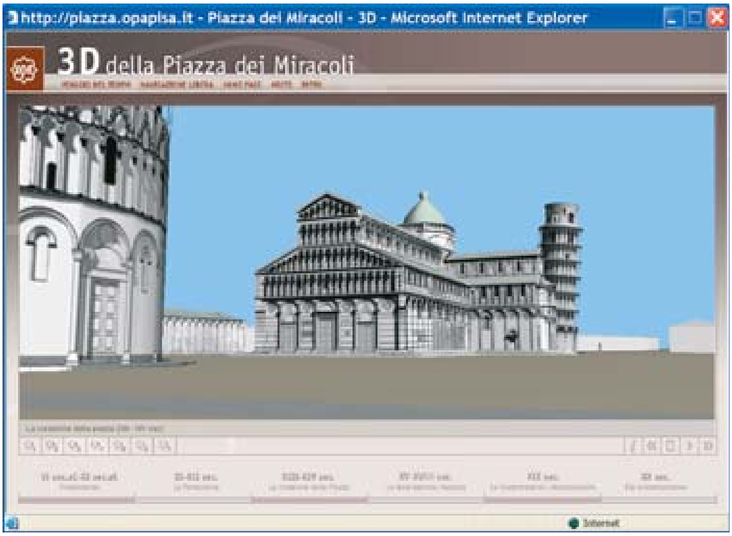

Fig. 7.8. Piazza dei Miracoli exploration with XVR technology (developed by Scuola Sant'Anna of Pisa).

Some projects have been built on privately commercial or open source game engines[127] or on development and deployment platforms, mainly proprietary, dedicated to interactive 3d content and game creation[128].

Exhibits Player, based on VirTools and Direct X, has been developed to support 3d online exploration of sites and monuments and to access multimedia contents, improving the communication value. It is a stand-alone software that runs on Windows, downloading all data at the beginning of the session, an operation taking some time, but avoiding any long wait after having data downloaded. Many examples can be seen in the web pages of the Italian Ministry of Cultural Heritage (MIBAC), Cultural Internet (Internet Culturale), such as Bologna 3d[129]. Another example has been built for the Virtual Museum of Ancient Via Flaminia

[126] http://piazza.opapisa.it/

[127] Most known game engines are: Doom, Kaneva, Torque, Unreal: proprietary; Delta 3D, Ogre, Panda 3D: open source.

[128] Such as VirTools, Unity 3d, etc.

[129] http://www.internetculturale.it/genera.jsp?s=12&l=en

(Appendix A), where the individual user version of the VR museum, dedicated specifically to the Villa of Livia, is available online[130] (*Fig.7.9*).

Fig. 7.9. VR single user application dedicated to the Roman Villa of Livia (developed by CNR ITABC).

Applications built on game engines are the *TiE project,* an EU funded project whose goal is to create an environment where you can have challenging and compelling game experiences by interacting with virtual representations of the European heritage. Specifically in the reconstruction of the scenario of the Mação archaeological site, that is part of the project, the Instituto Politécnico de Tomar in collaboration with the Museo Municipal de Mação used an integrated approach, including GIS data in a Game Engine, with the aim of developing a credible and educationally valid game adventure contextualized in the settings of an archaeological site[131].

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130 http://www.vhlab.itabc.cnr.it/flaminia/VR_DEMO/Release_Ver_1_en.rar
131 http://www.tieproject.eu

A recent low-cost engine, with great potential for landscape online visualisation, is *Unity 3d*. It is an open-ended 3D game/interactive software engine for web, Windows, Mac OS X, the iPhone, and Nintendo Wii. It includes a multi platform game development tool, designed from the start to ease creation. A pilot project was started by CNR ITABC and SoftLogic with the aim of building Cultural Heritage VR applications, specifically designed for IPhone. An example of this approach is the *Villa of Livia* interactive application for mobile phone, available on line[132].

There are also other case studies not specifically developed for or by the archaeological or environmental fields, but that are currently exploring new possibilities of using the network to exchange experience and information. This is the case of the City Cluster project, an artistic virtual installation created by Franz Fishnaller.

City Cluster is a virtual reality networking matrix, in which multiple environments or cities (Chicago and Florence have been the test cases), can be hosted, coexist and be connected through a common virtual territory, an high-speed network and a graphical interface, enabling distant users to collaborate in a shared environments (*Fig. 7.10*).

Fig. 7.10. City Cluster matrix: interaction of the users between the city of Chicago and of Florence. Example of exchange of digital 3d content.

Projects specifically built for communication, dissemination, and e-learning purposes are based on platforms dedicated to virtual communities or online games, such as Second Life or Active Worlds. The reconstruction in Second Life of the Akragas doors in Sicily has become a way to acquire knowledge of Greek military tactics (*Fig. 5.7*), while the "island" where the villa of Livia stands is

[132] http://unity3d.com/unity/

used for teaching about Roman architecture and cybernetics at the University of California – Merced. The natural and archaeological landscape of Mesa Verde, built on Active Worlds platform, is one of the learning activities schools all over the world can do within the Quest Atlantis project (*Fig. 7.11*).

Fig. 7.11. Mesa Verde archaeological site (left) and the learning session dedicated to the site in Quest Atlantis (courtesy of A. Arici, Indiana University).

Advanced applications which integrate online 3d exploration, multi-user functionalities like those required by virtual communities, VR behaviour and 2d and 3d editing functions, are *Collaborative Virtual Environments* (CVEs). They are, as already mentioned, new and promising tools, particularly for landscape reconstruction purposes. An experimental project was presented in 2009 by an Italian team (University of Pisa, Scuola Sant'Anna and CNR ITABC): "*Integrated Technologies of robotics and virtual environment in archaeology*". The project, described in Appendix A, concerns the development of a multiuser domain on the web for a multidisciplinary scientific community of archaeologists, historians, experts in the human and social sciences, topographers and communication experts, and it was founded by the Italian ministry of University and Research. The 3d environment, built on VirTools platform, can be accessed by scientists in charge of specific tasks regarding the reconstruction of an archaeological site (*Fig. A4. 1–4*), or by teachers interested in preparing a lesson in the "Virtuoteca". They are projected in cyberspace where they can be discussed using chat and start editing sessions, to add, modify, or eliminate digital content from the scene. Other solutions are based on the use of a *scene graph*, a middleware library with a level of abstraction between a base graphics library, like OpenGL or Direct3D, and a complete application as a game engine. It can be a good solution when multithread capability is needed to enable efficient data paging and when there is no particular need for advanced interactions, such as physics. VR webGIS such as the Appia project, Salerno Archaeological District, Cannes 3d or Virtual Rome are all based on a scene graph solution. There are several problems arising from the publication over the Internet of large 3d geospatial terrains, interactively explorable through complex behaviour: the dimension of the dataset (often GB of geoimages or DEMs); the coordinated systems management; the integration of high resolution 3d models, vegetation and vector thematic layers; the inclusion of multimedia content; the development of efficient and scalable navigation tools, useful fly or walk through functionalities; the creation of the 3d scene through editing tools, and the co-existence and harmonization of a research space with a communication space. The development of a specific plug-in, *OSG4WEB*, by an Italian team (CINECA and CNR ITABC), tried to offer solutions to these problems. It is based on the Open Source library OpenSceneGraph, and on previous work carried out for the Appia project, the Esaro and Salerno Districts (Calori *et al.* 2005; Pescarin – Calori 2005; Pescarin *et al.* 2005a). Features of this library (paging quality, cross platform, Internet publishing tool, large input formats, active development community, etc.) oriented the choice. It has also been extended with the osgEarth[133] plugin, which is able to page in directly from OGC repositories as well as Google maps and Nasa servers (Calori *et al.* 2009).

The *Appia archaeological park project*, directed by CNR ITABC, besides the Virtual Narrative Museum described in Appendix A, also created a VR webGIS for the team and the funding institution, the Superintendency, to offer a view of the state of the art of the survey work (years 2003–2006) (Forte *et al.* 2005; Dell'Unto *et al.* 2006). The original idea was to publish in real time and over the web all the digital dataset, vector layers, DTM and 3d models acquired in the fieldwork, month after month, enabling the team to visualize them interactively (with free and open access), and to download the raw data (restricted access). The goal of the project in fact was to acquire, with different techniques and technologies (DGPS, Total Station, Scanner Laser, Photogrammetry), several sites and monuments of the archaeological park. The acquired data were processed with open source software, QGis and GRASS, to produce Digital Elevation Models, geoimagery and thematic layers. They were then processed with OSG, obtaining the 3d terrain model, and paged with various levels of detail, published on line. The landscape, although quite extensive, could be easily accessed online, maintaining the geographical information, and explored in 3D, thanks to the Net plug-in of the OSG library. 3d models and vector layers were then added to the landscape using

[133] OsgEarth builds whole-earth or localized OSG terrain models at run-time: http://wush.net/trac/osgearth

VTP Enviro[134], which was appositely modified so as to use the OSG paged terrain already created, and to export in the OSG/IVE format other 3d needed content (*Fig. 7.12*). Thanks to Enviro, which already had a ready-to-use interface and several functionalities, archaeologists and architects have found a simple way to dynamically interact with the landscape, adding 3d models (3ds, obj, osg, flt, etc. file formats) or vegetation taken from a digital library (shp, xml, png), working at a continuously open and updated reconstruction. All the added or modified objects could then be exported in .osg or .ive formates and added to the 3d terrain for online exploration. The first plug-in built by CINECA, an ActiveX component for Internet Explorer, needed a further integration of PHP and JavaScript to add some more behaviour (switch, upload, view points). This plug-in, *OSG4WEB,* was further developed during two other projects, *Esaro Cultural District* and *Salerno Archaeological District*[135], which coincided with the development of the Mozilla Firefox version of the plug-in (Pescarin *et al.* 2005a; Pescarin *et al.* 2005b).

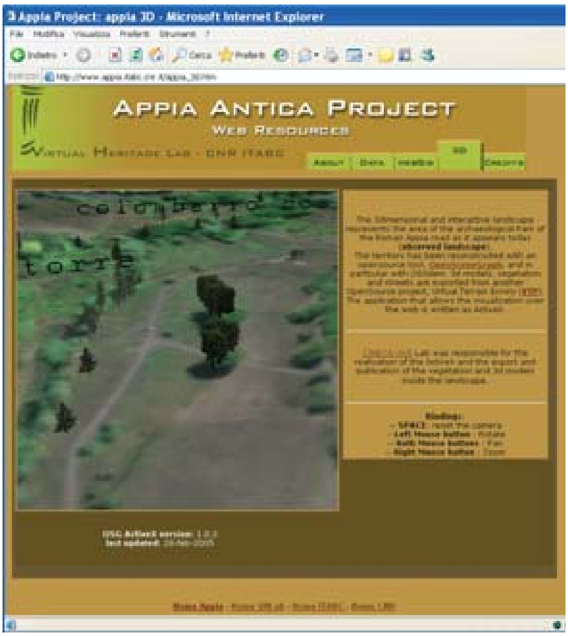

Fig. 7.12. Appia VR webGIS dedicated to the archaeological park of Roman Via Appia.

134 Virtual Terrain Project is an open source project available at: http://www.vterrain.org
135 http://www.vhlab.itabc.cnr.it/esaro/; http://www.vhlab.itabc.cnr.it/salerno/

Based on the same technology and on the same OpenSceneGraph library, there is another project, *Cannes 3D*, on the exploration of the city of Cannes, in France. It is a browser embedded application where users can interact with the 3d scene with the keyboard, the mouse, or simply by using the graphic interface. It runs only on Windows and on Explorer and Firefox, with an OpenGL graphic card and a good Internet connection (ADSL)[136].

The most updated version of the *OSG4WEB* software was released for the *Virtual Rome project*. This project, described in Appendix A, aims to study, interpret and reconstruct the archaeological landscape of ancient Rome, and enable distributed and interactive visualisation through a web-based VR application, based on Open Source libraries, on Remote Sensing and GIS data, and on 3d models (VR webGIS: *Fig. 7.13* left). It includes a front-end interactive interface, browser embedded, and a back-end 3d CMS online lab which enable professionals of various disciplines to update and modify a variety of parts that include archaeological and ancient landscapes (VR webLAB: *Fig. 7.13* right). Virtual Rome enables visitors to explore the landscape at different scales and resolution, thanks to the OSG4WEB plug-in and its functionalities, such as paged geospatial dataset support, coordination and projection handling (both in input and output), large 3d terrain dataset management, 3d models integration (modelled with software such as 3D Studio Max, etc); natural elements, such as vegetation integration, vector layers integration; on-line 3d data publication and interaction, possibly embedded into a web browser; fly and walk navigation tools; behaviour integration: terrain, model switching, vector information and 3d model loading, selecting and loading external pages or multimedia content; environment integration (Calori *et al.* 2008; Calori *et al.* 2009). The procedure followed, described in figure 7.16, starts with data processing in a GIS (GRASS). Here vector layers regarding natural aspects of the landscape are prepared, as described in chapters 3 and 4, and used as input in the ecosystem and terrain generators (Visual Nature Studio and OSGdem). New geoimages, representing the archaeological or potential landscape, and digital elevation models are built (river beds, roads or other modifications are calculated) and exported in GIS formats (geoTiff, Ascii grid). The vegetation is also exported as a GIS vector file (shape) and as a XML/database file containing coordinates of each plant, the name of the species, and the texture associated with it. 3D models are prepared apart, as multimedia information, but a shape file is also created with the indication of

[136] http://3d.cannes.fr/

the position of contents in the territory. All these data are finally joined in the back-end, where the graphic appearance of the site (the front-end) is established.

Fig. 7.13. Virtual Front-end, exploration of the contemporary and potential Roman landsacpes (left) and back-end (right).

7.4 From Mapscape to Webscape

This section provides a practical example of territorial dataset processing and 3d landscape online publication, using open source tools.

The reconstruction of ancient landscape is the last step in a complex process which involves the acquisition, analysis, and interpretation of the environment, of its natural, anthropic and perception features, and of the dynamics and relations which intersect it. This process is developed through the reconstruction of the archaeological landscape, its ecological significance, anthropic modifications, and the ancient potential landscape.

The communication of this final result and the creation of collaborative environments where this process can be approached in a real multi and inter-disciplinary mode will require, more and more in the future, the use of the Net.

In this section I will try to give a practical indication of the steps, data, and techniques required to build a simple example of *VRwebGIS*. The use of open source, free ware or low cost software will be taken as given, to enable every interested reader to start “having their finger in the pie”. This section is written as a tutorial for the creation of a simple three-dimensional terrain ready to be published on line through the osg4web plug-in. Let's start from the beginning.

What do we need? We need a variety of software and the basic knowledge of various disciplines:

– A GIS, to create vector layers, georeference geoimages, or re-project them from one coordinated system to another, to build digital elevation models of the terrain;
– a 3d modelling software: to include also 3d models on the landscape;
– an Image Processing software to eventually modify raster data;
– the OpenSceneGraph library compiled;
– an html editor to modify web pages and Mozilla Firefox as Internet browser;
– the osg4web plug-in installed.

It is clear that the basic knowledge required is quite extensive: cartography and topography to understand scale, projections, detail or accuracy issues; image processing to edit and modify digital images; GIS to handle geospatial datasets; photogrammetry, 3d modelling and computer-graphics to acquire, build or modify 3d models, handling geometric and texture optimization and terrain modelling.

In order to simplify the work, you can download a complete ready-to-use packet (OSG_PACK[137]), containing OpenSceneGraph already compiled, and other useful tools such as OpenEV, OSGdem, Gdal_info, Gdal_translate, Gdal_warp, and osg4web. To use this packet, it is necessary to unzip the file in a directory and then to double click on the file *_osgshell.bat.* This operation will open a DOS shell that will be used to lunch all the commands of the programs, such as Gdalinfo, Gdal_translate, Gdal_warp, osgdem, and osgviewer.

We should then define the goal of the project, and analyse available datasets, in order to eventually identify any further data required.

To build a VRwebGIS we would need, *at least:*

1. one Digital Terrain Model (DTM);
2. one georeferenced image (geoimage): aerial or satellite images, historical maps or other digital georeferenced images.

Complementary and accessory data are:

[137] The packet is available at http://www.vhlab.itabc.cnr.it/openVRwebGIS/software/osg_pack.zip (courtesy of L. Calori and Cineca)

3. Thematic vector layers (shape format) describing natural or anthropic characteristics of the landscape, such as rivers, road, etc.;
4. 3d models (*.3ds, *.obj, *.osg, *.ive), of which we need to know the geographical location;
5. multimedia data (html documents, video, images, etc.).

As fully described in the book, it is quite helpful to define a digital protocol in which all steps are indicated, together with required input and output. *Table 7.2* summarizes the activities required by the creation of a basic VRwebGIS.

Activities	**Software**
1. Spatial dataset creation: DTM, geoimages, vector layers	GIS Software (GRASS, ESRI ARCGIS, etc.)
2. Pre-processing of spatial dataset	GIS Software; Gdal library (Gdalinfo, Gdal_translate)
3. 3D models creation and export in OSG/IVE format	Plug-in OSG for 3D Studio Max (OSGexp)
4. 3D terrain generation	OSGdem, OSGviewer
5. Web Data integration (terrain, thematic layers, 3d models)	PHP, JavaScript, osg4web, web-design tools
6. Exploration of the landscape online	Internet Explorer/Mozilla Firefox, osg4web plug-in

Table 7.2.

7.4.1 Spatial dataset creation

To build a 3d terrain we need to describe its shape, in terms of clivometry, and its characteristics. We therefore need a DTM, raster georeferenced images, and eventually also thematic layers which describe the landscape. All this data can be processed with a GIS software. In case of operations such as geo-referencing, band combination or colour calibration, a remote sensing software is preferable[138]. We should take great care over the projection of the original dataset, eventually re-projecting in the desired output coordinate system. To start working with a sample dataset, it is possible to download geoimages from free online spatial repositories, such as the Global Land Cover Facility, through the Earth Science Data Interface (ESDI)[139], where a wide selection of Landsat imagery is

138 Some GIS products, such as GRASS, cover various spatial operations, including remote sensing analysis and georeferencing.

139 http://glcf.umiacs.umd.edu; http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

available. In these repositories files containing different bands (geotiff format) can be downloaded. A remote sensing software, such as GRASS or ErMapper or even OpenEV[140], can be used to perform data fusion, combine bands 3, 2 and 1, assigning respectively a Red, Green and Blue value, as explained in chapter 3 (*Fig. 7.14*).

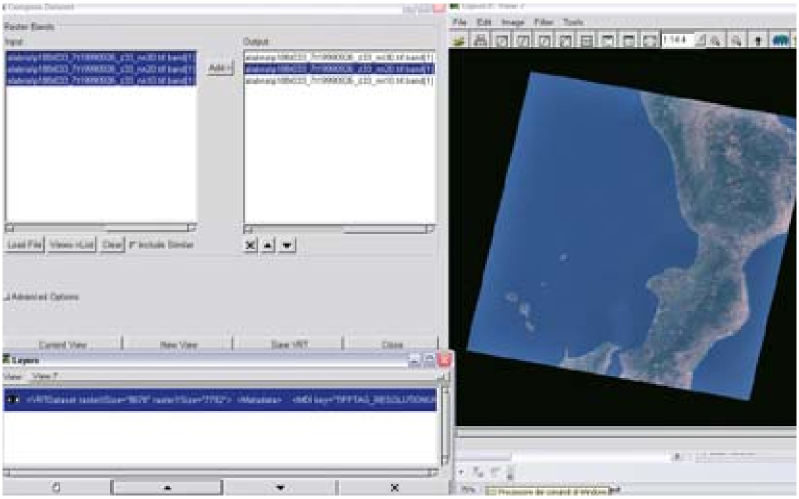

Fig. 7.14. OpenEV interface and bands fusion of a Landsat satellite image.

We should now obtain the DTM. We might already have elevation data (points, contour lines, grid, tin) or need to interpolate them in a GIS. They can also be downloaded from a repository, although at a low resolution (90 mt), such as from the above mentioned ESDI or directly from SRTM[141]. In this example a raster DTM is required (ascii grid or geotiff format). The DTM can be used to carry on further spatial analysis such as: slope, aspect, buffer, viewshed, Thiessen polygons, cost analysis to identify resource accessibility, site catchment or site exploitation territory analysis, and cluster analysis (Appendix B). Vector thematic layers might be acquired from repositories or libraries, or on the field, or they can be digitized from raster maps in various ways. What we would need are *shape*[142] files both in input and in output. Vectors can be used in an ecosystem generator, such as Visual Nature Studio, where they can contribute to creating

140 http://openev.sourceforge.net
141 See also Appendix B for a list of geospatial repositories; http://srtm.csi.cgiar.org
142 Shape is currently considered a standard in GIS.

new geoimages representing the visual aspect of the landscape (potential, archaeological, or interpreted).

7.4.2 Pre-processing of spatial dataset

We can now verify whether the files are correct and then export them in a format compatible to the Gdal library[143]. *Gdalinfo* and *gdal_translate* tools can be used for this purpose. *Gdalinfo* gives information on the raster files, and fundamental for the use of OSGdem are: *Coordinate System, Origin, Corner Coordinates: upper right* and *lower left* (*Fig. 7.15*). The syntax is:

`gdalinfo [options] [file path]`[144]

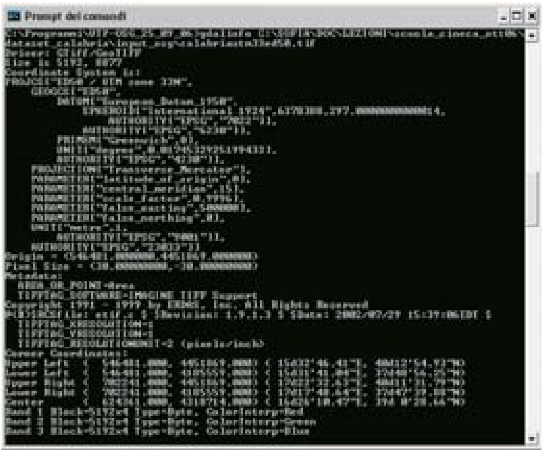

Fig. 7.15. The shell and the gdal command line.

Gdal_translate performs raster files transformations. The syntax is:

`gdal_translate [options] [input file] [output file]`[145]

---

[143] I recommend the use of the geotiff, *.tiff (with *.tfw georeferencing file) or *.ecw compress file for geoimages and Ascii grid or Geotiff for DTM.

[144] The commands must be launched from the shell. A complete list of Gdalinfo options is available at: http://www.gdal.org/gdalinfo.html

[145] A list of Gdal_translation options is available at: http://www.gdal.org/gdal_translate.html

7.4.3 3d models creation and export

3d models, natural elements (vegetation), visual quality effects (lighting, shadows etc,) are usually part of a reconstruction. The integration of these elements depends also upon the flexibility of the system: if there are ways to import models generated with off the shelf modellers, if the paging or streaming system can handle 3d models of interior scenes; if vegetation rendering is supported, if there are state of the art rendering techniques such as shadows and other visual effects supported. A rough qualitative measure is obtained by comparing the visual quality of the system on modelled input with that attained by commercial game rendering engines (Calori *et al.* 2009). 300–500 Kb per file (model or part of a model) could be considered an average limit for a acceptable download. For this reason it is recommended, for instance, to subdivide the model into different sub-objects.

3d models that will be placed on the landscape and published online should have certain characteristics to be interactively managed. They should be small files characterized by many different levels of detail of textures and geometry; they should have the centre of the model in geographic coordinate x,y,z (according to the projection chosen by the project) or, alternatively, have the centre corresponding to 0,0,0 coordinates.

Models are generally built with software such as 3d Studio Max, Blender, Maya, etc. The final output should be in the format required by the VRwebGIS platform. In our case *.osg or *.ive that can be obtained using a plug-in for the 3d modelling software[146].

7.4.4 Terrain generation

We now have all the necessary data to proceed in the creation of the 3d terrain (*Fig. 3.7.B*). In order to produce a 3d territorial model useful for online interaction, the model should have a *hierarchical* structure, different *Levels of Detail* (LOD), various *tiles*, and be *paged*. Paging is the system which enables you to access a multi gigabyte hierarchical dataset of geospatial data (images, terrain, or features) in real time, adapting the image quality produced to the available bandwidth. It involves image and terrain compression multithreading, caching, etc. Ideally

[146] OSGexp, the plug-in for Max is available at: http://osgmaxexp.wiki.sourceforge.net/; for Maya: http://www.cs.ucla.edu/~sunghee/osg2maya/user_guide.htm

it provides a player component, as well as a server able to build a hierarchical database out of standard GIS georeferenced data. The performance of such a system can be qualitative, compared by looking at how fast the perceptual quality increases when a completely new viewpoint is selected, given a fixed amount of bandwidth and hardware resources. Another point is the amount of visual artefacts such as popping, aliasing, or seams that the multi resolution visualization generates (Calori *et al.* 2009).

The terrain is created with *OSGdem*, launching the program from the shell, as we have seen before with Gdal tools. OSGdem has several options, but the basic syntax is:

```
OSGdem -t [ texture with path] -d [dem file with its
path] -o [output]
```

Example:

```
OSGdem -t c:\...\mosaic.tif -d c:\...\dem.tif -o
terrain.osg
```

Other important options concern the coordinate system (--cs: indicated also using the EPSG codes[147], the geodetic parameter dataset known by all GIS-based software internationally); the extent of the area to be generated (-e)[148].
A complete example:

```
OSGdem --cs EPSG:23033 --tile-terrain-size 128 --tile-
image-size 128 -v 2 -e 444482 4167928 375200 299600 -d
dem.grd -l 10 --levels 0 10 -t image1.tif --levels 5 10
-t image2.tif -o terrain.ive
```

147 Frequently used EPSG codes in Italy are: WGS 84 / UTM zone 32N: <32632> ; WGS 84 / UTM zone 33N: <32633>; WGS 84 / UTM zone 32S: <32732>; WGS 84 / UTM zone 33S; ED50 / UTM zone 32N: <23032> ; ED50 / UTM zone 33N: <23033> ; Monte Mario: <4265>; Monte Mario (Rome): <4806>; Monte Mario/Italy zone 1: <3003>; Monte Mario/Italy zone 2: <3004>; Monte Mario (RM)/Italy zone 1: <26591>; Monte Mario (RM)/Italy zone 2: <26592>

148 The extent might be written using this formula: -e = X [lower left x coord], Y [lower left y coord], X [upper right x coord – lower left x coord], Y [upper right y coord – lower lefty coord]

To visualise the result, we can launch the program *osgviewer* from the shell and explore it:

```
osgviewer terrain.ive
```

7.4.5 Web data integration

This includes all the aspects related to web usability and ease of integration with a typical web portal and applications. The comparison would again be qualitative and in some ways subjective. To name some criteria: browsers, operating systems and graphics platform supported, browser integrated or stand-alone application, the requirements of a special streaming server.

If we copy the generated terrain in a directory on a web-server, we can simply visualize it with osgviewer typing the URL:

```
osgviewer http://www.landscape.org/terrain.ive
```

To create an Internet application, with several possible behaviours, we should use a plug-in for the browser, in the case of a browser embedded project, or a stand-alone software. In this case we can use the osg4web plug-in for Mozilla Firefox[149]. There are several possible interactive levels with the 3d scene: view points, objects selecting and loading html, or other multimedia content, guided tours, model switching. The interaction can be programmed in JavaScript-Php, as in the case of Virtual Rome (Appendix A)[150].

[149] Actually the version for Firefox is fully supported (http://3d.cineca.it/storage/osg4web/htdocs/download_plugin/OSG4Web_1.0.2.xpi), while the ActiveX for Internet Explorer isn't currently supported. The source code, licensed under the GPL and LGPL, is available at: http://3d.cineca.it/storage/prove_repo/osg4web_bazar Tests have also been carried out by CINECA for Linux: http://3d.cineca.it/storage/bazaar_repo/BrowserEmbed/test

[150] An example of programming interaction javascript-osg4web is available at: http://www.vhlab.itabc.cnr.it/openVRwebGIS/tutorial/osg4web.html

Chapter 8

A Step into the Future

The ministry of culture has recently decided to start an extensive campaign of investigations, acquisitions and valorization of the region. The project is directed at the identification of the areas subject to a higher level of protection, and therefore to a narrower series of limitations in urban development and to a different kind and degree of exploitation (parks, etc.). It is a significant initiative, financed by the government and by leading private businesses and organisations of the territory itself, interested in its future prospects for tourism. The ministry has involved universities, public institutions and private companies in this work, but also the most important museums and a few schools. Moreover, for the first time, it has created a commission that has singled out a list of valid scientific work and activities, already produced by researchers, scholars, and various organisations in both public and private sectors. 12 months from its beginnings, the commission has published its report and produced an online available version, where the territory is explorable interactively in 2D and 3D and the whole project is geo-linked to the territory, subdivided for typology, chronology, resolution and results. This browser-embedded geo-report has been left open, in accordance with ministerial directions, to further updating by the developers themselves. Everyone may access the geo-report and indicate his own work by sending a mail, or locate it directly in the interactive map, clicking on the interested point or drawing an area. A new section has recently been updated, dedicated to the second phase of the project. As researcher of the European Council of Researches, I could ask for user password and be part of the team involved in the study of the north-east area. Although departments and institutes are involved, the ministry has singled out individual scholars who will be in charge of the work (as reference points and with responsibility for it). In addition to my lab, committed to 3d reconstructions and virtual heritage applications development, I'm actually working with a researcher of the Earth Science department and another of the Botanic, an officer of the archaeological superintendency and a couple of people in charge of 3d programming and of the web geo-database. The system is still being tested, but it seems quite promising. We are now working on the development of shared libraries (vegetation, archaeological remains, etc.) and in the mapping of the archaeological landscape. The botanists have finished identifying the main species in the area, from various periods, and they are working with geomorphologists and geographers to define the main ecosystems. Those who are probably finding the most difficulties are architects and in general modellers. The latter are in fact required to develop their final models at various levels of detail, at least in the last stage adopting common tools requiring an Internet connection, to check model validity (naming conventions, group definitions, geometry, texture, metadata, etc.). The final result, produced in several formats (standard and/or open), should certainly achieve remarkable results, but at the present stage what is visible in the webscape is just a series of simplified objects that are increasingly being substituted by more detailed ones. The way the webscape is changing day by day is impressive. It has never been "empty": the initial reported projects could (and can) be visible in this "restricted" section and may be consulted. But after this first starting point, the cyberspace has started to grow. I can arrive at the office and see that the site where I was working the day before has changed. New thematic layers and objects have been added and new signs indicate that there are studies or fieldwork going on at that moment. In this way, I can verify a problem I'm facing in a very short time, contacting the colleague directly or checking the archive. My lab will soon be able to start working also on ancient landscape (mainly the Iron, Bronze and Roman ages). We will be working on two different interactive projects. The museum's director has signed an agreement to include an interactive installation, in the new section he is creating, and this will ensure that the work will be widely communicated as well. There will also be a second project more oriented to educational purposes, we hope in a couple of years.

Unfortunately this has not happened – not already at least – but it is what is more likely to happen in the next future.

In the first part of this final chapter I tried to give a substantial idea of possible evolutions of the applications and processes we have been discussing in the book. Most of the technologies are already available, although not integrated or not off the shelf.

The use of Internet can really be addressed to various objectives: to diffuse results or just new approaches, to co-operate with people at the same level (scientists, tourists, students, etc.) or at different levels, to disseminate cultural information and the memory of our territories. Is it possible to strengthen this use, in connection with past landscapes? To diffuse the ecological approach in archaeology? And most of all to support the collaborative model within landscape reconstruction? A model adopted in a distant field has worked. It was proposed by the first programmers on Parallel Programming, adopting the slogan "*try it, play it, modify it*". This could be successfully used in our case, trying hard to create open systems, tested and used by different professionals, as happened in the Virtual Rome or the FIRB projects I have described in the previous chapter[151]. In the future most of the services will become Internet provided, as in the case of arc3D[152], but also most of our resources will be moved from our external hard drives to the web and, finally, even programs will be used through the Net (Granelli – Sarno 2007).

Virtual ecosystems might be seen as interactive online environments where it is possible to experience multiple voices, elements, relations, diversifications, and where new and different cognitive paths, directed to "decentralization", might be proposed (Turkle 1997: 167).

Models emerging from virtual ecosystems, like those discussed in this book, might support a more integrated vision of ancient landscape itself. But we also have to be aware of the risk represented by "opaque" systems, where virtual reality incorporates emotion and aesthetic. Nevertheless the introduction of complex systems in VR might also contribute to the harmonization and integration of emotion with logic, and game with analysis, for a better understanding and for a more efficient interpretation of our landscape, our future memory.

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151 A full description of these case studies is available in Appendix A.

152 http://www.arc3d.be

Appendixes

(I. Cerato, A. Palombini, S. Pescarin, E. Pietroni, V. Vassallo)

Appendix A

Case Studies

A.1. 20,000 years of history at Ca' Tron

Location: *Ca' Tron (TV), Italy*
Time: *Upper Palaeolithic, Bronze Age, Roman Times, Middle Ages*
Period: *Summer*

Sources, methodology and techniques

The research, conducted since 2000 by the University of Padua in this area of the Veneto plain, was addressed to the reconstruction of the "total history", from antiquity to the present, of a stretch of land (so far ignored by historical, archaeological and environmental research), and its valorisation by conveying the potential, historical landscape of this portion of the lowlands which was at last recovered from the marshes in the years 1930–40.

The area, of about 1137 hectares, is situated between the Sile river and the northern lagoon of Venice. It includes the Roncade municipality (TV) and a small part of Meolo (VE), now part of Ca' Tron estate farm, so named by a noble Venetian family in the early seventeenth century. It was once formerly included in the east Altinum Roman Ager, and the ancient Annia Street crossed through the southern sector of the estate along the stretch uniting Altinum and the site of Iulia Concordia.

Interest in this area of the Venetian lowlands involves both its geographical and historical features: the former is linked to its pivotal position between the large Brenta and Piave alluvial conoid and its location on the internal lagoon edge; the second is related to the neighbouring topography of the ancient city of Altinum (which is only two miles away) and to the road network realized by the Romans in the territory, partly exploiting the existing connections (in particular Annia Street – *Via Annia*).

In recent years the methodology used to study an area has evolved, absorbing interdisciplinary trends: information from various fields and research areas allows us to have highly scientific data available for a virtual reconstruction of the ancient landscape in its totality.

The study of Ca' Tron lends itself to this multidisciplinary logic due to the complexity of the morphological and human history of the area. Certainly one of the most advanced features of research into the past is the integration of historical and archaeological studies with studies of the environmental, and the relationships between environment and culture (Environmental Archaeology), reconstructing human history through the recovery of the temporal dimension of the environmental dynamic.

Archaeological research is carried out in close relation with palaeo-environmental research, making use of the most advanced technologies of investigation, detection and data processing, with the primary aim of grasping the relationship between man and his environment.

An interdisciplinary project of this kind, in a landscape context, among the most unspoiled of Venetian valleys, has stimulated reflection on the issue of the valorisation of acquired knowledge, both in scientific and communicative terms. One of the most innovative solutions in this area requires the use of multimedia: "virtual reality" techniques enable us to increase the amount of information and the quality of our perception. Precisely because of the wealth of data from the research at Ca' Tron, it was possible to verify the potential offered by a virtual reconstruction system.

The aim of the project was the reconstruction (starting from the research results) of the Ca' Tron archaeological landscape using visual simulations as a tool for hypotheses testing, and the geo-spatial contextualization in a diachronic way of the geological, botanical and archaeological information collected during these years of research. Unable to perform a continuum transformation of the landscape, four periods of significant changes in geomorphology, vegetation and human presence were identified:

1. the Last Ice Age Maximum (LGM), about 18,000 years ago,
2. the Bronze Age (second millennium BC) (*Fig. A1.1*),
3. the Roman Age (first century BC) (*Fig. A1.2*),
4. the Middle Ages (XIII–XVI century BC).

The work consisted in:

– Data Collection: geophysical exploration, probings, sediment analysis, interpretation of aerial and satellite photos, survey of the land by airborne

Fig. A1.1. The reconstructed potential landscape of Bronze age at Ca' Tron (3d rendering by I. Cerato, A. Palombini, S. Pescarin, GIS developed by Dept.of Archaeology and Geography University of Padova).

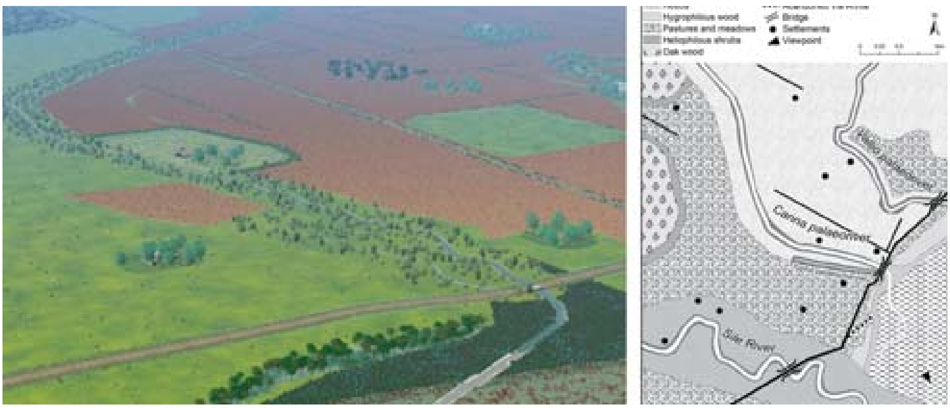

Fig. A1.2. The reconstructed Roman landscape at Ca' Tron (3d rendering by I. Cerato, A. Palombini, S. Pescarin, GIS developed by Dept.of Archaeology and Geography University of Padova).

laser scanner, palinological and other plant analysis, excavation samples, surface reconnaissance, detection campaigns.

– Data processing: creation of digital terrain model and its preparation for the four chronologically reconstructed phases, study of plant species documented in similar geographical and climatic contexts, study of the structures, surface and finds, 3d reconstructions.
– Creation of virtual system (*Fig. A1.3*): creation of a GIS system of the "observed landscape", identification of the most significant phases (LGM, Bronze Age, Roman Age, and Middle Ages); 3d virtual modelling of the main archaeological evidence, drafting in GIS of the "interpreted landscape" for the different phases; virtual landscape generation and its ecosystems (software VNS), data export into a virtual interactive GIS (VTP open source software, CNR-CINECA).

Fig. A1.3. The VR application developed for Ca' Tron in exhibition at Archeovirtual 2008, Paestum, Italy.

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[I. C. and V. V.]

A.2. Via Flaminia Roman Landscape

Location*: North of Rome, Italy;*
Time*: 21^{st} century AD and 2^{nd} AD;*
Period*: Summer*
Location*: North of Rome, Italy;*
Time*: 21^{st} century AD and 2^{nd} AD;*
Period*: Summer*

The project

The Virtual Museum of Ancient Via Flaminia, begun in 2005 by the Virtual Heritage Lab of the ITABC-CNR, aimed to reach a virtual reconstruction of the Via Flaminia archaeological landscape (about 2^{nd} century AD). The goal was the creation of a Multiuser Virtual Reality museum installation for the Roman National Museum in Rome. The VR system is a MUD (Multiuser Domain) planned for 4 users with single displays and a HD stereo display 1024 x 768. The visitors share interactively the same virtual space, interacting through their joined actions and creating a virtual performance which is visible to the other visitors in stereoscopy (Forte *et al.* 2007).

The reconstruction of the landscape was conceived of with two uses in mind. On the one hand it was targeted to be used in the Virtual Reality application and also to build computer-graphics movies, to be included in the VR multi-user system, developed using a story telling technique. This application is now installed in a specific room of the museum and it is characterized by four computers, connected in a network through a local server (*Fig. A2.1*). On the other, it was conceived as a basis for a 3D WebGis system, to allow people to browse the Via Flaminia landscape and reach its information content through the web.

The two platforms have different features and requirements. The museum VR system implies a limited time for users, and a cyclic and structured application, but at the same time it allows a wide-band of data-flow; whereas the web system allows users to decide their fruition timing and features, but is more limited in terms of data-flow.

The ancient landscape reconstruction has been carried out for use on both systems, aiming for at least two levels of detail: the first related to the whole territory around the Via Flaminia inside the Roman County area (about 20x40 km);

the second, more detailed, for the Virtual Reality high-resolution application, and limited to the areas of archaeological interest along the path.

At the same time, the double-sided work of reconstruction (monuments and landscape) implied different strategies. For the monuments, a top-down strategy was performed, starting from the hi-res reconstruction (obtained from Laser scanning), and simplifying data in order to reach a web-optimized version. For the ecological aspects of landscape, on the other hand, a bottom-up process was carried out: the simple GIS information layers (landscape features, ecosystems distribution and so on) were a starting point to obtain virtual reconstructions of natural items (plants, rivers, etc.) in the landscape context, at varying resolution.

In both situations, the reconstruction needed a complete and reliable definition of the ecological features for the whole territory studied, corresponding to about 135.000 hectares. As a matter of fact, while for the Virtual Reality application – focused on a few hi-res monumental areas – vegetation was no more than a frame for architectural context in the limited areas where users moved, theVR webGis system required knowledge of the whole browsable territory (*Fig. A2.2*).

Fig. A2.1. Flaminia Virtual Museum. The multi-user installation: Rerendering the project.

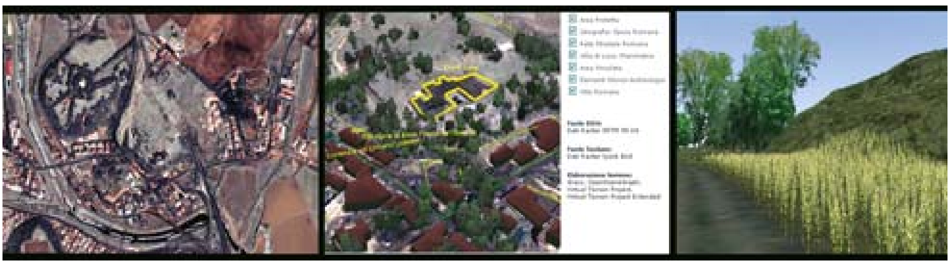

Fig. A2.2. The open process of landscape reconstruction: mapping the archaeological landscape (left), working in a shared on line environment (center), testing and simulating hypothesis (right).

Pre-processing and post-processing

The available data for an historical approach to landscape reconstruction are unfortunately quite incomplete. We have various resolution digital elevation models (DEM), but they represent the actual terrain morphology, which slightly differs from the ancient one, as does the hydrology. We also have nature studies and literary texts which can give us information on the presence or absence of species of vegetation, as well as distribution data on archaeological findings, which may lead to indirect information about the distribution and typology of human occupation (villas, necropolis, monuments, etc.).

Such data needs a certain amount of preliminary processing before it is suitable for an historical landscape reconstruction.

Concerning the terrain model, the first step is the collection of reliable data on the terrain height in antiquity, for the areas where such information is available (from archaeological excavations, the presence of clearly datable items such as monuments, roads, etc.). At the same time we delete the morphological items whose modern origin is certain (banks, earthworks, hill-edge cutting, etc.).

Such specific areas can be used to be connected and/or interpolated with modern observed DEMs, to get closer to the ancient landscape situation.

This kind of operation, particularly over extensive areas, is naturally not exhaustive for the features of an ancient landscape, but its reliability is proportional to the amount of available archaeological documentation and then of ancient human presence in the territory, to give the most reliable possible representation of it. When dealing with such a topic, we should recall the concept of uncertainty management: narrative or virtual reconstruction do not allow any "lack" of information. For this reason we are forced to operate choices among the various possible options, whenever a doubt arises, so that the fundamental issue is that choices should be transparent and plausible.

Once we have obtained a digital model of the ancient terrain, we have proceed to the next step, preparing thematic maps of all the ancient features of the territory: the reconstruction of the ancient hydrography, through the comparison of historical maps and analysis of aerial photographs (*Fig. A2.3*), the map of ancient roads, and the map of archaeological occurrences. The latter was divided into different themes according to archaeological typology: the thematic map of the villas was one of the most important parts of the work that followed, and it is very important to have a reliable scheme of such buildings' spatial position. To this end, to avoid considering the features of the same villa as different sites, all the occurrences lying at less than 150 meters from each other, were considered as individual instances (*Fig. A2.4*).

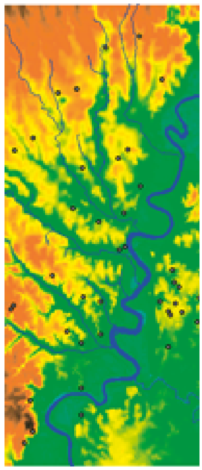

Fig. A2.3. Ancient hydrography, through the comparison of historical maps and analysis of aerial photographs.

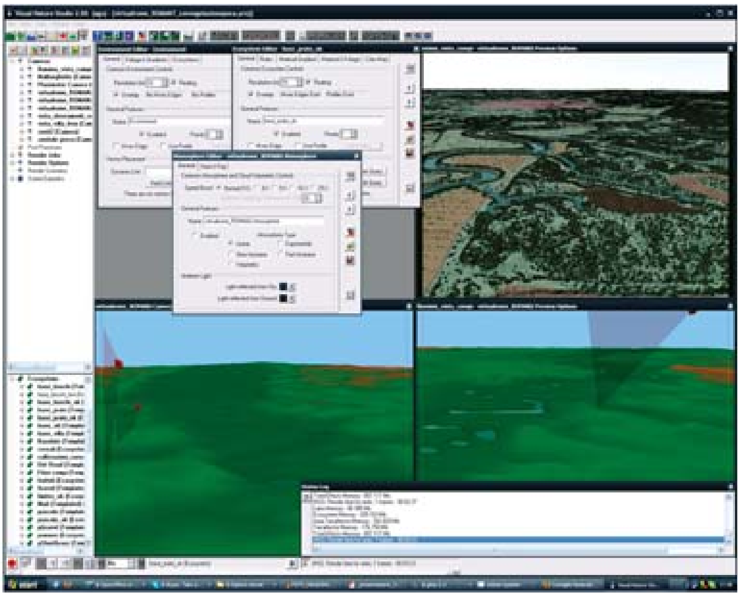

Fig. A2.4. The reconstruction of the Roman ecosystem and location of Roman villas.

Advanced elaboration

The next step represents the fundamental and original part of the landscape reconstruction process. Starting from the Digital Terrain Model, a new slope map was created and then simplified so as to reach a five slope categories map. Geological and agronomic scientific literature offered a wide range of documentation about possible cultivation on the terrain slope, so that it was possible to assign to each slope category a list of the vegetation potentially present (Chapter 4). Such a map was then refined by taking into account a lithostratigraphic soil map.

It was thus possible to obtain a new map concerning the ancient use of the soils, including different cultivation areas (vineyards and olives, cereals, and, particularly, fruits), as well as grazing areas, dense and light woods, bushes and areas of river shores, normally not cultivated and rich in a dense spontaneous vegetation (*Fig. A2.5*). Once all the areas potentially suitable for the various agricultural uses had been selected, we determined which ones were probably really cultivated among them. We hypothesized that such areas could be sought for among the ones closest to living structures and therefore easily accessible.

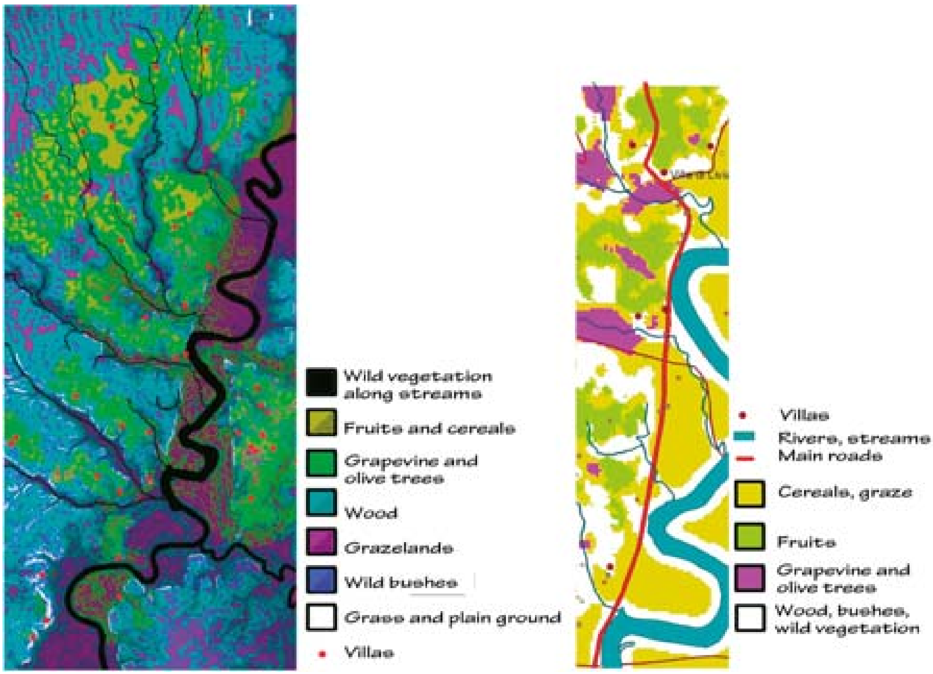

Fig. A2.5. New map concerning the ancient use of the soils.

Study of the ways to determine the most easily accessible areas for food production purposes in ancient societies is by no means a new subject, having been carried on since the dawn of spatial analysis in archaeology, well before the spread of PC use. An important step in such a direction was Site Catchment Analysis (Appendix B) (Higgs – Vita-Finzi 1970).

In the Roman context, we have many studies on the possible range of agricultural activities (Gaffney – Stančič 1991). On the basis of previous work and statistical analysis on specific site density, we chose to adopt 1357 mt ray areas, around the villas[153], inside such areas they are primarily considered the ones easily reachable in terms of slope and distance (cost analysis).

All these data and other analysis factors (the ancient hydrography, the reconstruction of possible ancient *limitatio*, the correlations of fields to roads and streams, and so on) can easily be integrated into the frame of GIS calculation formulas, to obtain thematic maps of the final hypothetical reconstruction of land use through a common GIS software (we used GRASS 6.0).

The first result of such an elaboration is highly bitty and fragmentary, so that another step has to be taken to give the map a minimal threshold in shape regularity and the size of cultivated areas. Once again it has to be stressed that what we're going to reach is a plausible reconstruction of an historical landscape, and not the reproduction of a real situation. In fact, the real situation of the landscape, even if accessible to our knowledge, would be a constantly changing context.

Nevertheless, this process, thanks to its scientific plausibility and procedural transparency, can be considered an ideal meeting point between the ecological a cognitive reality of a landscape, reproducing both the landscape's scientific model and (through the next step of terrain generation) the landscape's emotional impact on the observer.

Terrain generation

The reconstruction process performed so far has, for its output, a series of 2D maps (raster or vector) containing information on ancient landscape features and various areas. Specific Terrain generator software is used to shift from this level to the 3d landscape reconstruction.

Such software (we used Visual Nature Studio) helps in creating simple or mixed ecosystems, using GIS starting data as a basis, and generating single plants

[153] For a more detailed explanation of the process see Palombini – Vassallo 2007.

according to specific graphic libraries which can be customized through pictures of vegetables.

All ecological parameters (density, dimensions, the presence of species) can be customized as well. The next step is the insertion in the landscape of architectural models of monuments.

The final result (*Fig. A2.6*) is a real, highly impressive landscape, which can be rendered at various resolution and complexity levels, according to the required use (local or web-based).

Fig. A2.6. Roman potential reconstruction of the landscape along the ancient Via Flaminia.

Acknowledgements

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[A. P.]

A.3. The Narrative Virtual Museum of Appia Archaeological Park

Location*: Rome, Italy;*
Time: *21st;*
Period: *Summer*

In 2002, the Institute of Technologies applied to Cultural Heritage has signed a research agreement with Roman Superintendency with the goal of creating in four years a spatial two-dimensional and three-dimensional archive of the monuments of Appia archaeological park, Rome (Italy).

The Appia Antica project (the archaeological park of Roman Via Appia) was a good chance to experiment different technologies and approaches, allowing a continuous comparison with different mapping and VR techniques. It was developed between 2003 and 2006 by the interdisciplinary team of CNR ITABC, in collaboration with Roman Archaeological Superintendence. Within this project different results have been obtained: a spatial 3d digital archive, an open source VRwebGIS and a Virtual Reality application "*The narrative Museum of the Archaeological Park of Ancient Appia Antica*". The work was characterized by an intense activity of archaeological and architectonic survey with the goal of acquiring data for a real-time spatial interactive system. All the techniques used (DGPS, Total Laser Station, 3D Scanner Laser, 3D Stereo Photogrammetry, Photo-Modelling Techniques) were used in integration.

All the data acquired were post-processed: part of them (topography) were overlaid in a GIS project, while 3d models (architecture), obtained from scanner-laser and photo-modelling or reconstructed from archaeological sources, were geo-located and connected with external multimedia databases. For our activity it is very important to preserve the link between the fieldwork, survey activities and VR communication. That's why our efforts have been oriented to experiment a common protocol to manage data, without loosing information during the successive phases of elaboration and communication. The software used: ArcView, Terravista (GIS and terrain modelling), Photomodeler (photomodelling), Cyclone and RapidForm (laser scanner data elaboration) 3D Studio Max, Photoshop (optimization and design of the landscape), Virtools-DEV (real time engine), OpenScenegraph for the 3D webGIS .

The priority of the archaeological information consists in the contextualization of data and of cultural itineraries, in the inter-relation between human life and sites, landscape and archaeological objects, the life of the past and the life of the present. The more information enhances difference and connectivity, the more the symbolic associations grow up and also the possibility for visitors to assimilate and elaborate cultural contents. We need to introduce "life" in the environment, activities, characters, behaviours, narrative contents to allow to comprehend ancient people mind, in relation with cultural models of past and present. How did ancient people live in the territory? What kind of activities did they develop? Which symbolic values did they attribute to the places? What kind of cultural message did ancient people perceived from object and places? Which relations can we establish between the past and the present culture?

The aim of this project has been to utilize all GIS, topographical, architectonic data to construct digital spatial models, and associate them to a communicative system dedicated to the public and educational use.

A fly through the 3d model of the territory of Rome helps us to contextualize the Appia Park before analysing and observing in detail the environment. Some tools allow us to modify the visualization, changing the textures of the geometry and loading cartographic layers, highlighting areas of interest, taking measures on the territory. From the holistic level it is possible to choose two areas of interest, the Caffarella valley and the via Appia Antica and explore them in a successive, more detailed level of representation. When we choose to walk inside the park we are full immersed in the context, every element of the landscape is described in 3D and we can decide to interact directly with historical and cultural contents through complex behaviours, narrative metaphors, characters and avatars. While walking through the park we can meet ancient travellers, famous characters of the past, animals, talking sacred trees, gods that tell us some tales about the park, legends, myths, stories (*Figs. A3.1–2*).

When we get near the archaeological structures we can listen to an audio explanation of the monument we are looking at, we can open movies, tales, animations, iconography, and so on; all the metadata are associated inside the three-dimensional space. Sound is spatially integrated in the 3d space, so to communicate the specificity of different places also through the suggestions produced by sounds, noises, voices.

In the real time visualization and exploration of the whole landscape a simplified version of the object and monuments, obtained by photomodelling techniques, are used, while the high resolution version obtained by laser scanner are employed for a monographic analysis of the monument.

Fig. A3.1. Virtual Exploration of the archaeological landscape: the Caffarella Park and a Roman Cistern.

Fig. A3.2. Virtual Story Telling: a visitor meets an animated tree in the Sacred Wood who tells the story of the ancient territory.

Fig. A3.3. Nympheum of Egeria: transparency of digital process and further information are communicated through movies in the 3d space.

For the Nimphaeum of Egeria and S. Urbano Church we can explore and compare the models of the monuments as they appear today and their hypothetical original aspect (*Fig. A3.3*). The Roman road has been reconstructed from the fourth mile to Casal Rotondo, also in this case monuments have been acquired by laser scanner or photomodelling techniques.

An important part of the archaeological monuments along via Appia Antica have been restored, and recomposed by Luigi Canina (1795–1856), an architect exponent of the neoclassic and antiquarian culture. During his long studies he made a lot of prints, designs of archaeological views, prospects of building, detail of decorations. These views show funerary monuments as they were in the 19th century but also as Canina imagined they could appear in the ancient time. We have represented one of his views in three-dimensions, so we can make our avatar walk or run inside Canina's print, exploring and visiting monuments as he imagined them (*Fig. A3.4*). *The narrative museum of the archaeological park of Appia Antica* has been shown to the public during some international exhibitions of virtual

Fig. A3.4. A mindscape of the Roman Via Appia:
the real time exploration of a user inside the Canina vision of the territory.

archaeology: “Immaginare Roma Antica” (Trajan Market Museum in Rome, Sept.15–Nov.15, 2005) and “Archeovirtual” (Paestum, Mediterranean Exchange of Archaeological Tourism, November 2006) obtaining a good success. Public had the possibility to explore and interact directly with the virtual landscape and cultural contents wearing stereoscopic glasses to enhance the impression of immersion inside the 3d environment.

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[E. P.]

A.4. Integrated Technologies of Robotics and Virtual Environment in Archaeology

Location*: Rome, Pisa (Italy), Luxor, Medinet Madi (Egypt)* and *Khor Rori (Oman).*

A FIRB (Funds for the Investments of Basic Research) project, *Integrated Technologies of robotics and virtual environment in archaeology*, financed by the Italian Ministry of the University and Scientific Research, gives us the opportunity to experiment and realize a multi-user domain on the web addressed to a multidisciplinary scientific community. The project, in collaboration with the Department of Archaeology of the University of Pisa and with Scuola S. Anna of Pisa, focuses on three archaeological sites: the Teban tomb 14 in the necropolis of Gurna-Luxor, the Temple A of Middle Kingdom in Fayum Medinet Madi, both in Egypt, and the ancient settlement of Khor Rori, in Oman.

Typically the scientific communities do not consider VR environment an operative tool for archaeological research and, in particular on the web, there are few examples of 3D e-learning and e-communication. It is not yet common to share interpretations, hypotheses and data in the same virtual domain.

We think it could be very important to promote the use of the "virtual" also within scientific communities of experts, researchers, managers of cultural heritage. How technologies, and in particular virtual reality, can develop the organization and visualization of cultural contents? How can they support us in the interpretation, simulation of hypothesis and in the creation of integrated informative systems? Which are the most efficacious ways to interact with models and metadata? How can we share and exchange data? Archaeological research produces during the phases of acquisition, post-processing and communication, huge quantities of spatial data, disseminated in different archives (with various formats, ontologies and typologies). The consequence is that the process of *interpretation* and communication becomes partially compromised, or even obstructed, by the inaccessibility of all data inside the same informative system. Moreover in most cases virtual reality applications are developed as final processing and 3d output of a previous long term work of research and study. They are not conceived as environment for simulation, sharing of information, testing hypothesis, editing of digital ecosystem in order to experiment different solutions.

The three archaeological sites involved in the projects present very different characteristics and interpretative aspects. The tomb TT14 is a small and narrow space with a very complex stratigraphy; the Temple A is a well preserved architectonic context; Khor Rori is a typical example of archaeological landscape correlated with environmental studies. We have expressly distinguished and emphasized these features of all the archaeological contexts in order to apply different methods of communications and virtual re-contextualization. This variety of conditions of the archaeological contexts has required the use of different integrated technologies of data acquisition, elaboration and representation: scanner laser, computer vision and topographic relief for TT14 (*Fig. A4.1*); GPS, total laser station, GIS, remote sensing, photogrammetry, computer vision, 3D panorama for the settlement and the landscape of Khor Rori, 3D computer graphics on the base of topographical relief for the Temple A of Medinet Madi. A collection of metadata, interpretative layers, multimedia contents are linked to models and integrated in the three-dimensional space.

All these data converge in a virtual scenario in the web where the scientific community can meet and interact in real time, exchange and test hypothesis, share data and make simulations in the 3d space. This virtual space is an editable and dynamic environment in continuous evolution.

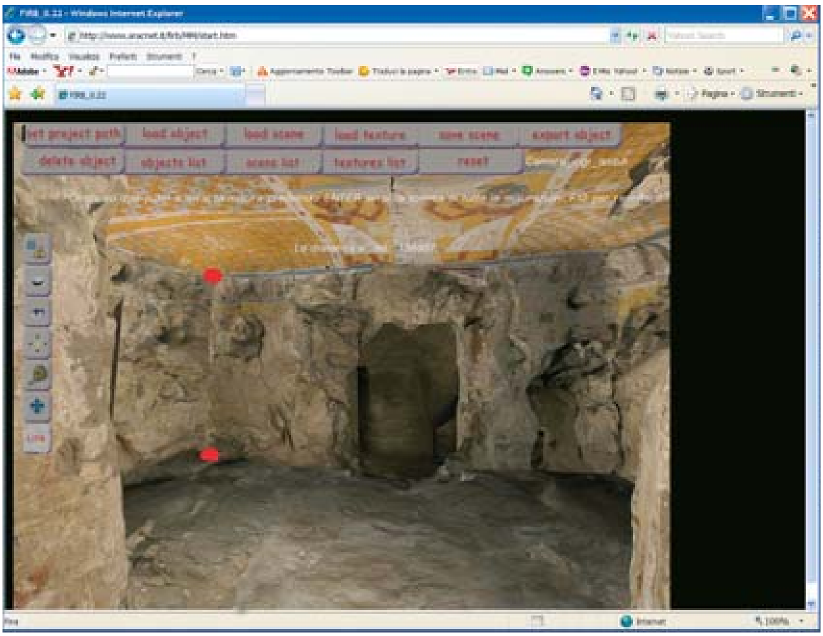

Fig. A4.1. Teban Tomb14 acquired by laser scanner.
Screenshot from VR multiuser application, the tools measure is active.

In fact 3d models are not closed and no longer accessible from users, as in most part of VR applications. On the contrary, they are open to continuous possible re-elaboration; they can be disassembled and recomposed according to different combinations and solutions. The models can be also exported from the application in “obj” format and re-used for different purposes. Beside the 3d models of architectures and archaeological structures, obtained from topographical reliefs, the VR application introduces other kinds of ontologies such as the *“Virtuoteca”* (*Fig. A4.2*), an imaginary cyberspace, like a library, where users can find digital contents, papers, multimedia related to the archaeological site and studies.

Fig. A4.2. Virtuoteca for the site of TT14.
The spheres represent users moving in the 3d space and chatting.

These are the main functions and tools of the applications (*Fig. A4.3–4*):

1) set project path; 2) load object (in .nmo format); 3) load scene (in .txt format); 4) delete object; 5) load texture; 6) change the camera; 7) change textures on models; 8) tools of lightening; 9) tools of measurements; 10) move object; 11) hide/show objects; 12) link metadata to 3d models; 13) chat; 14) walk and move in the space through the avatar; 15) export 3d models; 16) save scene.

Every new version of the virtual environment can be saved and uploaded on the web as a new “space” of the MuD (only users with full rights), so that

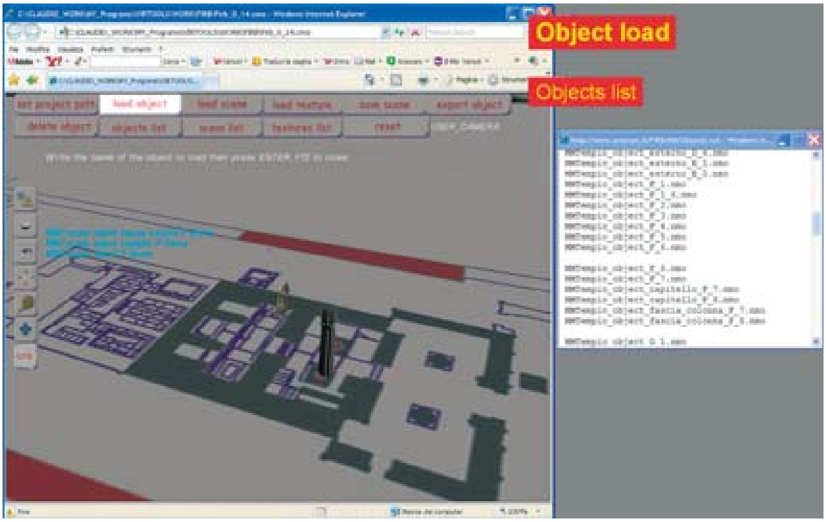

Fig. A4.3. VR multiuser application: function load object,
useful to create customized scenes, loading resources to any server.

Fig. A4.4. Chatting community is moving inside the 3d reconstruction of the
archaeological landscape of Khor Rori, market area.

many different informative worlds can coexist and be compared in real time. The possibility to load, share and interact with data in the same spatial virtual environment can increase the level of learning and scientific communication; in this way the information become hyper-real and contextualized.

The application is developed in Virtools DEV, a real time rendering engine, and Virtools Multiuser Pack.

It can be very usefull for education, collaborative sessions of learning, design and planning of conceptual maps. A possible scenario is the virtual classroom where the teacher can interact in 3D with the students, discussing about key features of the archaeological sites, interpretations, hypotheses and general overviews.

Acknowledgements

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http:// www.vhlab.itabc.cnr.it/FIRB/Release/Home.html

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Transparency, interaction, communication and open source in Virtual Archaeology. In: Campana, S. – Forte, M. (eds.), *From Space to Place. Proceedings of the 2nd International Conference on Remote Sensing in Archaeology.* 535–539. BAR International Series 1568. Oxford, Archaeopress.

PIETRONI, E. – FORTE, M. 2006
The Museum's mind: a cybermap for cultural exhibition. Proceedings VAST 2008, Nicosia, Cipro 30 ottobre – 4 november. In: Ioannides, M. – Arnold, D. – Niccolucci, F. – Mania, K. (eds.), *The evolution of Information Communication Technology in Cultural Heritage*. 70–73.

[E. P.]

A.5. Virtual Rome

Location*: Rome, Italy;*
Time*: 2nd AD;*
Period*: Summer*

Virtual Rome is an open project whose aim is the interactive exploration and dynamic editing of 3d cultural information regarding landscape reconstruction of the territory of Rome. One of the result of the project in fact has been the identification of a method and the reconstruction of the potential landscape of Rome during Imperial times (2nd AD) (*Fig. A5.1*). Virtual Rome has also developed an Open Source VR webGIS application, based on geospecific data, 3d models and multimedia contents, and a VR webLAB Content Management System dedicated to interactive and shared reconstruction process.

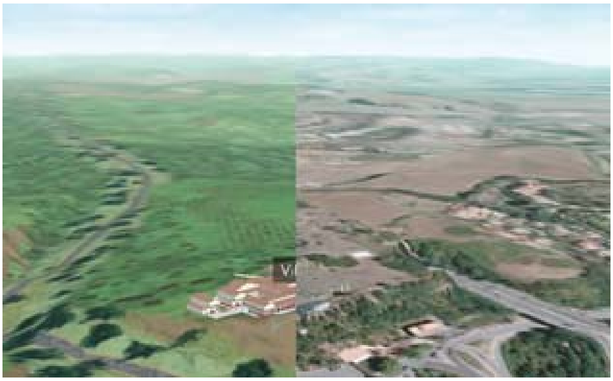

Fig. A5.1. The archaeological and potential landscapes reconstructed for Virtual Rome project.

In the web browser, final users can interact dynamically in the reconstructed space and activate different behaviours in order to enhance their knowledge of the territory. The VR webLAB is developed as to involve different researchers in the complex activity of landscape reconstruction, inside a cooperative environment. The VR webGIS, on the other side is built to enable visitors to explore archaeological landscape, trying to understand how should have been in the past, where can most important and best preserved monuments be found and how eventually to visit them, need. It is based on previous works, developed in 2004 and 2005, for the Appia and Esaro Cultural District projects (Forte *et al.*

2005; Pescarin *et al.* 2005b). After an analysis of different open source projects and 3d graphic toolkits, such as Virtual Terrain Project, OpenSceneGraph, OpenSG, etc., we decided to base the work on OpenSceneGraph, the only one that in that period was offering paging support for terrains and on-line publication capabilities, through the *.net* plug in (Kuehne – Martz 2007). It was specifically developed a plug-in, OSG4WEB, for Internet Explorer and Mozilla Firefox.

For Virtual Rome project the following characteristics and behaviours have been developed:

- paged geospatial dataset support
- coordinate and projection handling (both in input and in output)
- large 3d terrain dataset management
- 3d models integration (modelled with software such as 3D Studio Max, etc.)
- natural elements, such as vegetation, integration vector layers integration
- on-line 3d data publication and interaction, possibly embedded into a web browser
- Fly and walk navigation tools
- Behaviours integration:
  - terrains, models switching
  - vector information loading
  - models loading
  - picking and loading external pages or multimedia contents
  - overview map
  - environment integration.

The project followed three main directions:

1. the definition of a digital pipeline which could enable a share collaborative work,
2. the creation of digital contents (study, interpretation and reconstruction of the landscape and main archaeological sites),
3. the development of the software.

Digital contents include:

- archaeological and Roman potential landscapes reconstruction;
- 3d models creation, optimization and integration in 3d scene;
- vegetation creation and integration;
- multimedia Contents creation and integration in the 3d space (*Fig. A5.4*).

Software and developed tools are:

- OSG4WEB plug-in;
- front-end web site, based on JavaScript, PhP. and Ajax programming, which embed the plug-in (front-end section) (*Fig. A5.2*),
- CMS which integrates the plug-in and enables scene creation and project publishing (back-end section) (*Fig. A5.3*).

Virtual Rome project has identified a methodological approach which allowed, first of all, the definition of the archaeological modern landscape and, secondly, the reconstruction of the ancient landscape. The latter is based on the same GIS data used for the first, modified in accordance with archaeological data and with the integration of all relevant paleo-environmental and historical information. *Fig A5.5* and *Table A5.1* describes various activities, software and formats defined.

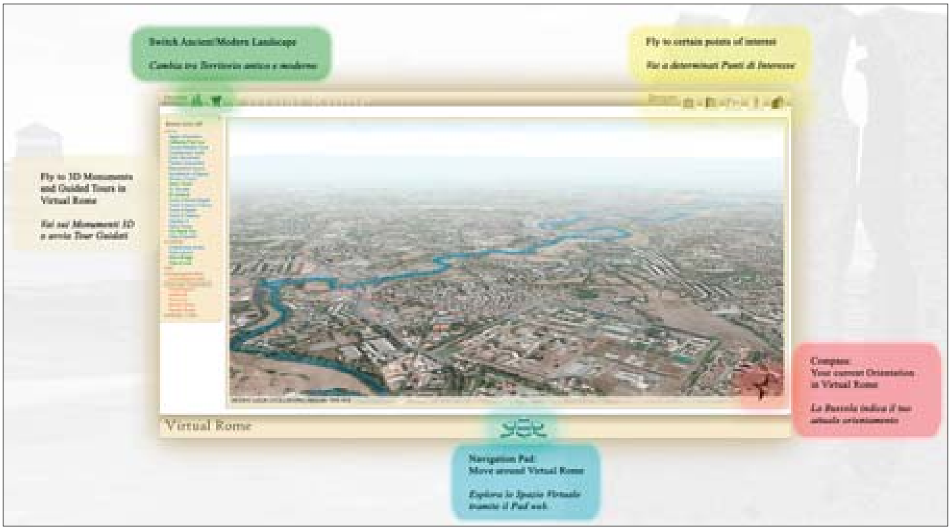

Fig. A5.2. The VR webGIS application of Virtual Rome (courtesy of B. Fanini).

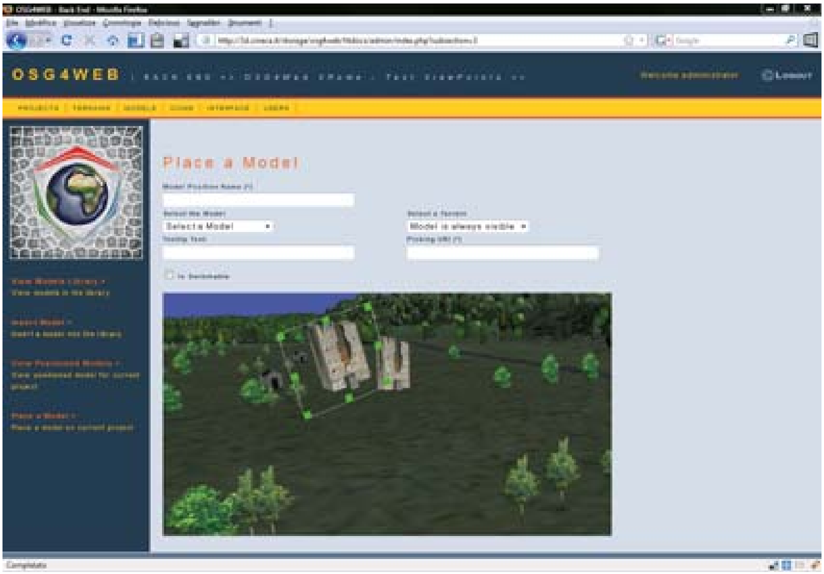

Fig. A5.3. The VR webLAB content management system of Virtual Rome (developed by C. Camporesi, L. Calori).

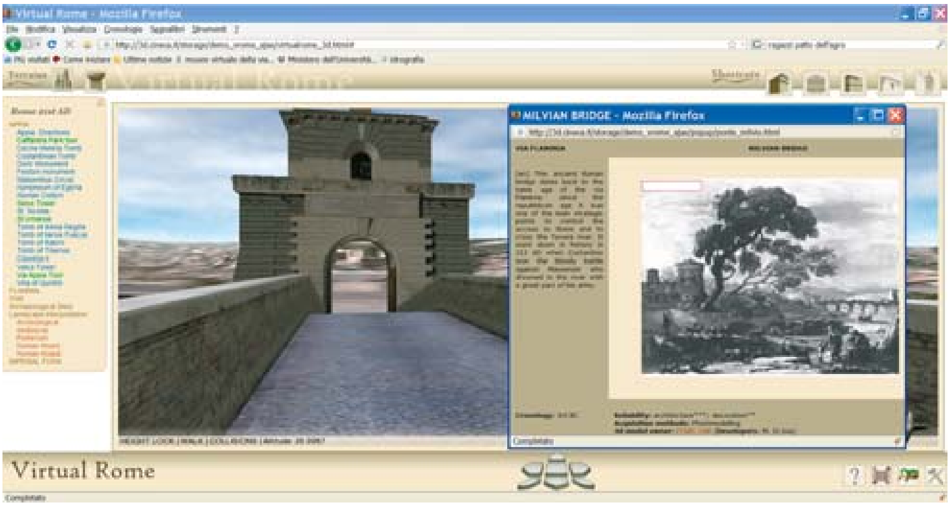

Fig. A5.4. Every 3d object on the cyberspace can be interactively queried and open a multimedia content.

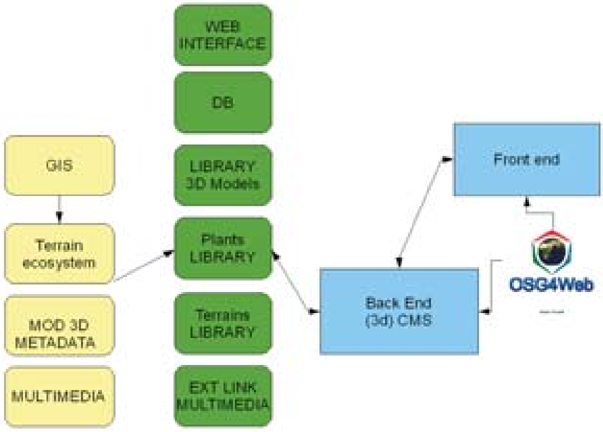

Fig. A5.5. The digital pipeline followed in the Virtual Rome project.

Steps in the reconstruction of Virtual Rome landscapes	
1. Geoimagery, vector and DTM data acquisition	*GRASS GIS, QGIS*
2. Data re-projection in the same coordinate system	*GRASS GIS*
3. Colour calibration	*GRASS GIS and Er Mapper*
4. Archaeological Landscape: Terrain Generation	*OSGdem*
5. Vector thematic layers (Interpreted landscape)	*GRASS GIS and Quantum GIS*
6. Database annotation	*DBF and MySql*
7. Export of shape files in OSG format	*VTP ENVIRO extended version or direct integration*
8. Geo-archaeological maps integration in the GIS and DB	*GRASS GIS*
9. Creation of Roman Land Use Map	*GRASS GIS (or other GIS software)*
10. Virtual Ecosystem generation	*Visual Nature Studio (or other terrain and ecosystem generator)*
11. GIS and vegetation Export	*Visual Nature Studio and GIS*
12. Ancient Landscape: Terrain Generation	*OSGdem*
13. Vegetation integration	*OSGdem*
14. 3d models integration	*OSG4WEB, Python and MySQL*
15. Publication over the web for end user	*OSG4WEB and JavaScript*
16. Updating of the process through cooperative environment	*3d CMS*

Table A5.1.

To reconstruct the archaeological landscape, it was necessary to build an initial GIS archive, containing all spatial information, such as the aerial photographs (20 cm resolution) provided by Nuova Telespazio, and other satellite images with different resolutions in integration to not covered areas. The used coordinate system was WGS84 UTM32N. The entire geoimages dataset was quite big (35 GB) and in order to handle it we preferred to maintain separately all photographs, after blending and colour calibration, rather then producing one large mosaic.

The available DTM (10 mt resolution) was used with the geoimages dataset to build the 3d terrain with OSGdem. The final result was a 3d model of the entire Roman area, divided, geometry and texture, in various Level of Details (LOD) and in tiles. During the exploration, the user doesn't have the feeling of the amount of data that are loading, because of the hierarchy of the model.

Vector thematic layers regarding the archaeological landscapes were also added to the GIS, such as location of archaeological sites, Roman roads, river system, etc. The majority of this information came from archaeological excavations and surveys, aerial photo interpretation, historical maps and geoarchaeological observations. A modified version of the open source tool VTP (Builder and Enviro) was used to export vector layers in the *.osg and *.ive file format. Data in this formats may be in fact published on line, and, in our case, they have been published in the front-end, though the 3d plug-in and also thanks to the back-end interaction.

Potential Roman Landscape was than reconstructed and published as well as a further "switchable" layer. It was obtained thanks to the soil map and land use map of Rome developed by Rome City Council. This map was then modified in order to define different (Roman) Classes, and Land Uses (aLU: Chapter 4) (Arnoldus-Huyzendveld 2003; Volpe – Arnoldus-Huyzendveld 2005). Each dominant soil use of the various areas was reconsidered, comparing it with Roman geomorphology and known archaeological sites or paleo-botanical analysis. In this way the territory around Rome was divided into different potential environmental classes, accordingly with different land capacity values. A new map was thus obtained, representing the different potential ecosystems of Roman period in that specific part of Rome (*Fig. A5.6*). Each ecosystem has been better defined by specific species, taken from a digital library of Roman vegetation appositely created, and also by characteristics, identified by sub-categories, such as top and bottom vegetation, density, rules of nature, etc. Visual Nature Studio by 3D Nature was used for this specific project. At the end of the process new geoimage were generated and exported. Different view points have been rendered and movies produced. The entire coverage was also exported in GIS to generate the 3d terrain models in osg for real time on line purposes. 3d models have been added in the ecosystem generator, in the CMS or in the 3D graphic software.

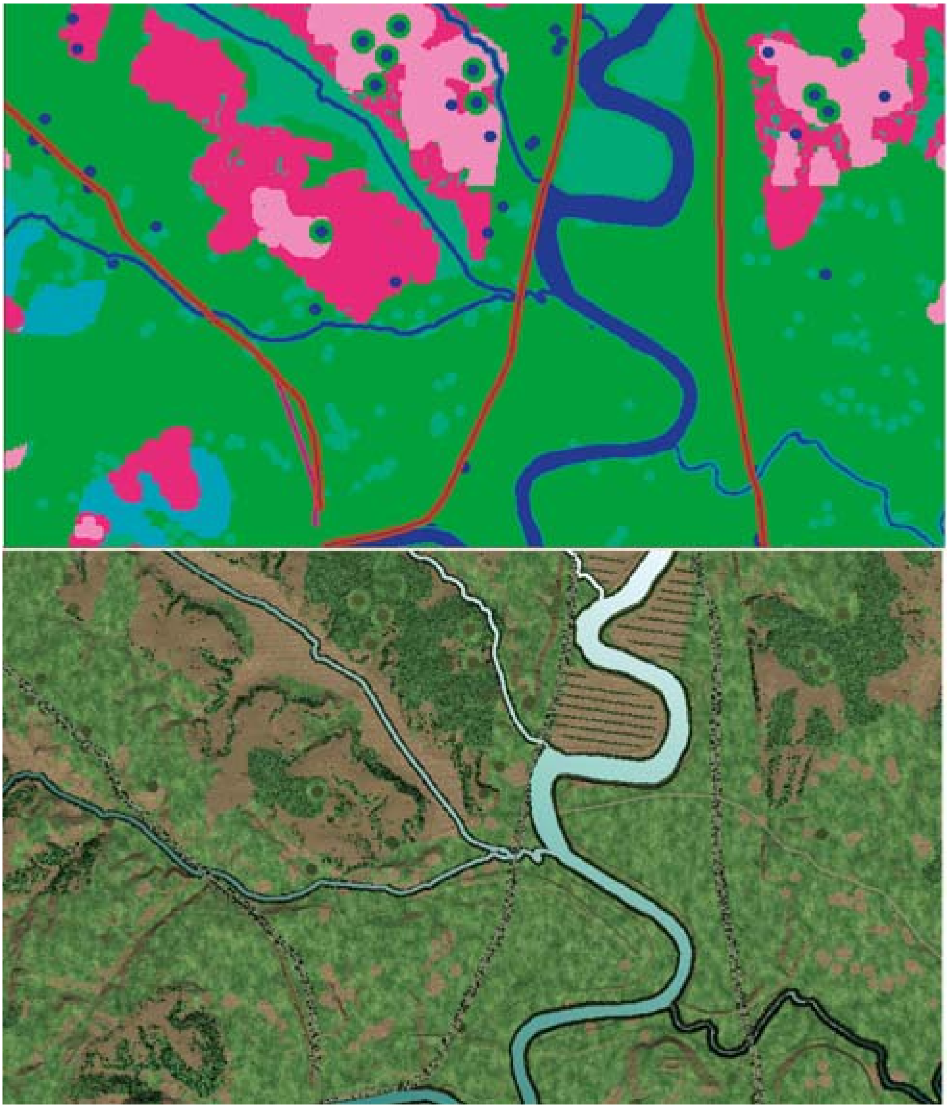

Fig. A5.6. An example of the ecosystems map obtained and of the reconstruction of the environment exported in GIS.

The interpretation and reconstruction process of this project is not finished yet. New data and new information can be always found, new hypothesis formulated, new areas investigated. Nevertheless, although a work in progress, the VR webGIS has been available since the beginning of the project on line (the front-end) at www.virtualrome.net (*Fig. A5.7*).

Fig. A5.7. Virtual Rome application during Archeovirtual 2008 exhibition in Paestum, Italy.

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Vassallo; 3D Modelling: F. Galeazzi, M. di Ioia, A. Moro, L. Vico (ITABC); F. Delli Ponti (CINECA). Foundings and sponsorship: Seat Yellow Pages, Roman Chamber of Commerce. Cooperation: Rome Dept. X - IV° U.O. and A. Arnoldus-Huyzendveld.

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Virtual Rome: a FOSS approach to WEB3D. In *Web3d International Symposium 2009.*

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Back to II AD. A VR on-line experience with Virtual Rome Project. In: Ashley, M. – Hermon, S. – Proenca, A. – Rodriguez-Echavarria, K. (eds.), *Proceedings of the 9th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2008)*. Eurographics.

[S. P.]

Appendix B

Sources and Resources

B.1. Spatial repositories

Global Land Cover Facility

GLCF is a centre for land cover science with a focus on research using remotely sensed satellite data and products to assess land cover change for local to global systems. The GLCF provides earth science data and products helpful for the study and understanding of global environmental systems. It develops and distributes remotely sensed satellite data and products. Every primary data and products available at the GLCF are free to anyone via FTP (and on-line accessible through the Earth Science Data Interface, ESDI): they are satellite imageries and products derived from that, such as vector products. http://glcf.umiacs.umd.edu

Military Geographical Institute (Istituto Geografico Militare: IT)

This is the organization preserving the largest aero-photographic collection of Italy, providing geo-topo-cartographic support to the Units and Commands of the Italian Army as Cartographic Organization of the State. Of fundamental importance are the photos taken before or during the Second World War.
http://www.igmi.org/

Italian Aerial Photo Archive (aereofototeca)

Since 1973, it is a centre for the collection and study of the Italian territory aero-photographic material and it has acquired over the years a heritage of over two million images.
http://immagini.iccd.beniculturali.it

Italian State Archives

The Italian Archive of Cultural Heritage.
http://www.archivi.beniculturali.it/
Access with search engines and on-line inventories:
http://www.archivi-sias.it/index.asp

Mapping Mediterranean Lands project

Part of the Digital Library for International Research and under the aegis of the Council of American Overseas Research Centrers, it aims to identify, catalogue, conserve, and make electronically accessible early and unique or rare maps from archaeological excavation and exploration held in the collections of American overseas research centres around the Mediterranean Sea. The multi-phase project resulted in fully searchable catalogued records of over 4,000 single maps and maps in books through an on-line catalogue.
http://www.aiys.org/aodl/public/medmaps/Digital_Maps_MEDMAPS_project.htm

OpenStreetMap

A free editable map of the whole world, made by users. Creating and providing free geographic data allows to view, edit and use them in a collaborative way from anywhere on Earth. The project was started to overcome the problem of legal or technical restrictions on the use of maps, and to enable to use them in creative and productive ways.
http://www.openstreetmap.org/

Remote Sensing Data: various sources and resources

- EROS Data Gateway:
  http://edcimswww.cr.usgs.gov/pub/imswelcome/plain.html
- Astronaut Photography:
  http://eol.jsc.nasa.gov/default.htm
- MrSid GeoCover Landsat TM images:
  https://zulu.ssc.nasa.gov/mrsid/
- Terraserver:
  http://terraserver-usa.com

- Astronaut Photography:
  http://eol.jsc.nasa.gov/default.htm
- NGA Raster Roam:
  http://geoengine.nima.mil/geospatial/SW_TOOLS/NIMAMUSE/webinter/rast_roam.html
- GeoData:
  http://gos2.geodata.gov/wps/portal/gos
- Landsat:
  http://www.landsat.org
- Tropical Rain Forest Information Center (TRFIC):
  http://www.trfic.msu.edu/index.html
- African Data Dissemination Service:
  http://edcsnw4.cr.usgs.gov/adds/index.php
- Centre for Remote Imaging, Sensing and Processing (CRISP):
  http://www.crisp.nus.edu.sg/crisp.html
- ESA Earth Observation Earthnet Online:
  http://earth.esa.int/
- SPOT Vegetation products:
  http://free.vgt.vito.be/
- Free data for Canada:
  http://geogratis.cgdi.gc.ca/clf/en
- Shuttle Radar Topography Mission (SRTM):
  ftp://edcsgs9.cr.usgs.gov/pub/data/srtm/ and GLCF
- ASTER Protected Area Archive:
  http://asterweb.jpl.nasa.gov/APAA/default.htm

Rome: Map Resources

Project developed by the Dalton School and thought as a collection of Rome resources for the community and a useful research tool to find interesting information. It is divided in several categories: literature, archaeology and maps of Roman Empire, etc.
http://intranet.dalton.org/groups/rome/RMAPS.html

United States Geological Survey (USGS)

American national centre for collecting, managing and analysing data aimed at providing scientific understanding about natural resource conditions, issues and problems. It offers a variety of maps and digital data (maps, aerial photographs, satellite images, remote sensing resources etc.).
http://edcsns17.cr.usgs.gov/EarthExplorer/

[V. V.]

B.2. Sources

The reconstruction of the archaeological landscape is a very complex process including many kinds of data and activities in a virtual ecosystem following a multidisciplinary approach. The integration of different data, makes it possible to interpret the functions, aspects and uses of structures and places and propose a reliable reconstruction. Very important for the study of the ancient landscapes and for the organization of the settlements are: ancient writers (Vitruvius, Cato, Varro, Columella, Pliny the Elder, etc.), inscriptions of monumental roads, topographical and thematic maps, etc.

Archaeological maps

Fundamental to landscape reconstruction. The use of archaeological maps allows to analyse in a wider way sites distribution within a territory and report survived archaeological elements or even contribute in sites and remains recognition. Thanks to archaeological maps it is possible to identify ancient roads, linear structures, ancient buildings, etc. They contribute in the evaluation of preventive archaeology. These maps can be used to find sites position and orientation. They can be found in every official archaeological offices of different regions or counties, or, in some cases, they may be recovered on specific texts[154].

Geological, lithostratigraphic and geomorphological maps

Geological maps show the distribution of geological features. They are usually built on top of a base map, printed with light colours, to not interfere. Geology is represented by colours, lines, and special symbols unique to geologic maps. They describe superficial rocks and soils, deepen rocks and soils, age of the rocks, etc.
http://geology.wr.usgs.gov/wgmt/aboutmaps.html
http://www.nature.nps.gov/geology/usgsnps/gmap/gmap2.html

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[154] Such as the *Forma Italiae* volumes, founded by G. Lugli and it is currently directed by P. Sommella, published by Leo S. Olschki, Florence.

Land evaluation

“the process of assessment of land performance when used for specified purposes” involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation” (FAO 1976).

Soil maps

Soil maps present soil classification and distribution in a specific area, through a geographically referenced soil database generated at a given resolution by using field and laboratory observation methods coupled with environmental data through quantitative relationships[155]. There is an International Soil Classification Systems that serves to correlate experiences on similar soils all over the world. A World Reference Base for Soil Classification was published by International Union of Soil Sciences in cooperation with the International Soil Reference and Information Centre (ISRIC). The classification is based mainly on soil morphology (FAO 1988).

Greek and Roman sources (regarding the landscape)

– **Agricultural landscape** of the Agro Pontino: *Dionysius of Halicarnassus* 5.6.2-4; *Livy,* 2.14.6; (Roman and Greek). *Archytas,* De Agricultura (from *Diogenes Laërtius* 8.82)
– **Gardens as farms of poor people**: *Pliny,* 19,52; **Urban gardens disappearance**: *Pliny,* Naturalis Historia, 19,59
– **Landscape**: *Tacitus,* Germania 5,1-3; Aboriginal people myth and forest-marshy landscape. *Sallust,* De coniuratione Catilinae 6,1; Archaic landscape: *Lucretius,* 5.1241, 5.1248, 5.1365; *Cicero*, De re publica 2.6.11; *Hesiod,* Teogonia. v. 1013; Conflict between city and countryside: *Cicero,* De officiis, 1, 150–151; Inexhaustible natural resources: *Aeschylus,* Agamemnon, 958–962; Inexhaustible natural resources: *Aulus Gellius,* Noctes Atticae 2,22,27; Limits of man against nature.

155 Working Group on Digital soil Mapping, WG-DSM: http://www.digitalsoilmapping.org

Varro, De Re Rustica, 2, 1–2–3; 1,4,3–5; 1,12,1–4; Natural beauties of Italy.: *Q. Curtius Rufus*, *Strabo* 2,5,26; *Propertius,* Elegies, Book III, XXII elegy; Not propagandist story about natural beauties of Italy. *Pliny the Elder,* Nat. Hist., Book III

– **Natural resources**: tuft galleries. *Pliny,* Nat. Hist., 36, 108; 36, 124; agricultural resources are not inexhaustible. *Sophocles,* Antigone 332–40:43; Not inexhaustible natural resources: *Pliny the Elder,* Naturalis Historia, 2, 207–8; 33, 1–3; Exploitation of natural resources, *Seneca,* Controversiae, 2,1,11; Inexhaustible natural resources. *Virgil,* Georgicon, 2, 165–6; *Xenophon,* De Vectigalibus, 4, 25–29
– **Pollution**, *Vitruvius,* 8,4,2; *Pliny the Elder,* Naturalis Historia 18, 2–3; Pollution by lead in water pipes, *Vitruvius* 8,6,10–11; Air pollution due to the smoke of the chimneys: *Seneca,* Ad Lucilium de providentia, 104, 6
– **Roman Landscape**: *Cato,* Beginning of the De Agricultura 1,1–3; *Cicero,* De lege agraria; *Columella,* 1,3.1–2; *Virgil,* Georgicon, Book II, 109–135; *Virgil,* Aeneis. 3,701
– **Rome**: crowd and traffic. *Juvenal,* 3,25; 3, 254–62; Everyday life scenes. *Horace,* Epistulae. 2,2,65–80; *Martial,* Epigrammata 12,57 1–17; Noise *Seneca,* Epistulae, 56, 1–4; Marshes of the first settlement is crossed by swimming and sailing. *Chronica urbis Romae, 18;* Rome originally was settled in a landscape of hilltop settlements that overlook watercourses and swampy areas or subjected to flooding and suitable for grazing. *Livy,* 1.4.6; 1.7.4
– **Urban landscape**. Against the excess of buildings; on the increase of villas and decrease of gardens: *Horace,* Carmina 2, 15; Buildings height in the city: *Strabo,* 5,3,7; Building rules: *Ulpian,* Digesta 43,8,2,8; Directions on where to build: *Vitruvius,* 1,4,1–5; Urban development: *Seneca,* Epistulae, 89,21
– **Viability**. Etruscan and Roman road system (Tiber) *Polybius,* 3.22.11
– **Water** resources: water sacrality and prohibition of intervention: *Tacitus,* Annales, 1, 79; *Vitruvius,* 1,2,7; Attica hydrogeological instability: *Plato, Crizia,* 110e – 111d; Creation of pipes to improve marshes: *Vitruvius,* 1,4,11–12; Channel dug by Scaurus between Parma and Piacenza to reclaim the marshes. *Strabo,* 5,1,11; Ostia connected to Rome by channels for transporting salt. *Virgil,* Aeneis. *8.87* ss; 9.314 ss
– **Woods**. Sacred woods in imperial times in Rome *Pliny,* 15, 77; 16, 235; Decrease in sacred forests due to the construction expansion. *Varro,* De

Lingua Latina, 5, 49; Deforestation dedicated to pasture. *Lucretius,* 41; Deforestation in ancient time (Greece): *Theocritus,* 17, 9–10; Deforestation in some areas made with criterion. *Cassiodorus* Variae, 5, 16, 2; Etruria wood for house girders. *Livy,* 28.45.13; Larici road cut: from the north crossed the Po up to Ancona, but didn't arrive in Rome: *Vitruvius,* 2, 9, 16: Laws or measures to counter the excessive deforestation and protect forests and water. *Plato,* Leges, 824a; *Pliny,* 17,1; Pitch extracted from Sila forests (known as Calabrian). Used in medicine and to treat the jars: *Pliny* 14, 127; 24, 37–40; Ravenna built entirely of wood, *Strabo,* 5, 1, 6; Search for minerals causes the demolition of the mountains and natural upheavals. *Pliny the Elder,* Naturalis Historia, 33, 1; Sila wood (poplar, beech, pine, oak, ash) used for construction and shipbuilding. *Dionysius of Halicarnassus,* Antiquitates Romanae, 20, 15; Villas and palaces of Rome constructed with Etrurian wood. *Strabo,* 5, 2, 5; Wood uses in Rome. *Pliny,* 12,5

[V. V.]

B.3. Geographic spatial analysis

During the second half of 20th century, archaeologists and environmental scholars developed many models for spatial analysis (Hodder – Orton 1990), that is to say, to better understand the criteria of human organization in relation to settlement distribution in the landscape. Today, many of these models are easily developed by GIS software. Here below, we'll describe some of the most diffused operations on raster and vector files, to apply spatial analysis models.

Buffering

Buffering is the operation of defining a circle with a given ray (or more concentric circles) around points, defining areas referred to sites. This operation has a really high number of applications. From an ecological/economic point of view the most interesting can be considered the site catchment analysis.

Cost analysis

It is a study of the cost of paths, from a starting point to different destinations around it. It can be calculated taking into account the linear distance together with slope and other factors affecting each grid cell.

Delaunay triangulation

The Delaunay triangulation is the operation to collect all the points on a surface by lines forming a series of triangles not overlapping each other, the mathematical definition is that *"a Delaunay triangulation for a set P of points in the plane is a triangulation DT(P) such that no point in P is inside the circumcircle of any triangle in DT(P)."* It is used in many applications: is the basis of 3d modelling, being the first step to create polygonal surfaces from vector points, and can be used as well to calculate the Clarke-Evans index of randomness/organization in settlement pattern through the nearest-neighbour analysis (see below). Delauney triangles also have many important geometrical properties and can be used in a wide range of algorithms.

Nearest neighbour analysis

It is a method used to study the characteristics of a distribution of objects/sites and to compare different distributions or parts of them, identifying different settlement logics in an area. For each point the distance to the nearest point is calculated. The average of these distances (observed value) is compared with the value that it would have if the distribution of points was random (expected value). If the observed value is similar to that expected it means that the distribution of points is similar to a random scatter. If the observed value is significantly lower than the expected, it means that the points are grouped, because the distances between them tend to be low. In the opposite case the observed highest average means that items are regularly distributed in space, since they tend to have the greatest possible distance between them.

Site-catchment analysis

Site-catchment analysis can provide valuable information on ancient survival strategies and social organization. Developed by Eric Higgs and Claudio Vita-Finzi during the late 1960s (Higgs – Vita-Finzi 1970), the purpose of site catchment analysis was to reconstruct economical aspects of an archaeological sites. The size of the areas may be based on the sources of material found in the site, or on deductions such as the distance that could be covered within a day's journey. It was noted that in ancient societies, most of the settlements are located in territories located within a radius of 2–3 km from the site. Using site catchment analysis, it is possible to analyse settlement choices of a group. A group, in fact, tends to minimize the energy needed to survive, choosing a settlement, permanent or seasonal, located in such a way to facilitate the exploitation of the certain environment, according to given rays of action. This technique can be used to rebuild the productive development of a region. The relationship between sites and environment can also be analysed also for predictive purposes: developing models on site selection and settlement patterns improve analysis.

Thiessen polygons

This method assumes the sites as set of points in a plan without dimensions, hierarchies or characterizations. It divides the space geometrically in areas belonging to each point. Polygons are composed by a series of lines equidistant from the two closest points and perpendicular to the lines which joins the same points. The result is an ideal model of the zones of influence for individual points: it does not evaluate the geomorphological differences of the areas and considers centres of the same type and size. To create models closer to reality, it is possible to get some corrections taking into account other factors, or improve the model by the use of polygons “weighed”, according to the importance of the site (economic, demographic, etc.).

Viewshed analysis

It is the analysis of the part of a territory that is visible from one or more given points. Taking into account the terrain’s morphology, it is useful to select part of the landscape particularly suitable for strategic settlements and to study inter-visibility among sites.

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B.4. Software

3d Modelling

MeshLab: a software developed by the ISTI-CNR (Pisa, Italy), for the advanced elaboration of 3d Scanner data. It is a mesh processing system, for user assisted editing, cleaning, filtering and rendering of large unstructured 3d triangular meshes (typical 3d scanning meshes). It relies on the gpl VCG library (vcg.sf.net); OS: Windows, Linux, MacOS. http://meshlab.sourceforge.net

ARC3D webservice: It is a web service allowing to create a 3d model from a series of digital pictures uploaded by the users. OS: Any; http://www.arc3d.be

Blender: is a 3d object creating suite, for 3d modelling and advanced editing. OS: Windows, Linux, MacOS; http://www.blender.org

3D Studio Max: is a three-dimensional vector graphics and animation. It has strong modelling capabilities and is mostly used by video game developers, TV studios and architectural visualization. OS: Win. http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=5659302

Maya: is a powerful, integrated 3d modelling, animation, visual effects, and rendering solution. Is based on an open architecture and for this reason is used in different fields OS: Win, MacOS (cinema, television, game development, and design projects). http://usa.autodesk.com/adsk/servlet/

Cinema 4D: is a commercial, cross-platform, high-end 3-D graphics application. It can operate with solid modelling or 3d mesh surfaces and is very popular due to its simple interface and speed. It is mainly devoted to post-movie for the creation of special effects, but is also appreciated in the world of graphics and animation, thanks to integration with the most widely used software. OS: Win, MacOS, Linux http://www.maxon.net/

AutoCad: is the first CAD software (computer aided design) developed for PC. It is mainly used to produce 2D/3D drawings in engineering, architectural, mechanical, etc. The product is a vector and it also allows to create three-dimensional models of geometric objects in vector mode. OS: Windows. http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=2704278

Game engines

A List of game engines, authoring tools and 3d toolkits is available at: http://en.wikipedia.org/wiki/List_of_game_engines
Delta 3D: It's an open source game engine suitable for a wide range of modelling and simulation applications. OS: Win, Linux http://www.delta3d.org/
OGRE: is currently one of the most powerful open source rendering engine. OS: Win, MacOS, Linux http://www.ogre3d.org
Unity 3D: is a multiplatform game development tool, with a high compatibility both in terms of file formats and hardware applications. OS: Win, MacOS http://unity3d.com
VirTools Dev: is a development and deployment platform with an innovative approach to interactive 3d content creation. It facilitates prototyping and robust development up to large-scale and the immersivity. OS: Windows. http://a2.media.3ds.com/products/3dvia/3dvia-virtools.

GIS, webGIS, Remote sensing

A lists of available mapping software is available at: MapTools (http://maptools.org/) or GFoss (http://www.gfoss.it/drupal/software).
ARK (The Archaeological Recording Kit) is a web-based 'toolkit' for the collection, storage and dissemination of archaeological data. It includes data-editing, data-creation, data-viewing and data-sharing tools, all of which are delivered using a web-based front-end. OS: Any. http://ark.lparchaeology.com
BASP: The Bonn Archaeological Software Package, since the late 70s provides a set of tools for managing archaeological records through database systems, statistical analysis, mapping facilities and low-level remote sensing algorithms. OS: Windows; http://www.uni-koeln.de/~al001/basp.html
ENVI: it is a powerful software joining GIS and image processing/analysis features. OS: Win http://www.ittvis.com/
ErMapper: It is the a rich software for remote sensing and advanced multispectral image analysis OS: Win http://www.ermapper.com
ESRI ArcGIS is a leader services company providing Geographic Information System and geodatabase management applications. Its products, as ArcGis, are affordable, easy-to-learn desktop mapping tool. OS: Win http://www.esri.com
GRASS: is the most famous and powerful Open Source GIS suite. It allows all kind of GIS analysis, on raster and vector data, as well as advanced geoimage

processing. The referring site includes links to OSGeo4W Project. OS: Windows, Linux, MacOS. http://grass.itc.it
Idrisi: one of the earliest GIS software, still preserves the feature of very impressive and pleasant graphic outputs. OS: Win http://www.clarklabs.org
MapInfo: one of the earliest GIS software, for geo-spatial data visualization and analysis. OS: Win http://www.mapinfo.com
OpenEV: Is an open source graphic library and application for viewing and analyzing raster and vector geospatial data. OS: Windows, Linux. http://openev.sourceforge.net
OSGeo4Win: Project is a binary distribution of a broad set of open source geospatial software for Win32 environments (Windows XP, Vista, etc.). It includes many of the most useful geographic libraries and applications. OS: Win (GDAL/OGR, GRASS, MapServer, OpenEV, uDig, QGIS etc.) http://trac.osgeo.org/osgeo4w/
QGis: is a simple and very easy-to-use Open Source GIS allowing to visualize, manage, edit, analyse data, and compose printable maps. OS: Windows, Linux, MacOS. http://www.qgis.org

Terrain generators

For a complete list of terrain generators the most updated document is: http://www.tec.army.mil/research/software/TD/tvd/survey/vendors_web_alpha.html
OSGdem: it is a part of the OSG (OpeneSceneGraph) package for terrain generation. It is a command-line tool which allow to create a paged terrain starting from DTM and geoimage data. OS: Windows, Linux, MacOS. http://www.openscenegraph.org
Presagis Tools: Presagis has acquired and developed some of the earliest suites for terrain and 3d environment generation, such as TerraVista and Multigen Creator. The software still keep an intuitive interface and realistic immersive outputs. OS: Win, MacOS, Linux.http://www.presagis.com
Visual Nature Studio: VNS is a terrain generator which allows to create highly realistic geocoded landscapes from GIS data. It has a wide range of output formats in terms of raster/vector layers, movies and pictures, and terrain/3d environments. OS: Win http://www.3dnature.com
VTP: Open Source suite for viewing, creating, editing 3d environments, to be browsed or exported for web publishing. OS: Windows, Linux. http://www.vterrain.org

Terrain (2d–3d) web-viewer

MapServer is a webGIS, an Open Source platform for publishing on the web spatial data and interactive mapping applications to the web in a 2d space. OS: Windows, Linux, MacOS. http://mapserver.org
OSG4WEB is the result of a CINECA and ITABC-CNR effort to provide a framework for in-browser OpenGL-based application wrapping. The projects started in 2004 to fill the need of web-enabled 3d terrain and geo-spatial data browsing in a pre-Google-Earth time. The plug-in allows run-time loading of different application cores at the web page opening, allowing the same installed plug-in to brows pages that require different application codes. OS: Win, Linux, MacOS. http://3d.cineca.it/storage/demo_vrome_ajax/osg4web.html
3d Via Player is the free on line viewer developed by VirTools Dev for real time on line experience. http://dl.3dvia.com/software/3dvia-player/
Unity web player is the free on line viewer developed by Unit 3D engine. It enables to view 3d content created with Unity directly in the web browser. http://unity3d.com/unity-web-player-2.x.html

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B.5. Projects

Geo-spatial 3d viewers

Google Earth is a stand alone software that allows to explore the 3d World at multiple levels, from Space to the streets, identifying maps, directions and various kind of points of interest. It is freely distributed by Google and requires a Microsoft Windows operating system, Mac OS X or Linux and currently has developed a version for iPhone and iPod Touch. Satellite images and photographs of the Earth are displayed with a very high detail (res. 15 mt) and, in some cases, with a resolution less than one meter. http://earth.google.it/
Google Maps allows to view 2d maps in the web browser. On the base of the location, it is possible to view standard or customized maps and information. Interesting the “StreetView” application recently automatically available after a certain scale. http://maps.google.com/
Google Plug-In and JavaScript API let embed Google Earth, a true 3d digital globe, into the browsers. Using the API it is possible to draw markers and lines, drape images over the terrain, add 3d models, or load KML files, allowing to build sophisticated 3d map applications. The Google Earth API is a free service, available for any web site that is free to consumers. http://code.google.com/apis/earth/
Google O3D is an open-source web API for creating rich, interactive 3d graphics applications (games, ads, 3d model viewers, product demos, virtual worlds) in a browser window. It provides a browser plug-in that adds graphics capabilities inside standard web browsers, and a sample COLLADA Converter, which can be used to import files in the COLLADA format, an open standard for 3d assets that is supported by popular content creation applications.
Google SketchUp is a very simple software to learn and allows to create, edit and share 3d models. The program is part of the same family of GoogleEarth, which ensures the exchange of information between them in a very simple way. It allows to import and export different formats (DXF, DWG and 3DS, JPG, TIFF, etc.). http://www.google.com/sketchup/download/gsupwitthankyou.html.
Nasa World Wind. World Wind is a free open source virtual globe developed by NASA. The program overlays NASA and USGS satellite imagery, aerial photography, topographic maps and available GIS data on 3d models of the Earth and other planets. Apart from the Earth there are several worlds in World Wind:

Moon, Mars, Venus, Jupiter and imagery of stars and galaxies. http://worldwind.arc.nasa.gov
Microsoft Virtual Earth allows to visualize geographic and location-based information by combining on-line maps with single users' data. The platform is an integrated set of services and helps to visualize data and provide immersive end-user experiences. The Virtual Earth platform consists of three services: Virtual Earth Map Control that includes immersive imagery; Virtual Earth Web Services; MapPoint Web Service, a programmable Web service hosted by Microsoft to integrate location-based services into software applications and business processes. http://www.microsoft.com/virtualearth/
Skyline, founded in 1997, is a leading provider of 3d earth visualization software and services. It offers 3d geo-spatial applications, with support for real-time fusion and streaming of massive data sets, open standards and a full API. http://www.skylinesoft.com/SkylineGlobe/corporate/home/index.aspx?

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Second Life projects

The Akragas doors, dedicated to the Archaeological Park of Agrigento Temples Valley, aims at illustrating the defensive structure of the city in the 4th century BC, through the creation of immersive stereoscopic images and a reconstruction in Second Life. Here visitors can actively participate, also dressing as a soldier, thus entering into history.
Villa of Livia in Second Life at the UCM Virtual Heritage Island: UC Merced is experimenting digital learning and research in Second Life. In these experiments of virtual reconstruction of different landscapes (for example the reconstruction of the ancient Villa of Livia) is possible to test feedback, reactions, participation, and informational transmission between users and environments.
Digital Humanities Island is a Sim in Second Life developed by King's College of London, under the direction of Prof. Beacham. It has been opened in 2007 and it is currently used for educational activities on ancient theater and Roman architecture.

Active Worlds projects:

Quest Atlantis. QA is an international learning and teaching project that uses a 3d multi-user environment to immerse children, ages 9–15, in educational tasks. QA combines strategies used in the commercial gaming environment with lessons from educational research on learning and motivation. It allows users to travel to virtual places to perform educational activities, talk with other users and mentors, and build virtual personae. http://www.questatlantis.org

Other geospatial projects:

Bologna 3D was developed from maps with the buildings elevation and aerial photos. The 3d model of the city is explorable in Internet through a flight simulator (by Skyline). http://sit.comune.bologna.it/sit/volo3D/bo.FLY
CyArk is a non-profit entity whose mission is to digitally preserve cultural heritage sites through collecting, archiving and providing open access to data created by laser scanning, digital modelling, and other state-of-the-art technologies. CyArk has developed the Total Process for Digital Preservation. http://archive.cyark.org/
Exhibits 3D, based on VirTools Dev engine, provides a dynamic virtualization system of historic and cultural reality to organizations, institutions, galleries, museums, both public and private, for the dissemination and promotion of cultural heritage on-line. In a section it is possible to visit the virtual gallery of available projects. http://www.exhibits.it
Fasti on line. It is a webGIS database of archaeological excavations since the year 2000. It was created by AIAC (International Association for Classical Archaeology) and supported by PHI (Packard Humanities Institute). http://www.fastionline.org/index.php
Florence on Earth (IT). This project, GoogleEarth-based, regards the visualisation of one century urban archaeological researches in Florence, referred to various periods: Roman, Late Roman, Early Medieval and Medieval. The archaeological finds have been located in GoogleEarth (trough the its API) and sub-divided into categories (roads, buildings etc.). http://florenceonearth.com/
Itinera Time Machine (IT). It is a project developed by Digital Archaeology Laboratory of the University of Foggia, about the archaeological site of Faragola (Ascoli Satriano, FG) and reconstructed using the scientific documentation derived from the field survey. The Time Machine allows the user, trough an avatar, to travel in the time and visit both the different virtual reconstructions

and the entire stratigraphic process. http://www.archeologia.unifg.it/ric/lab/Lad/Farlad.asp

NuME project (IT) aims at creating a digital museum of the historical city of Bologna, with a specific interest in the reconstruction of the Medieval period, based on historical sources, archive documents and historical maps. Visitors and scholars may explore the city in different chronological periods and analyse relating historical sources. http://3d.cineca.it/3d/Nume/nume_3d.php

Pagine Gialle Visual (IT) by Seat Yellow Pages integrates into a Shockwave-based multimedia tool the Italian territory. 103 cities can be explored and queried with high spatial graphic detail (resolution of 20 cm), accuracy and richness of contents. http://www.visual.paginegialle.it/3d

Sardegna 3d (IT) is an application which enable to explore Sardinia in three dimensions, offering a complete geographic information of the island (cultural, historical and environmental heritage are constantly update on the base of a regional GIS), through a tool designed to strengthen the government and management of the territory and to promote sustainable development. http://www.sardegna3d.it/

Virtual Archaeologist Educational Environment. This project is a virtual, immersive, multi-user, spatially oriented, 3d educational environment that simulates the real world conditions of an archaeology excavation (developed by the Archaeology Technologies Laboratory of the North Dakota State University). This environment allows students in archaeology to enter in the role of an archaeologist, encouraging them to evaluate and solve scientific problems. The project permits students to think like archaeologists, creating an active and educational space that promote exploration and problem-solving. http://fishhook.cs.ndsu.nodak.edu/

XVR project and Piazza dei Miracoli (Pisa, IT). XVR (eXtreme Virtual Reality) is an innovative development environment dedicated to virtual reality and augmented reality applications, created by VR Media, a spin-off company of “S. Anna School of advanced studies” in Pisa. The website allows multilevel access with guided tours for the simple user. http://www.vrmedia.it/Xvr.htm, http://piazza.opapisa.it

Virtual Rome, coordinated and directed by CNR ITABC in collaboration with CINECA, aims at studying and reconstructing the archaeological and potential landscape of ancient Rome (21st century – 2nd century AD) and at enabling its distributed and interactive visualization through a web-based Virtual Reality application, based on Open Source libraries, on Remote Sensing and GIS data and on 3d models and through a OSG based plug-in, OSG4WEB. Detailed exploration is possible in three areas: via Flaminia, via Appia and Roman Imperial Fora. The project has also developed a 3D CMS, with the goal of creating an on-line cooperative laboratory for landscape interactive reconstruction. http://www.virtualrome.net

[V. V.]

Appendix C

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