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ARCHAEOLOGICAL COMPUTING AND ANCIENT CITIES: INSIGHTS FROM THE REPOSITORY OF «ARCHEOLOGIA E CALCOLATORI»

1. Introduction

First of all, I wish to express my gratitude to the organisers of this stimulating Conference for inviting me to participate and celebrate all together Giuseppe Sassatelli's 70th birthday. A sense of profound admiration has bound me to Professor Sassatelli for over thirty years. We share a unique perception of the need for archaeological methods to evolve thanks to a fruitful dialogue with scientific techniques. One simple but thought-provoking statement of Giuseppe Sassatelli can highlight and summarise our common point of view: the question is not so much the speed of the machine, but where it is directed (Sassatelli 2009, 506). And the right direction is certainly the one aiming at the reconstruction and interpretation of historical and archaeological evidence. This is the bridge, or better the "interface", between the two cultures: the Humanities, which are our background, and Science, in which we are all passionately involved through our engagement in field research.

Thank you also for giving me the opportunity to share my research experience in the field of archaeological computing, in particular in its relationship with the study of ancient cities, two of the main paths which I followed in orienting my studies. When the organisers of the Conference kindly invited me to review the current status of this interdisciplinary research field, I initially thought of using the term "urban archaeology", but I soon realised that, in spite of being the spark of an innovative global approach to the study of ancient cities in close connection with conservation, research and modern planning issues, this choice would lead to a restrictive and misleading approach. Indeed, the history of archaeological computing, a discipline that originated in the 1950s, is marked by a series of evolutionary stages that took shape from the analysis of single-task archaeological issues and from the use of a narrow set of data-handling methods, ultimately reaching, and only in recent years, a global integrated and interactive computer-based archaeological perspective (Moscati 2009a).

The theme is very appealing, but at the same time daunting and complex. Fortunately, the international Journal «Archeologia e Calcolatori» (http://www.archcalc.cnr.it/), currently at its 28th issue and one of the first archaeological scholarly journals to join the Open Archives Initiative (Barchesi 2006; Moscati 2012), will provide an ideal vantage point to illustrate past and present research scenarios. A few enlightening words may effectively describe the publishing policy of the Journal in four points: fostering intense contact

with the international scientific community; promoting multilingualism as a cultural resource; improving the dialectical relationship between theory and experimentation; embracing the open access policy to encourage the dissemination of public research results (Moscati 2009c).

Today, the repository of «Archeologia e Calcolatori» gathers more than 800 articles, signed by more than a thousand authors for a total of over 13,000 pages. The articles are classified on the basis of 20 main topics, subdivided into computer applications and archaeological research areas. This is the reason why we will proceed through some meaningful insights in order to illustrate the close link between the evolution of archaeological computing and the history of ancient towns and cities. Given the extent of the subject-matter, I will focus on Italy's position, not without an explicit reference to the international context, and, given the large number of examples, my paper will be supported by some illustrations excerpted from the Journal, which show specific case studies rooted in an evolutionary research framework.

It might sound bizarre, but I will concentrate more on the last decades of the 20th century than on the most sophisticated, perhaps spectacular, recent achievements. Indeed, those years were permeated by a lively debate focused on the relationship between theory and technology, which has represented the inescapable bedrock for future methods.

We can start with a concise analysis of what had happened before 1990, the point in time when the Journal was established. In Italy, the relationship between computer science and the study of ancient cities is undoubtedly linked to two decisive factors: first, in the 1980s the development of computer graphics paved the way for new and unexplored paths to represent urban and architectural space. Second, the perspective of involving private enterprises within the cultural heritage sector, a policy massively adopted within the "Giacimenti Culturali" project[1] – i.e. cultural heritage as the "oilfield" of our country – soon showed considerable potential (*Rapporto* 1989; see also Eco 1988 for the meaning of "cultural deposit"; for a rather negative judgement on the initiative and its lack of a preventive coordination policy, see Ferrari 1991).

In the mid-1980s, Paolo Sommella, in cooperation with ENIDATA, promoted the use of digital cartography within an archaeological information system, testing it first in the ancient cities of Atri and Todi (Sommella 1987;

[1] L. 41, 28 feb. 1986, art. 15, c. 1 «È autorizzata la spesa di lire 300 miliardi per l'anno 1986 e di lire 300 miliardi per l'anno 1987, di cui il 50 per cento riservato al Mezzogiorno, da destinarsi alla realizzazione di iniziative volte alla valorizzazione di beni culturali, anche collegate al loro recupero, attraverso l'utilizzazione delle tecnologie più avanzate, ed alla creazione di occupazione aggiuntiva di giovani disoccupati di lungo periodo, secondo le disposizioni del presente articolo. Il Ministro per i beni culturali e ambientali, d'intesa con il Ministro del lavoro e della previdenza sociale, definisce entro il 31 marzo 1986 un programma che dovrà concernere le seguenti aree d'intervento prioritarie: patrimonio archeologico, patrimonio architettonico e urbanistico, patrimonio librario, patrimonio letterario e linguistico, patrimonio storico archivistico, arti figurative e arti minori».

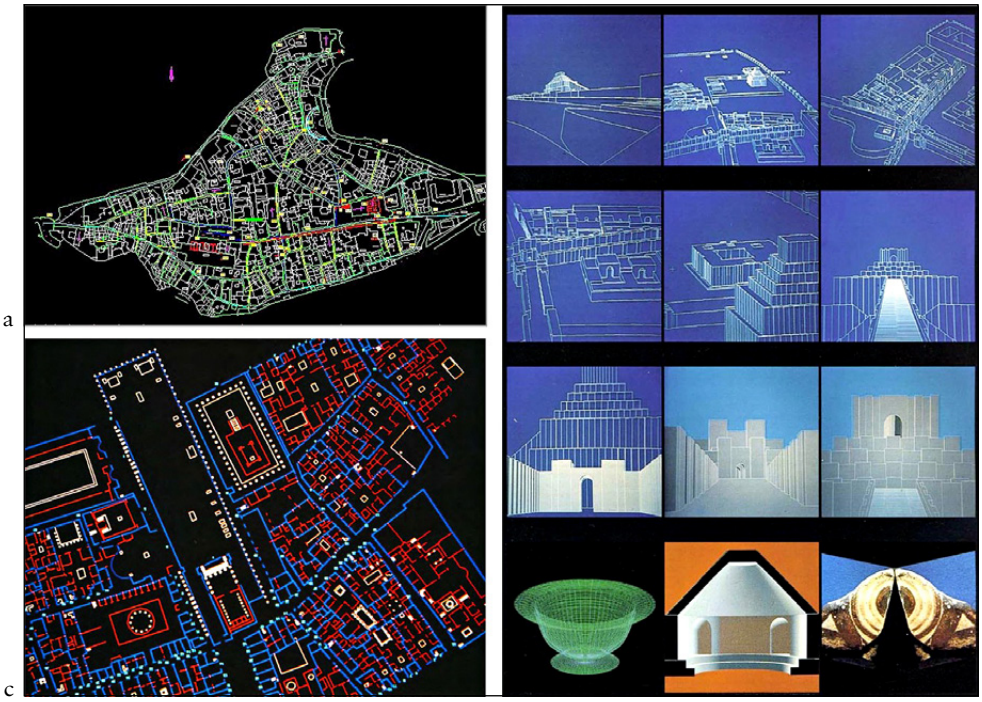

Fig. 1 – a) The digital map of Atri (Azzena 1987); b) Simulated reconstruction of some monuments and objects from Babilonia (Gullini 1989); c) The digital map of Pompeii (*Rediscovering Pompeii* 1990).

Sommella, Azzena, Tascio 1990); Giorgio Gullini simulated a tour within the reconstructed monuments of the ancient city of Babilonia (Gullini 1987, 1989); Baldassarre Conticello, Superintendent of Pompeii, turned to IBM Italia and Fiat Engineering expertise to develop the Neapolis Project that provided the first photoplan and digital map of the ancient city (*Rediscovering Pompeii* 1990[2]) (Fig. 1).

In a nutshell – and considering that the exact location in space is pivotal in several areas of archaeological research – in the 1980s the study of ancient towns benefitted from the development of digital cartography and mapping strategies allowed archaeologists to go beyond the spatio-temporal scale restrictions traditionally imposed by paper maps. In addition, the use of Global Positioning Systems became a viable tool for use in archaeological

[2] Thanks to liberality of the Publisher (L'"Erma" di Bretschneider) some chapters of the sumptuous Catalogue of the New York exhibition are reproduced for the first time in the "Virtual Museum of Archaeological Computing" (http://archaeologicalcomputing.lincei.it/index.php?en/80/exhibitions).

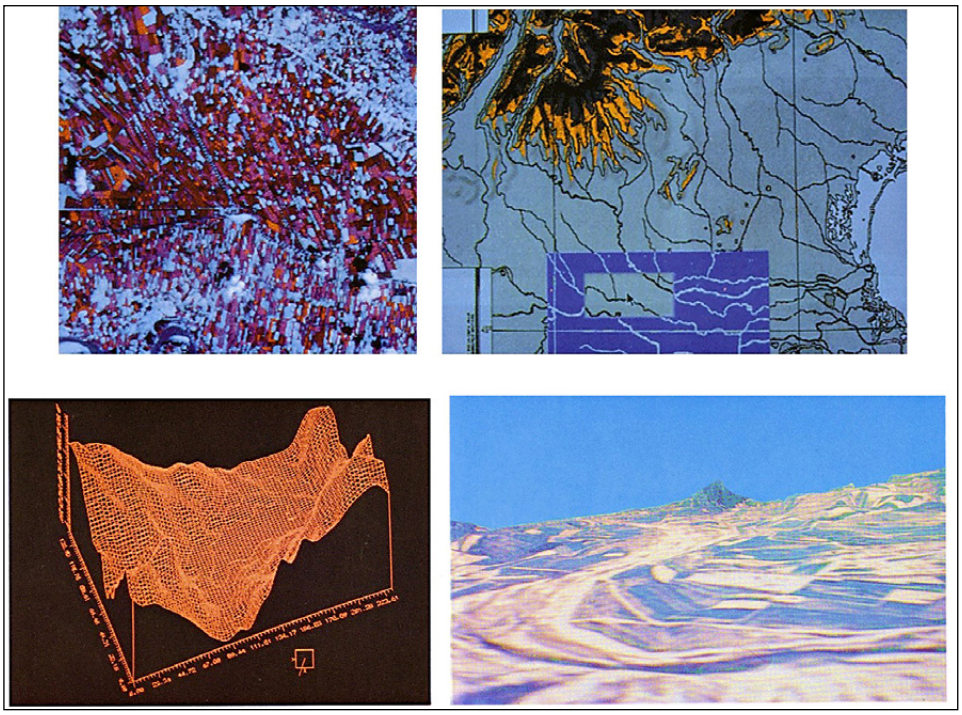

Fig. 2 – a) Veneto Region: Alto Medio Polesine-Basso Veronese Project (De Guio 1991); b) DTM of the Reno Valley and virtual navigation in the landscape (Forte 1993).

field mapping, making it possible to generate accurate, high density and geo-referenced digital data sets and to upgrade topographic landmarks.

As a natural consequence, in the early 1990s the adoption of Geographical Information Systems fully met the specific demands of archaeologists who were looking for a single and integrated platform upon which their fieldwork could be reproduced (Allen, Green, Zubrow 1990). In Italy, two research sectors were characterising computer applications: the first covered regional studies (Fig. 2) for the analysis of large landscapes (see e.g. De Guio 1991; Guidazzoli, Forte 1992; and Forte 1993, in which, among other applications, the first DTM of the archaeological area of the Etruscan town of Marzabotto in the Reno Valley is illustrated); the second concentrated on the study of ancient cities along their development (I refer in particular to the first volumes of the series *Città antiche in Italia*: http://www.formitaliae.it/cai/progetto.html). By recording environmental factors, anthropic activities, and the distribution of material remains, urban fabrics were stratigraphically and chronologically analysed within a historical coherent context integrated into a single geographic coordinate system.

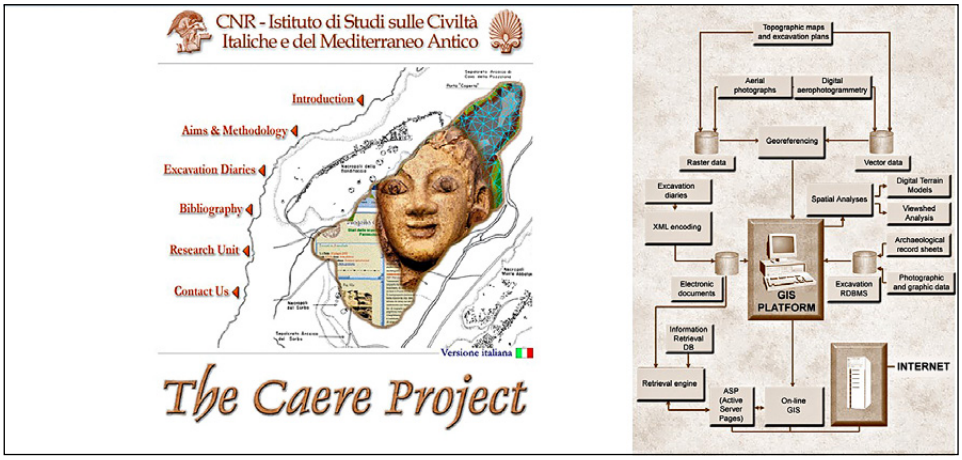

Fig. 3 – The homepage of the website dedicated to the Caere Project (http://www.progettocaere.rm.cnr.it/) and the Archaeological Information System as designed at the end of the 1990s.

2. The first insight: GIS and archaeology

In the pages of «Archeologia e Calcolatori», the term GIS was introduced for the first time in the fifth issue of the Journal (Gaffney, Stančič 1994), when it began to embrace and replace the use of more specific isolated technical terms, like Database Management Systems, Computer-Aided Design or Computer-Aided Mapping Systems, Spatial Analysis techniques. The first insight into the Journal's repository is provided by the results of a census conducted by the Istituto per l'archeologia etrusco-italica in 1997. This was the first outcome of the Caere Project (Fig. 3), promoted by Mauro Cristofani as part of the CNR Cultural Heritage Special Project, and the subject of a special theme issue dedicated to "Methodological Problems and Future Perspectives in the Application of GIS in Archaeology" (Moscati 1998a).

Since the Caere Project was expected to be an experimental benchmark, the early phase was mainly focused on designing and administering an online questionnaire with a view to gathering information on current GIS applications. The aim was to collect a highly representative sample of GIS-based projects within key archaeological application fields. To this end, an international Scientific Committee, coordinated by François Djindjian, was established and its members were given the task of coordinating the project in their own geographical area.

The results achieved were summarised by François Djindjian (1998) in the opening article. The scholar reported a 25% global annual growth of GIS projects over the previous decade and equated the revolutionary role of GIS in the 1990s with that of mathematics in the 1980s. The debate on the

meaning of the term GIS was an explicit sign that something more than a technical achievement was happening in archaeology. The search for a more comprehensive definition, such as Archaeological Information System or Archaeological Multimedia Information System (Djindjian 1998), or – more comprehensively – Spatial Technologies and Geographic Information Science (Lock 1998), was an attempt to completely cover all potential applications, from intra-site to regional settlement analyses.

In addition, scholars agreed that the results generated by thematic maps should become a heuristic tool at the service of researchers to capitalise on the full range of GIS features. Therefore, it was acknowledged that the spatial analytical functions accomplished by GIS were opening new, inspiring approaches in the study of regional and urban space. In terms of both aims and methodological solutions, the distinction between projects carried out within the Cultural Resource Management (CRM) environment and those promoted by academic and research institutions was internationally recognised. Such a distinction was mainly due to an oversimplified categorisation: the former driven by data-recording and documentary purposes, the latter by data-analysis and interpretation purposes.

In Italy archaeological GIS-based projects covered nearly the entire national territory, from Valle d'Aosta to Apulia, as far as Sicily and Sardinia and some areas outside the national borders, like the Iberian Peninsula, North Africa, Greece, the Near East, and Asia (Moscati 1998b). The application of GIS to archaeological excavations was rather limited, as the use of databases and CAD software packages was still prevailing. In any case, a significant development was underway in many different geographical and cultural contexts, from the pre-Roman settlements in the Salento region (D'Andria, Semeraro 1993) to the medieval settlements in Tuscany (Francovich 1990; Valenti 1998) (Fig. 4).

Italy emerged from the international arena thanks to the wide dissemination of intra-site projects. This outcome stems from a solid scholarship tradition pivoting around the centrality of archaeological cartography in topographic and urban planning studies, as strongly promoted by the Roman School of Ancient Topography (Castagnoli 1974; Azzena, Sommella 1993). The advent of digital cartography met the need to combine graphic data with descriptive information. Digital mapping was therefore considered not only a technical tool for data documentation, but also an administrative tool for improving on-site intervention and cultural heritage conservation and enhancement, above all in continuously inhabited cities, where pages and pages of an almost uninterrupted urban life are overlaid and complex layouts of ancient sites and monuments are hidden within the existing building fabric (Sommella 1992 and, most recently, Sommella 2009).

As an example of ancient towns reviewed in our survey on GIS-based research projects, we may cite: Padua, Modena, Faenza, Forlì, Roma, Catania,

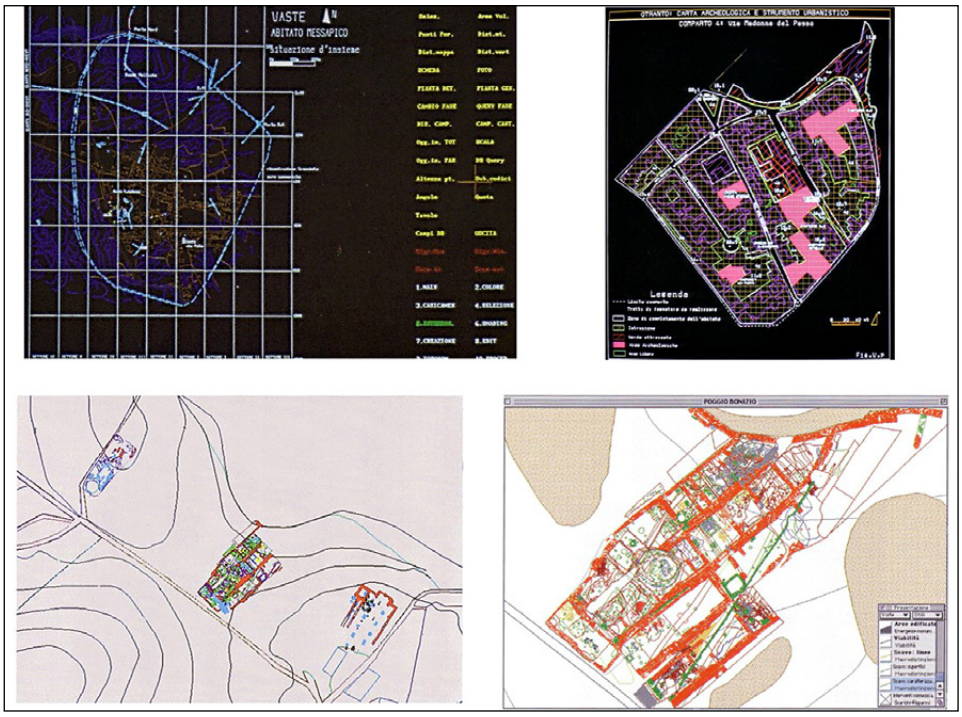

Fig. 4 – a) ODOS excavation data management system: intra-site information system of Vaste and Otranto (D'Andria, Semeraro 1993); b) OpenArcheo System: GIS platform of the excavation area at Poggio Imperiale (Poggibonsi, SI) (Valenti1998).

Termini Imerese and, as already mentioned, the various towns documented and published until 1997 – i.e. the date of the survey – in the series *Città antiche in Italia*: Atri, Todi, Piacenza, Ancona and Venosa. In the meanwhile, the CART Project, coordinated by the Istituto Beni Culturali of the Emilia Romagna Region (Guermandi 1997), was developing a "preventive" tool for producing archaeological risk maps in order to settle the recurrent conflict between modern urban planning development and cultural heritage safeguarding.

3. The second insight: the spread of the Internet and the role of ICT technologies

At the very beginning of the new Millennium – and this is our second insight – a new transformation came about as a result of the dissemination of the Internet. Advancements can be measured thanks to a terminological study of GIS occurrences in the Journal. The sudden introduction of qualifying

terms indicate both specific requirements of the archaeological research – I refer in particular to Time GIS, Object-Oriented GIS, and Virtual Reality GIS (D'Andrea 2000) – or new technical aspects – I refer in particular to webGIS, webmapping and, more recently, GIScloud.

Although the role of the Internet in fieldwork projects had already been perceived since 1995, as confirmed in the Proceedings of the Rome international Conference on Computing and Archaeology[3] (Moscati 1996; see also Gottarelli 1997), the terms webGIS, together with Internet GIS, were first used in the illustration of the Caere Project (Ceccarelli 2001), where a pioneering attempt was also made to encode the yearly excavation diaries in hypertext format through the use of markup languages in order to preserve the semantic structure and the logical thinking process of the archaeologist and, simultaneously, to test new kinds of queries and information retrieval within a GIS environment (Moscati, Mariotti, Limata 1999; Bonincontro 2001; Moscati 2003; Fig. 3).

The introduction of the term webmapping is documented in 2008, in the Proceedings of the Conference organised in Paris by our French colleagues (Djindjian *et al*. 2008), together with the term "geoportal" that spread out rapidly, as a key element of Spatial Data Infrastructures that give access to information, data and services (Djindjian 2008). GIScloud is the most recent term, which was first attested in 2014, when a cloud system was tested for the production of the digital archaeological maps of the cities of Lecce and Taormina (Di Giacomo, Scardozzi 2014).

Besides the obvious association with the development of ICTs, from a methodological point of view these terms are linked to the transmission and sharing of spatial data as well as to a new way of doing archaeological research, in which separate investigation procedures, such as fieldwork and lab data processing, could be finally synchronised. A kind of "remote" archaeology therefore emerged (or "tele-archaeology", as J.A. Barceló, I. Bogdanovic and R. Piqué defined it in 2004), whereby the time elapsing between data acquisition and post-processing is cut down and fieldwork methods renewed.

In the analysis of ancient cities, the use of Spatial Analysis techniques was encouraged for various purposes: the knowledge of the territory with its multiple cultural facets and its relevance in modern landscape planning; the distinction between "place" and "space" in relation to visibility analysis and ancient communities' perception of their environment; the relationship between city and landscape, even from an administrative point of view, as a result of the

[3] Thanks to the first results of the initiative "Support Archeologia e Calcolatori" (http://www.archcalc.cnr.it/support2.htm), the Proceedings of the International Symposium on Computing and Archaeology, held in Rome in 1995, are now available to visitors for downloading in the Virtual Museum of Archaeological Computing (http://archaeologicalcomputing.lincei.it/index.php?en/254/symposium-rome-1995).

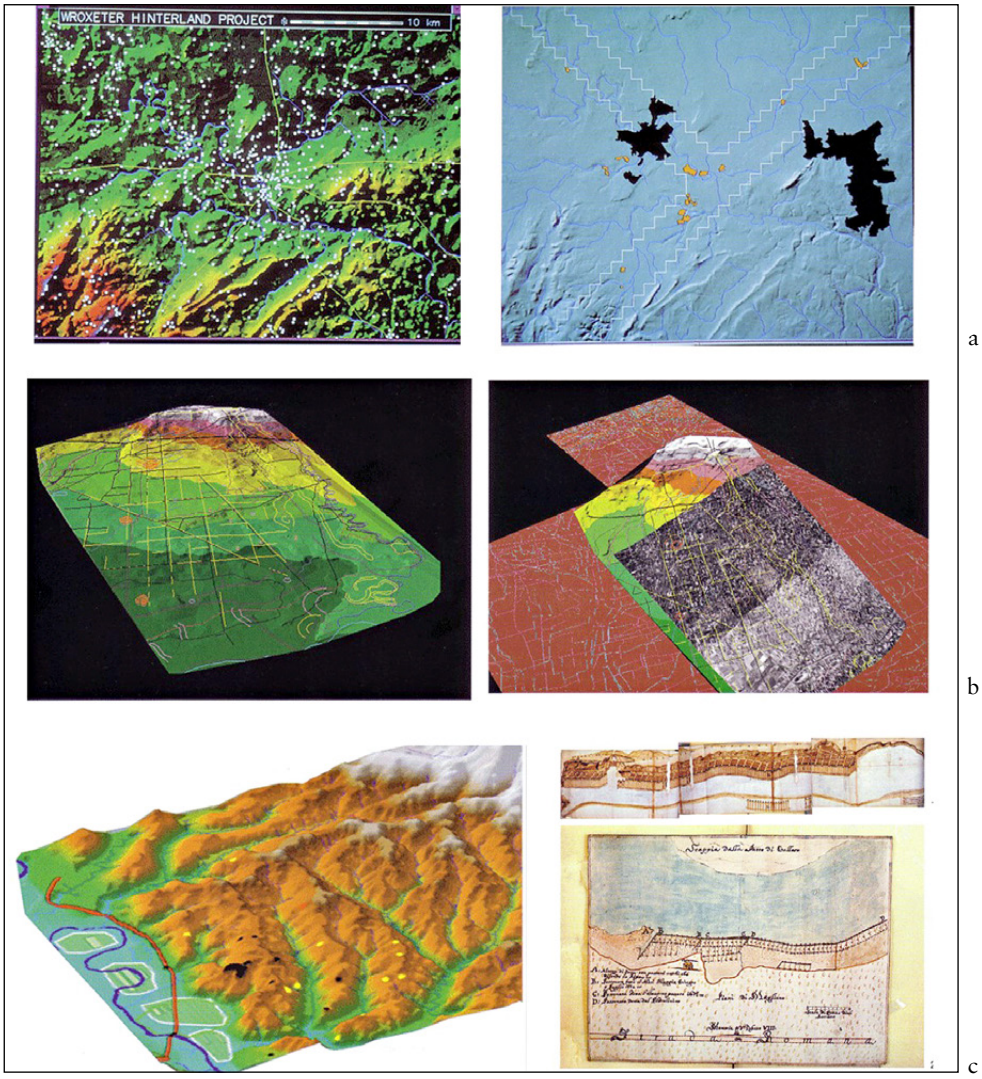

Fig. 5 – a) The Wroxeter Hinterland Project (White 1996); b) The central Po Plain: texture mapping and aerial photomosaic superimposed on the DEM (Cremaschi, Forte 1999); c) The Tiber Valley and the original course of the river as derived from archival sources (Colosi *et al.* 2000).

interaction between nature, individuals, and society, as highlighted by disciplines like psychology of space, landscape ecology or spatial economy (Figs. 5-6).

All these themes suggested the use of new methods to be employed in the generation of geo-scientific information systems, in which "data models"

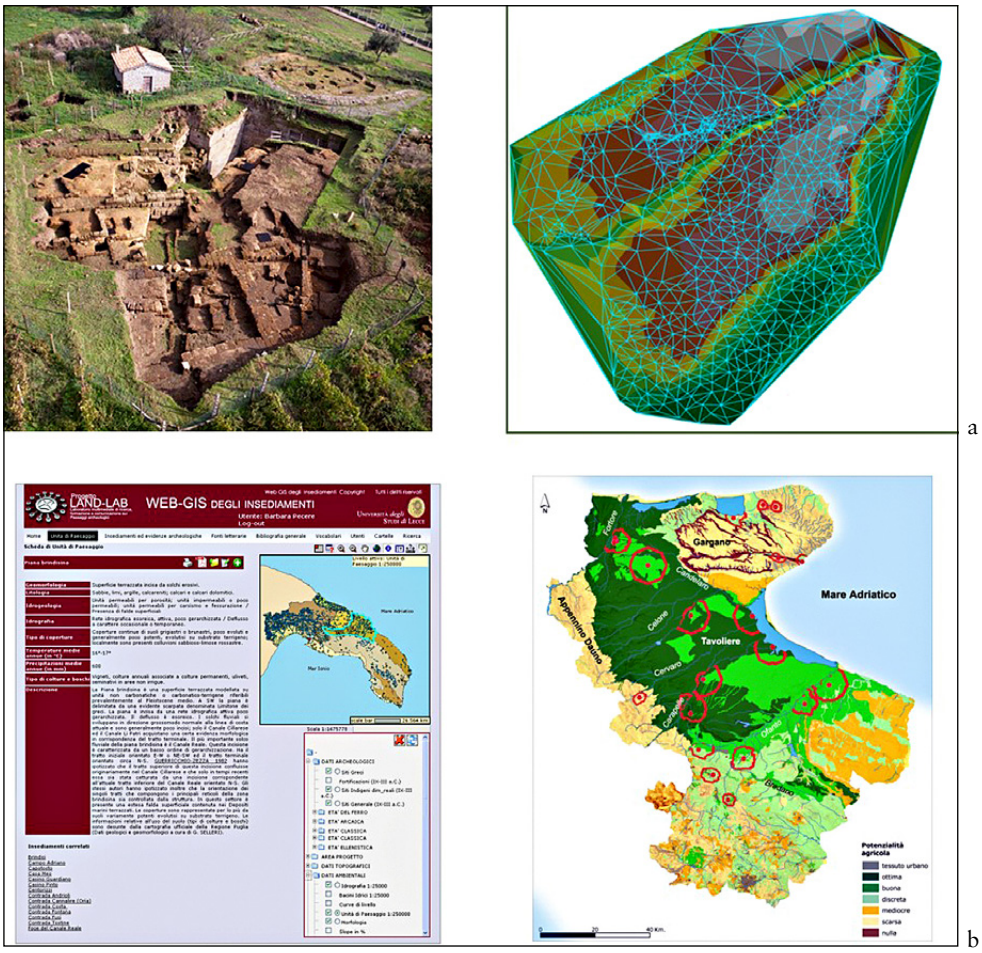

Fig. 6 – a) The Caere Project: intervisibility analysis between the urban plateau and the Banditaccia necropolis (Ceccarelli 2001; Moscati 2003); b)The LandLab Project (Semeraro 2007) and the intervisibility analysis of the Pre-Roman Daunian settlement system in the Iron Age (Pecere 2006).

figure as electronic cultural atlases for storing and retrieving archaeological data (Johnson 2008), in response to the three key concepts of digital culture: i.e. interactivity, hypermediality, and connectivity.

From this perspective, the advocates of Virtual Reality techniques sought to evaluate the effects on cultural transmission as well as on learning rules. Through the use of computer graphics, image processing, high performance computing, animation, and full immersion, data representation could constitute a means of gaining a better insight into archaeological data.

4. The third insight: Virtual Archaeology and the experience of exploring ancient cities

In 2007, upon request of the Italian CNR, the first Supplement to «Archeologia e Calcolatori» was published and dedicated to the memory of Mauro Cristofani, ten years after his untimely passing (Moscati 2007). The theme of virtual museums – the third of our insights – had already been afforded in «Archeologia e Calcolatori» since the beginning of the 1990s, when scholars advocated the enhancement of multimedia solutions in museums and exhibitions, in order to enrich the audio-visual experience (Pagliani 1992; Gottarelli 1996; Guermandi, Santoro Bianchi 1996).

3D imaging and animation technologies as well as simulation tools soon became instrumental in the design and implementation of virtual itineraries to visit cities, buildings and works of art within their geographical and cultural context. Archaeology proved to be particularly receptive to Virtual Reality techniques in various application sectors: from the reconstruction of the stratigraphic sedimentation of archaeological areas, to the simulation of the original aspect of sites and monuments, the diagnosis of their state of preservation, the recommendations for restoration methods and, lastly, their virtual "musealisation".

"Landscape virtual museums" and "diffused museums", often pivoting around historical centres, were proposed in order to compensate for the inefficiency of GIS and spatial modeling tools in representing the dynamic behaviour of ancient and modern rural and urban layouts. The revolutionary role played by high resolution images and remote sensing techniques was therefore encapsulated into a multi-stratified system in which it was possible to move from the object to the historical context, virtually operating on different scales of detail useful both for specialists and remote visitors (Fig. 7).

The experimentation of innovative systems is accompanied by the achievement of two main scientific results: the requalification of sites and monuments, with particular reference to those inaccessible to the public, and the automation of traditional analytical processes, such as the assisted integration of missing architectural elements. The investigation of new research paths designed to re-conceive the processes of urban evolution was the main challenge of archaeologists, art historians, architects, urban planners, and scientists in general, who were responsible for preserving and validating the reality which is represented and animated.

5. The fourth insight: advanced methods for archaeological data integration

Leaving behind the virtual world, we may approach our fourth and final insight, which concentrates on the most recent achievements of archaeological computing. Today, the real impact of ICT on the study of ancient cities may

Fig. 7 – a-b) Some of the CNR research projects illustrated in the Supplement "Virtual Museums and Archaeology" (Moscati 2007); c) The installation "Virtual Exploration of the Regolini-Galassi tomb" in the Vatican Museums (Pietroni 2013).

effectively be resumed in one single word: integration. Therefore, I will illustrate the most accredited, technology driven, archaeological research model (Moscati 2015; see also Djindjian 2014 for the current role and targets of computational archaeology).

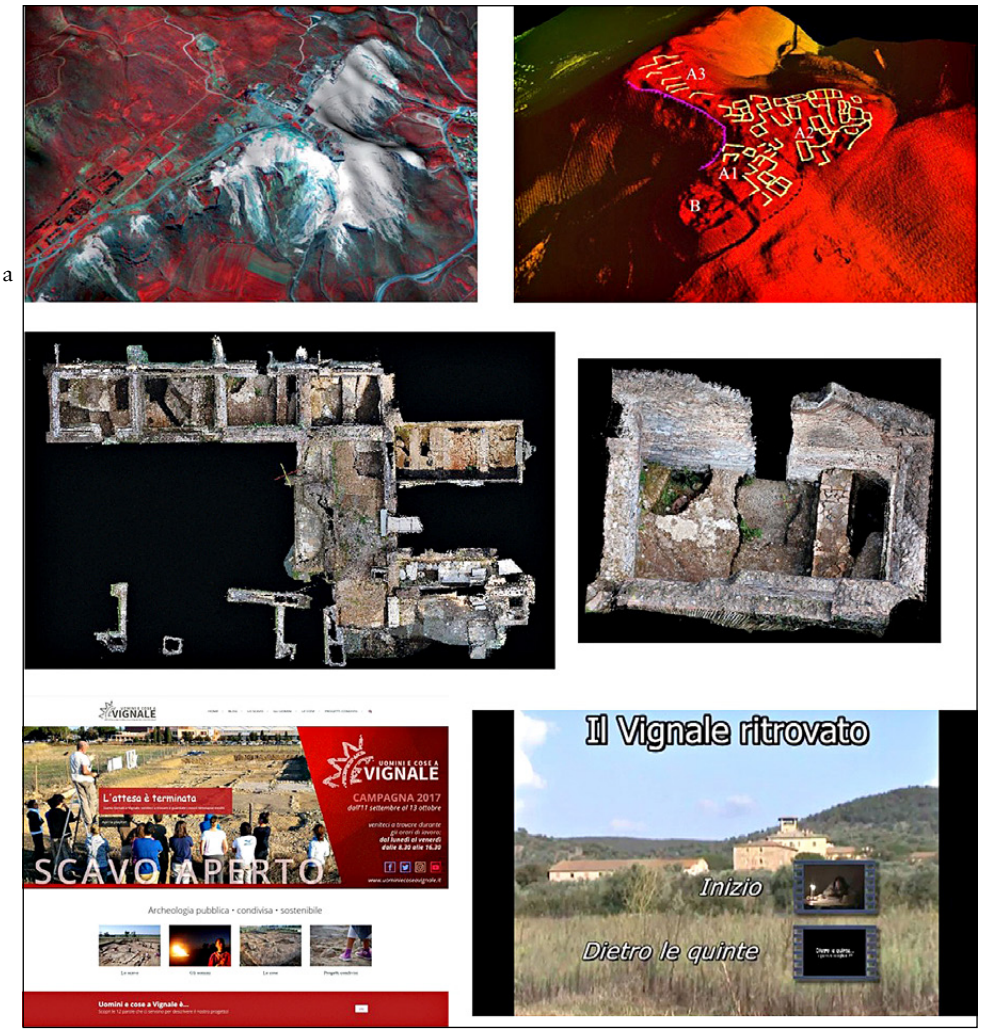

Fig. 8 – Satellite and airborne laser scanning: a) Hierapolis of Phrygia (Lasaponara, Masini, Scardozzi 2007); b) Yrsum, Basilicata (Masini, Coluzzi, Lasaponara 2010); c) Rome, Palatine Hill, "Terme di Elagabalo": photogrammetry and 3D rendering (Panella, Gabrielli, Giorgi 2011); d) The archaeological site of Vignale (Livorno): video docudrama to involve local population (Zanini, Ripanti 2012).

Digital mapping and GIS are at the core of each investigation and standardised procedures are required to formally record and represent spatial data. In addition to conventional topographic and photogrammetric surveys, specific sampling methodologies allow data to be acquired, based both on satellite

and airborne remote sensing, and on geophysical prospecting, in which state-of-the-art technologies provide 3D high-resolution images of the subsurface. Webmapping, webGIS and GIScloud techniques spread and field operations and lab data processing are in synch. "Digital-enabled excavations" call on researchers to be engaged in a range of activities that also result in hypertextual, diagrammatic and narrative interpretations of archaeological sites in order to promote a "public archaeology" approach (Fig. 8).

Spatial statistics, based on Digital Terrain Models, investigates space distribution phenomena and, trading on geo-referenced data, focuses on the role played by human visual perception in settlement, urban and architectural choices. The archaeo-geographical approach tends to investigate the memory, transmission and transformation over time of specific rural and urban planning structures, thanks to a cross-cutting integrated approach, which is based on the dialogue between archaeologists, historians, geographers and paleoecologists.

Archaeology of architecture aims at documenting built heritage, from wall stratigraphy to construction materials and building techniques, and makes use of laser scanners and photomodeling techniques for documenting plane surfaces through 3D metric models manageable in a GIS environment. 2D digital documentation techniques give way to 3D models and, thanks to the recent adoption of BIM (Building Information Modeling) technology for the design and life-cycle management of ancient buildings, they acquire a significant interpretative impact on reconstruction and restoration activities at different metric scales, from the urban settlement to the single building (see in particular the proceedings of the workshops *Documentare l'archeologia*: Curci, Fiorini 2012, 2013, 2015, and, lastly, Garagnani, Gaucci, Govi 2016) (Fig. 9).

Conservation and enhancement of the archaeological heritage become an economic priority of the European policy. Preventive archaeology is seen as the most likely approach to ensure coordination between archaeological protection and urban planning requirements, and archaeologists are a key part in the safeguarding process of our cultural and historical identity. GIS constitutes once again an ideal IT platform, capable of generating risk assessment maps and vulnerability indexes. In terms of built heritage, both in ancient cities such as Pompeii, and large architectural complexes such as the Hadrian's Villa in Tivoli, results coming from the monitoring of archaeological risks are recorded as GIS attribute values.

Data sharing intensifies via the web, supranational representation standards and data transmission protocols gain momentum and European e-infrastructures and services are designed to facilitate interoperability between existing open digital repositories (for the policy of the Italian ICCD, see Mancinelli, Negri 2016; for the Archaeological Territorial Information System of Rome, see lastly Serlorenzi, Jovine 2017). The concept of data

Fig. 9 – a) GIS of the city of Lucca in the Roman era (Camin *et al.* 2010); b) Building analysis of the provincial Forum of Tarraco (Vinci 2012); c) Pompeii, Roman forum: rendering of the textured digital model (Russo, Remondino, Guidi 2011); d) Marzabotto (Bologna): BIM model of the Tuscanic Temple of *Uni* (Garagnani, Gaucci, Govi 2016).

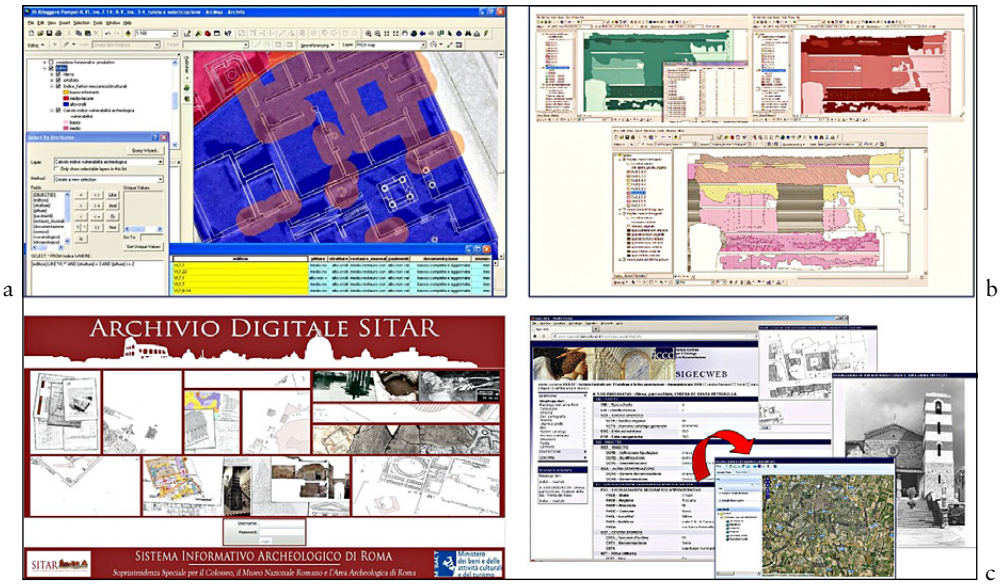

Fig. 10 – a-b) Vulnerability and damage assessment in GIS environment: Pompeii, "Casa dell'Argenteria" (Maratini 2011) and Hadrian's Villa, Tivoli (Lazzeri 2011); c) SITAR on line Digital Archive (Serlorenzi, Leoni 2017) and ICCD, General Cataloguing Information System, SIGECweb (Mancinelli, Negri 2016).

storage coincides with that of digital libraries with the ultimate goal of collecting, managing and preserving rich digital contents over the long term, in a free and open access environment (Fig. 10).

This utmost effort to build dynamic and enhanced knowledge bases is undoubtedly steeped in new challenges and opportunities. Research and policy areas, being so far apart, are reconciled, national intervention strategies are conceived in a globalisation context, lawyers and economists are engaged in solving issues related to open science and art production and consumption.

6. Conclusion

Despite such a fervor of activity and the exponential growth of technological solutions, something of the past experience has been lost. Attracted by the achievements of science and techniques, young archaeologists often lose sight of the ultimate goal of their research. Sometimes, archaeologists are not even involved in this triumph of technology, where everything seems to be achievable without the intervention of experts, forgetting that knowledge distillation is necessary in the art of building models and that model builders have to be deeply conversant with the relevant discipline.

Unlike what occurred in the infancy of archaeological computing, today little emphasis is given to the revolutionary significance of digital mapping and geometric modeling, or to the need to represent reality thanks to encoding procedures and relational data models and check whether raw data that leads to the interpretive phase is the result of an extensive and systematic survey. This is the reason why we are trying to store and preserve historical memories within the Virtual Museum of Archaeological Computing, an international project that we are promoting in partnership with the Accademia Nazionale dei Lincei (http://archaeological computing.lincei.it/).

With this in mind, I would like to conclude by coming back to Professor Sassatelli's words and their educational implications: getting lost in the jungle of technologies may involve the risk of losing sight of the true mission of archaeologists. Therefore, if nowadays technical training cannot be ignored, technology should not overshadow the ultimate purpose of the historical reconstruction and interpretation of the past.

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