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Acquisition of archaeological, geomorphological and stratigraphic data for the urban and peri-urban area of Pisa and preliminary analysis

Anichini F., Bini D., Bini M., Dubbini N., Fabiani F., Gattiglia G., Giacomelli S., Gualandi M.L., Pappalardo M., Rossi V., Sarti G., Steffè S.

After defining the area of investigation, the methods used for acquiring new data will be described. The archaeologists will address the problems encountered with the archives and the status of documentation, the sedimentologists will identify the areas for continuous coring, whilst the geomorphologists will base their analyses on micro-relief, photointerpretation and remote sensing techniques. Finally, the mathematicians will describe the classic page rank model, adapted to the determination of archaeological potential.

Keywords: Archives, archaeological documentation, paleogeographic scenarios, stratigraphic-depositional model, page rank

Introduction

The collection of archaeological, sedimentological and geomorphological data is a preliminary phase to our research. This phase is anything but mechanical: examining a sample, performing acquisition procedures and evaluating the quantity and quality of the data deeply influence subsequent analysis. For this reason, we believed it essential to take into careful consideration the acquisition procedure by analysing the knowledge already acquired and the problems inherent to the areas of investigation. To begin with, the area of intervention was delimited; this did not simply include the historical centre or its immediate suburban area, but a larger area of the plain where the city stands. This is, indeed, the area usually considered more suitable for analysing subsurface geomorphological and sedimentological data. The implementation of a map of archaeological potential for such a large area also provides an urban planning tool for areas where rapid expansion is to be expected in the near future. The team members examined, each for their own area of investigation, the state of knowledge, type of data and acquisition procedures – ranging from complex archival systems that preserve heterogeneous and dissimilar archaeological documentation, to micro-relief, photo-interpretation and remote sensing techniques for the reconstruction of the geomorphological context, and to the analysis of subsurface data belonging to the urban and peri-urban area of Pisa – with the aim to develop a preliminary stratigraphic-depositional model and to identify the areas for new continuous coring. These activities will allow us to obtain new

sedimentological-stratigraphic, geo-chemical, pollen, geomorphological, paleontological and archaeological information.

The mathematicians have also started studying the definition of a model for determining archaeological potential. The page rank model appears to be particularly suitable, so far used to classify search-engine web pages: the importance of a find is not absolute, but depends mainly on "nearby" finds, which attribute importance to it: this is the same criterion used for page ranking.

1. Delimitation of the area of investigation

The sedimentologists, geomorphologists and archaeologists agreed and defined together that the area of investigation should be a rectangle including the urban and peri-urban area of Pisa measuring around 33 km2. Starting from the area of the Morto river to the north, the area of investigation extends south beyond the Arno river, bordering southwards near Putignano. The western border is located at Barbaricina, which extends eastwards slightly beyond Cisanello and Ghezzano, and almost touches Rigoli which represents the eastern border.

Here it is possible to identify and characterise with sufficient detail the main morphological units that constitute the plain. With regard to the definition of the subsurface depositional architecture, the extension of the area and the concentration of data contained in it allow us to contextualise the space-time evolution of the depositional environments, as emerged after the preliminary analysis of the database. Furthermore, continuous coring was recently performed in this area for research purposes, which currently represent the stratigraphic reference of the entire plain of Pisa in terms of data detail and quality.

Archaeological data within this perimeter were analysed only for the municipal territory of Pisa and not for neighbouring municipalities. The historical centre and the peri-urban zone were already subject to archaeological site protection constraints under Law 1089/1939 and two judgments of 10 April 1986 and 29 June 1993 , respectively, drawn up by the Superintendent for the Archaeological Heritage of Tuscany and directly addressed to all interested Institutions . The decision to extend the map of archaeological potential to a much larger area appeared to be highly functional, in order to include both the suburban areas subject to recent urbanisation and areas where the city and its infrastructures are expected to develop in the near future.

2. Acquisition of archaeological documentation

2.1 Criteria for collecting documentary material

The project objectives – the creation of a database that may be consulted through mapping via the Web-GIS and the subsequent definition of an Open Data archive – required us to thoroughly reflect on the type of data needed to create these products and, furthermore, to define the archaeological potential of an urban area (see MapPapers 2).

An analysis of existing bibliography on these issues and the activities already developed for Pisa (Anichini 2005; Gattiglia 2010), guided the collection of documentary material based on the following criteria:

- No type of chronological selection, either for the source or the archaeological record. Diachrony will be one of the cornerstones of the following work phases, especially for the creation of the DTMs and the reconstruction of the city throughout various periods. We are convinced that a relationship of continuity/discontinuity exists among the uses of different urban sectors, which may be partly understood by identifying and analysing certain components that stretch over time, in some cases, to the present day.

- Given the gaps in documentation directly related to archaeological interventions (reports, photographs, cataloguing, plans, etc.), "indirect" sources containing information need to be checked: maps, issuing of opinions and authorisations, ordinary communications, papers for the granting of discovery awards, etc. A good deal of information about minor interventions may be read between the lines of all this documentation, such as surveys that did not provide any archaeological evidence (giving a significant "no data" result); inspections carried out directly by Superintendency officials who noted down measurements and the executors and chronology of works; the reporting of occasional discoveries of which only the finder's declaration remains. This is an important body of more or less detailed information, sometimes providing further elements to already existing but incomplete data.

- Much of the data collected relating to archaeological investigations lacks topographic details: although recording of the stratigraphic data is complete and very often accurate and truthful, geographic data are instead sometimes inaccurate or completely lacking.

- A large number of excavations cannot be located in mapping terms but simply contain general city indications (name of road, house number, etc.) which are not as univocal as a geographical coordinate. The need for highly accurate georeferencing of all archaeological evidence led us to seek sources that are not normally used. The collection of technical documentation connected to works that required or led to archaeological investigations, such as project plans, technical reports, etc., will allow us, in many cases, to have a mapping reference (either cadastral or on the Regional Technical Map) of the areas examined, representing a starting point for the georeferencing activities.

- The data collected are not selected in advance. The same significance is given to all type of data during acquisition. Complete acquisition of all the different

procedures followed for recording the stratigraphic archaeological data (graphical, photographic, compiling, etc.) will allow the data to be interpreted from different viewpoints. Since discrepancies have already been found in previous works, we believe that in many cases a cross check will be needed between the summary information provided, for example, in the excavation reports, and the raw data, especially whenever the person recording the data has not complied with the rules generally acknowledged or defined by the Central Institute for Cataloguing. The current state of archaeological practice – whether developed by research institutions or heritage protection institutions, either directly or through cooperation with external experts – presents the common habit of delaying the publication of archaeological results. Many are the cases in which results have been published many years after the end of the excavation or in which information has remained unpublished. Unfortunately, this is directly related to the fact that not all the documentation produced during the archaeological search is deposited with the specific institution. For this reason, it is essential to fully examine all published material in order to check if there are any interventions that have not been archived and if the data found in the archives correspond to the body of documentation originally produced. Printed or electronic editions containing complete, raw data are rare in any case, as also publications taking into account stratigraphic sequences without exclusively providing a summary interpretation. Furthermore, very few publications attach stratigraphic diagrams, material quantification, and the description of the methodological criteria adopted in the subsequent summary.

On the basis of these criteria, we decided to go through the various archives and at the same time examine the material already published, bearing in mind the area of investigation defined by the project.

2.2 The archives

In order to allow access to state-owned archives, an agreement was defined with the project partner institutions and supporters in order to provide the researchers with all the information needed for the successful outcome of the activities.

The documentation is mainly preserved in the Archive of the Soprintendenza per i Beni Archeologici della Toscana (Superintendency for Archaeological Heritage of Tuscany) in Florence (Historical, Current, Graphic, Photographic and Plans Archives) and in the archive of Pisa. Another important source for information is the Archive (General and Photograph Archives) of the Soprintendenza per i Beni Architettonici e per il Paesaggio, per il Patrimonio Storico, Artistico ed Etnoantropologico per le province di Pisa e Livorno (Superintendency for Architectural, Landscape and Ethno-anthropological Heritage for the Provinces of Pisa and Livorno): the archive contains the finds discovered during the recovery and restoration of public and private constructions, from the medieval age to most recent years. The information may be found in the reports drawn up by the architects and/or works directors, and sometimes in the photographic documentation of the inspections conducted for ordinary control and protection activities.

The greater part of the documentation contained in the archives of the two Superintendencies had already been collected for degree and PhD theses (Anichini 2005, Gattiglia 2010) and within the project for contextualising the finds of the archaeological site of the ancient ships of San Rossore, which SBAT commissioned to the Department of Archaeological Sciences (2007). Since the project did not envisage the acquisition of all excavation documentation, but only an initial cataloguing, filing and geographical positioning of the interventions, it became necessary for us to review the data already collected, acquire any missing data and fully examine the documentation regarding the most recent interventions, conducted after the previous work.

At the same time, the Historical Archive and the Archive of the Opera del Duomo of Pisa were consulted: although the majority of data have already been published, information about old finds preserved in these archives could disclose data that so far have been overlooked, as well as maps or sketches.

The deposits of the Soprintendenza per i Beni Archeologici (Superintendency for Archaeological Heritage) represent another source of information. Although our intention is not to specifically examine the preserved materials, it should be pointed out that documentary traces are missing for certain interventions (especially those far back in time), apart from the acronym written on the boxes of material deposited.

2.3 Acquisition procedures

Given the heterogeneity of the type of data, various acquisition procedures were defined based on the actual need to transfer the data entirely or not. This operation was planned with a view to optimising the time and resources used, also in the light of future project implementation phases: entry in the database, creation of the Web-GIS mapping tool and the Open Data archive.

- All documents not directly connected with the recording of the archaeological data (especially stratigraphic recording), but used as a source of information for some of the definition fields (maps, opinions, etc.) were directly filed (if containing simple or limited amounts of information) or were photocopied in order to be newly read and filed at a later stage. In cases where the document represented the only source of information for a certain intervention, it was scanned and preserved in an OCR searchable format in order to be subsequently entered in the specific database form.

- The graphic documentation of stratigraphic interventions and other kinds of intervention (pencil-drawn plans or plans finished with Indian ink) were scanned in original scale with 300 dpi resolution, ar-

chived, and divided by intervention, for subsequent digitalisation and geo-referencing.

- The Stratigraphic Unit sheets were photocopied or, if already available in digital format, acquired as an electronic copy.

- Regarding photographic documentation, prints and slides were scanned whereas digital photographs were copied electronically.

The material so far acquired has been processed in accordance with the privacy rules provided for by law.

2.4 Time and workforce used during the first phase

This work phase started on 1 August 2011 and should be completed by the end of October. Phases regarding data review, transfer to the digital archive and geo-referencing are not included in this deadline, since they are the subject of further WPs. A full-time collaborator was employed during the first 3 months and was supported by one of the team managers. She was involved in defining the access procedures with the bodies and institutions that run the archives and in periodically checking the intermediate steps of the project. Two further full-time collaborators shall be included from the month of October.

2.5 Retrieving data and data quality: several considerations

The tight project deadlines clashed with various practical and structural problems which we admit were underestimated when evaluating the deadlines for this phase. The bureaucratic procedures for the definition and signature of the agreement with the partner institutions required much longer time than expected. The start of the activities coincided with the month of August and, therefore, with the summer holidays. Given the organisation of the public archives, they are not open continuously throughout the year (often due to reduced staff) and can often only be accessed on certain days and during certain hours.

After accessing the archives, the next difficult step is to actually retrieve the documents inside the archive. The archive of the Superintendency for the Archaeological Heritage of Tuscany, for example, which is not yet computerised, initially sorts the documents chronologically and geographically according to their date of protocol and province of origin. Subsequently, the material regarding the same intervention is further sorted into distinctive documents (graphic, compiling and photographic documents and heterogeneous attachments). Physically, the archive is composed of a large number of rooms that are not contiguous to each other, in which part of the material is not catalogued (drawings archive) and another part has been poorly preserved (plans archive).

Furthermore, the archives are incomplete because documentation is missing for certain investigations. Whilst it is possible to draw information from published material for some investigations (although the informative significance of raw archaeographic data and of summaries offering a legitimate, albeit personal, interpretation of such data, is quite another matter), there is little trace for others which can only be inferred from accessory documents or from the acronyms of the deposited material. Even in this case, however, the data are not easy to read: since there is no centralised control for the acronyms used, it was sometimes impossible to understand the acronym and to recognise the intervention, while in other cases the same acronym was assigned to more than one excavation. The absence of documentation, whether attributable to wrong archiving or to non-delivery by the persons carrying out the work, freelance professionals or State officials, deprives archives of important parts of collective heritage.

A further problem must be added to the difficulty in retrieving documentation: its quality. This depends on the different level of analysis, ranging from simple preliminary reports to partial communications and notices, and, ultimately, to integral publications, but also on the different people who have collected the data (voluntary persons or professional archaeologists), on when the intervention was conducted and on the type of intervention – occasional recovery, preventive inquiry and/or research. In general, it is possible to notice that the passage from emergency and/or occasional actions, which dominated until the early 1990s, to planned actions, such as archaeological assistance and preventive excavations, adopted almost systematically between the end of 1980s and early 1990s, inevitably led to an increase in the quantity and quality of the data produced, as well as to greater attention to the diachronic nature of the finds, especially to post-classical phases. It was possible for us to establish, for instance, that graphic documentation is available only for interventions after 2000 and very sporadically during previous years. However, even in recent investigations, differences (at times strong differences) continue to be found in the quality of the documentation produced or delivered, which does not always include complete written, graphic and photographic production (stratigraphic unit reports, matrices, plans, phase plans, photographs and tables of material). To this regard, a list of all known interventions was drafted with information about the presence/absence of all different types of documentation. There are also cases that feature original forms of documentation, regarding both sheet items and the drafting of stratigraphic sequences: although it is important to keep alive the debate on methodological search aspects, the rules defined by the Central Institute for Cataloguing and Documentation guarantee data comparability and a shared language.

3. Collecting geomorphological data

Bibliographical data were collected and selected both specific to the area of investigation and to the

geomorphological survey procedure to be adopted in urbanised plain areas.

3.1 Geomorphological knowledge of the plain of Pisa

With regard to the area of investigation, modern geomorphological works that examine the diachronic evolution of the landscape are amazingly very few (Della Rocca et al. 1987; Federici, Mazzanti 1988; Mazzanti (ed) 1994; Federici, Mazzanti 1995). Paleogeography is described in detail at regional or at the most at subregional scale, yet lacks resolution in the most recent period of the Upper Holocene, of greatest interest for the project. The first bibliographical work mentioned, which is the most complete and exhaustive, abounds much more with indications from historical sources than with relief shape identification and interpretation. Apart from numerous paleo-traces (related to several generations of paleochannels), which are the result of photointerpretation and remote sensing techniques applied to low-resolution Landsat images, the interfluvial areas differ only for their surface lithology. From a chronological viewpoint, the deposits of the Upper Pleistocene differ from those of the Holocene. The former are eolianites, the remains of a paleomorphology that evolved during low sea level conditions, of unknown age but probably belonging to the Marine Isotope Stage (MIS) from 5.3 to 3 (Sands of the Island of Coltano). Two types of overbank deposits (coarser and finer) and marsh deposits (organic clay) may be found for the Holocene. The latter are limited in size depending on the location of the depressed areas inferred from historical sources. A morphological interpretation of the altimetric variations in the plain is totally missing.

This overview also reveals that in terms of landscape evolution, the fluctuations of the hydrographic network and of morphological depressions are the items of greatest interest. Landscape modification features prograding of the coastline which, starting as far back as II century B.C., led to the formation of a coastal strip composed of beach and dune ridges (Mazzanti, Pasquinucci 1983; Pranzini 2001), reaching a width of around 7 km in XIX century. The morphology may be described as a typical fluvial delta morphology, with a barrier that separates the open sea from a depressed area, gradually filled by the solids of the watercourses flowing into it. The landscape in this area reflects a gradual continentalisation, modulated by outflow modifications.

Regarding the hydrographic network, the reconstruction of its diachronic evolution is extremely complex. We have greater evidence from historical and archaeological sources than from geological archives and geomorphological analysis based on photo-interpretation and remote sensing techniques (Della Rocca et al. 1987), sporadically associated to targeted geo-physical prospecting (Marchisio et al. 2001). The sources reveal a complicated network of paleo-traces related to several generations of paleochannels, at times of uncertain identification. Basically, there are no definite reconstructions of paleo-hydrographic scenarios at the moment but, for the most part, assumptions on the identification of specific paleo-traces with watercourses existing in certain periods according to the historical sources.

The issues of greatest interest are the separation of the hydrographic basins of the River Arno and the River Serchio, the history of the southern branch of the River Arno and the evolution of the final part of the River Serchio.

Another issue that has been examined only marginally with a geomorphological approach is the evolution of the lacustrine/marsh areas. Della Rocca et al. (1987) identify them on the basis of historical documents and distinguish them in lithological terms; they group them, however, with silting deposits which are much more recent and genetically distinct, and it is not clear on which grounds they delimit them (maybe as a result of spectral signatures). This is a particularly critical aspect, since the extent of the so-called "paduli" has changed frequently over time, and it is important to attribute a perimeter to the respective time interval.

3.2 Potential and prospects of the geomorphological approach

A bibliographical search on methodological aspects allowed us to identify among the large amount of modern geo-archaeological works produced, those which examine the role of geomorphological research in geoarchaeology (Beach et al. 2008). With reference to the Italian scenario, among the many case studies that relate to plain areas, we decided to select those (Ninfo, Piovan 2006; Piovan 2008) in which geomorphological surveying was able to complement the subsurface data more effectively for diachronic paleogeographic reconstruction purposes (such as the eastern Padana plain).

The difficulty in addressing a geo-morphological study in a plain area, especially if anthropised, is well known in literature (Castiglioni, Pellegrini 2001) and clearly emerged in 2005 when the first geo-morphological map of the Province of Pisa (scale 1:10,000) was drawn up.

The stereoscopic analysis of aerial photographs in 1975 was integrated with micro-relief reconstructions resulting from contour line interpolation and by comparing the coring databases available in each Municipality. This allowed many elements related to fluvial dynamics – such as interfluvial ridges and abandoned river-beds – to be characterised. The latter were especially identified in the agricultural area north of the inhabited part of Pisa, whilst for the urban area, only around ten traces were identified in the historical centre located north of the Arno. The comparison between old geomorphological data as well as the data from the Cosci archive and a preliminary analysis of multi-temporal frames revealed high concordance for certain elements (e.g. paleo-river bed running south of Piazza dei Mircaoli), but also

differences such as the presence of river-bed strips not previously reported. Given the detailed nature of our work, it became clear that information needed to be drawn from the highest number of sources, especially since the different humidity levels when taking aerial shots strongly influences the legibility of the frames, and only makes certain shapes visible. It seemed essential to us, therefore, to retrieve all the aerial photographs available at various Institutions. The data were collected and organised in a geo-database created for the specific purposes of our study.

The geodatabase included the following feature classes:

- Mapping data (CTR scale 1:10000 and 1:5000);
- LIDAR data for implementing the DTM, separated according to different levels;
- Satellite data in raster format;
- Geo-referenced aerial images, divided by year of aerial shots.
- Existing theme maps (geological, geomorphological and pedologic maps).
- Geophysical data
- New GPS data

The geo-database will be completed with a feature data set (divided into three feature classes: polygons, lines and dots) which will include the new geomorphological map in which the single elements will be divided according to morphogenetic process, type of shape and state of activity.

With regard to the aerial images, all flights providing partly overlapping frames for the examined area and available at various Institutions were entered in the geo-database (National Aerial Museum, Regione Toscana, Military Geographic Institute, the Municipality of Pisa, Marcello Cosci Archive). The time interval covered by the frames ranges from 1937 to 2010.

Regarding satellite images, recent archives (from 2009) were examined to search for images from second generation high-resolution satellites (VHR). A product (GeoEye1) was identified that represents a good compromise between quality and price. It features 4 bands and 2 m resolution in the multi-spectral mode and 0.50 in the panchromatic mode. Furthermore, it includes good-quality acquisitions taken in September 2010 because taken with a clear sky. Satellite data are currently being acquired in order to cover an area corresponding more or less to the extended area.

The fluvial dynamics, as well as the prograding of the coastline and the localisation and evolution of the wet areas will be analysed in the extended area, with different levels of investigation: these are all elements that influence population. The search for paleo-environmental information deriving from written/archaeological sources was particularly easy since the archaeologists provided mapping summaries in a useful format for use as geo-referenced data.

4. Stratigraphic-depositional architecture: analysis of subsurface data and creation of a preliminary depositional model.

During the first phase of activities, around 400 items of subsurface data were acquired, including coring and penetrometer tests, located in the urban and suburban area of Pisa and resulting from the catalogues of public institutions and private firms.

The data acquired were handled in GIS environment to create a geo-referenced database of the uppermost subsurface of Pisa, which contained the main geographic (geographic coordinates and height above sea level) and descriptive (depth reached by the test) information for each test treated as a point object (shapefile-point).

An initial detailed analysis of the database revealed uneven spatial distribution of the data and qualitative heterogeneity of the stratigraphic documentation acquired. This made the subsequent facies interpretation phase particularly complicated, as also the reconstruction of an initial subsurface depositional model, aimed at identifying the depositional environments and main sedimentary bodies through creation of two-dimensional stratigraphic sections.

During this preliminary phase, continuous coring was taken as reference, which featured a high percentage of recovery and a complete and detailed stratigraphic description (lithological, sedimentological and at times paleontological data).

On the basis of the sedimentological (granulometry, sedimentary structures, colour and accessory material) and fossiliferous (molluscs, benthic foraminifera meiofauna and ostracods) features, four main depositional facies were identified within approximately the first 20 metres of subsurface: lagoon, marsh, flood plain and fluvial channel or distributor channel, which have developed in the plain of Pisa over the last 7000 years circa.

Twelve two-dimensional transversal sections from NW to SE (with a high angle with respect to the current course of the River Arno) and seventeen longitudinal sections from SW to NE were interpreted using the correlation criterion for depositional-facies environments. This section grid allowed us to rebuild an initial stratigraphic-depositional subsurface model, essential for choosing the key areas for new continuous coring which will increase the existing database.

In brief, the stratigraphic sections revealed the presence of lagoonal clay-silty clay in the subsurface, resting from around -15m/-20m above sea level up to varying heights depending on the presence or absence of overlying channel bodies. The latter, which developed during the subsequent prograding phase of the delta-alluvial environment, may have influenced the lagoonal clays to a greater or lesser extent, thus creating depositional hiatus or stratigraphic gaps.

In cases where there are no channels above the la-

goonal clays, fine sediments rich in organic material, which are attributable to a marshy environment, document the silting up and closing of the Pisa lagoon. In both cases, the stratigraphic succession ends at the top with fine flood-plain sediments (silt-clay) or fluvial channel sands attributable to deposits of the recent alluvial plain.

At the same time, the criteria to be used for localising the six/eight continuous coring boreholes was discussed and a proposal was made, which was agreed upon by the team. The criteria for choosing the key coring sites considered both the indications of the preliminary subsurface model and the gaps in the database from which the model was obtained; the latter were mainly due to the uneven distribution of data throughout the territory and their heterogeneous quality. Strategic areas were chosen with the aim of acquiring the largest amount of sedimentological-stratigraphic, paleontological, geo-chemical, pollen, geo-morphological and paleontological information. Each core will include a detailed stratigraphic analysis with photographic documentation, and sampling of sediments for paleontological, pollen and geo-chemical analysis. The detailed stratigraphic analysis, together with paleontological and pollen lab tests will allow us to fine-tune and optimise the stratigraphic-depositional subsurface interpretation resulting from the preliminary model, necessary for creating the paleogeographic maps. The geo-chemical tests, instead, will discriminate the areas of origin (Arno system/Serchio system) of the deposits, which will help us reconstruct the paleo-geographic evolution of the area of investigation.

The operating procedures for a shared reading of the cores have also been defined. An archaeological stratigraphic analysis will also be carried out which, in addition to implementing the data already collected with the new, accurate interventions, will allow the first metres of subsurface to be precisely examined, where anthropic traces or historical chronologies will presumably be found.

5. A mathematical model of archaeological potential

Page rank models appear to be a suitable approach for determining the archaeological potential of the urban area of Pisa, starting from existing data. Indeed, if suitably modelled, the criteria used for attributing archaeological potential are particularly reminiscent of the criterion used to assign importance to web pages, since each archaeological find/object gives importance to those nearby, from which, in turn, it receives importance. Consequently, the importance of a find and the archaeological potential of a point in the subsurface basically depend on the relevance of the finds and on the archaeological potential of nearby areas, and vice versa. Page rank models are used by search engines to attribute importance to web pages. Our intention is to extend these models so that they can be used to determine archaeological potential. The following paragraph gives details on the original model and on the changes that need to be made for its adjustment.

5.1 The page rank model

The main concept upon which a page rank model is based will be described in this paragraph. Since out of this report's scope, we will not provide mathematical details (some of which are covered by industrial secret since used by companies in web search engines). The criterion used for giving importance to web pages is based on the number of links going out of the page. A page i that points to (i.e. has a link to) other pages, which we will call j¬¬1 , j¬2 , …. , jk, distributes its importance in equal parts to pages j1 , j2 , . . . , jk, and therefore gives 1/k of its importance to the pages it points to. Starting from this criterion, and applying it to every page, the importance of each page is assigned according to the weight attributed to it by the other pages; vice versa, it assigns importance to the pages it points to. Application of these operations results in a linear system comprising an extremely large number of equations (in the case of web pages, around 10 billion): the result of this system of equations, after it has been solved, is the importance of each single page. To solve this system, a so-called "eigenvalue problem" must be solved, which can be theoretically solved with the Perron-Frobenius theorem, which guarantees the existence of a solution depending on certain conditions. Instead, in computational terms, since there is an enormous amount of equations, the solution can be calculated because the matrices are "scattered", i.e. they have a large amount of zeroes.

5.2 How to adapt the model to archaeological potential

In order to adapt a page rank model to the determination of archaeological potential, variants need to be created that take into account some of the problem's characteristics. The subsurface will be modelled as a set of cells in a three-dimensional space; importance will be transferred from one cell (acting as the web page) to the others on the basis of a (previous) categorisation of finds. The strategy that will be implemented to adapt the page rank model is the following:

- A three-dimensional grid will model the subsurface of the urban area of Pisa. The single cell of the grid will act as the web page, and the importance of the cell, determined at the end of the procedure, will be the archaeological potential;

- The archaeological potential available for a cell will be used in a twofold manner: in a relative manner to build the elements of the matrix that controls the transfer of importance of the cells, and in an absolute manner, providing a value of importance to the specific cell where an archaeological find is present;

- The part regarding the construction of the matrix that controls the transfer of importance will be carri-

ed out on the basis of categories used for classifying the archaeological finds; in particular, each category will characterise the geometry of the distribution of importance;

- Finally, the part regarding the specific importance of the single cells will determine the actual value of archaeological potential; in fact, the matrix controlling the transfer of importance will determine the "archaeological potential" of one cell instead of others, however, in order to provide an absolute value, a "base value" must be assigned to certain cells, essential for calculating all the other values.

Geological information, regarding the presence of watercourses or specific land configuration, will be used in a binary manner, i.e. it will be used as a necessary condition for a value of archaeological potential greater than zero: this information will allow us, beforehand, to exclude certain cells from the calculation of archaeological potential.

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