Archaeological predictive model of an urban area. The study case of Pisa, Italy

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Abstract: The Department of Archaeological Science of the University of Pisa is undertaking a research project aimed at the creation of a predictive model for urban areas. The case study is the town of Pisa, but the aim is to realize a replicable model useful for similar urban areas. Through the use of spatial and geostatistical analysis, the cooperation with geologists to analyse to ancient surrounding environment and with mathematicians to elaborate a specific algorithm, we want to realize an Archaeological Information System able to define the specific nature of archaeological practice. Pisa's AIS was developed to manage heterogeneous data, which drawn the urban archaeological complexity, and to develop effective predictive tools, working on an intermediate scale which allows to analyse how the geographic space have influenced the economic, political and logistic choices. This has led to the need to work with both topographical (geomorphologic, hydrographical, toponymic data, etc.) and urban data (archaeological stratifications, buildings, road network, hypotheses of historians and archaeologists, etc.), combining inter-site analysis and archaeological excavation GIS' resources. To combine multi-temporal and multi-scale data, it was necessary to provide for digital data conversion and georeferencering of archaeological excavation data acquired at different times and different scales and the integration and overlap of data obtained with different techniques and diverse topographical reliability and precision. The particular attention to the aspect of management of the archaeological raw data, that is all the excavation and fieldwork recording (planning of context, context recording sheet, photographs, findings quantification sheet), suggested the necessity to realize an open digital archive and to provide possible standardization of digital formats, metadata records and archaeological data recording, so as to allow the comparison between the data.

Keywords: Predictive archaeology, open digital archive, urban area, algorithm.

MAPPA project: Methodologies Applied to Archaeological Potential Predictivity

Introduction

Like many other Italian cities, Pisa (Italy) is a settlement that goes well back into history, so it's an excellent case study. Its subsurface conceals the remains of walls, floors, tombs and roads, as well as the fragments of tiles, vases, lamps and sculptures: briefly, the more or less solid traces of the lives of the people who have inhabited the city over its almost three thousand years of history. By studying the city's archaeological artefacts and its pollen, coal and human/animal bone remains and by analysing the area's geological and geomorphological features and its resources, it is possible to reconstruct the landscape, or better the landscapes, that have evolved over time and have influenced the city's economic and cultural development, and in turn have been influenced by them.

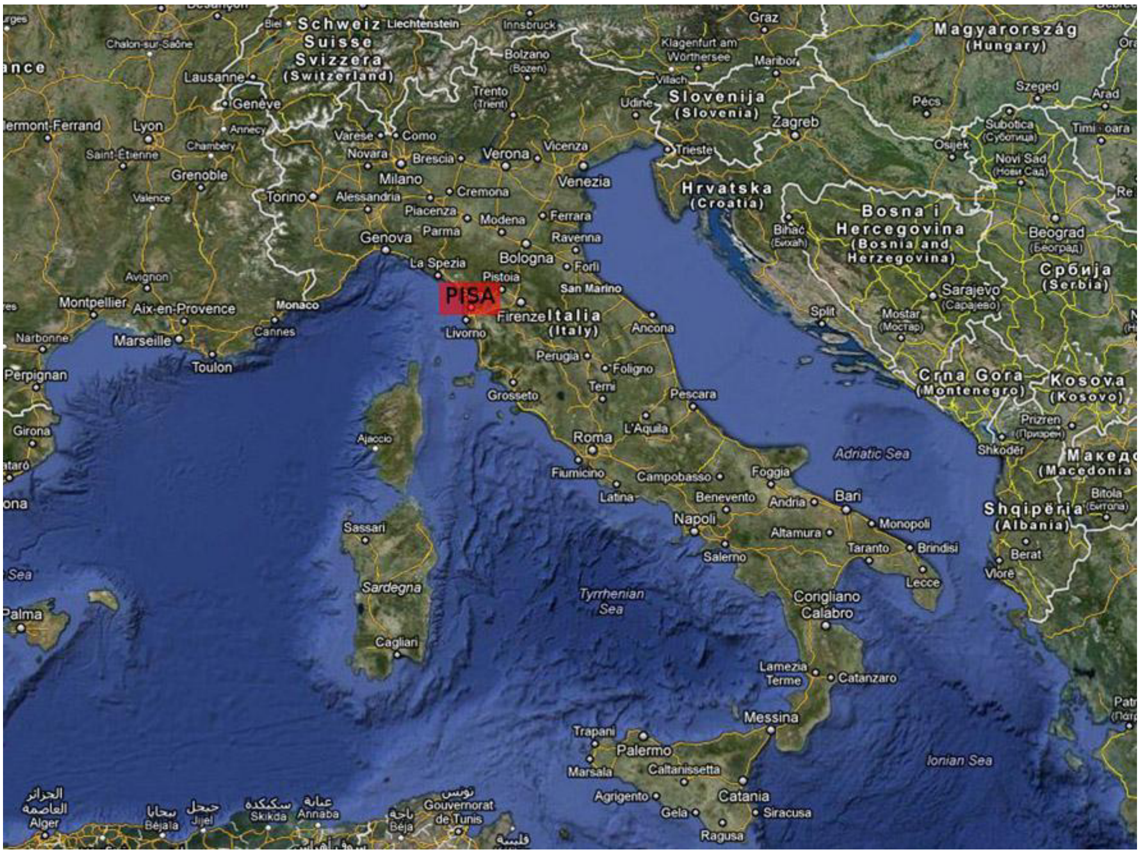


Fig. 1 – Pisa, Italy (copyright MappaProject – Università di Pisa from Google Maps).

The ground on which we walk, build and live today is an extraordinary palimpsest where uncountable traces that have been left by our predecessors evolve, merge and overlap. Yet since these traces lie under the ground, the vitally important needs of the city's life and development need to be taken into account: safeguarding archaeological heritage does not mean fighting development, on the contrary, sustainable management models should be proposed and solutions should be studied which do not simply safeguard but enhance archaeological heritage in terms of cultural enrichment and of further development of the supply of tourism services. They should also aim to recover technological experience and rediscover traditions and trades which could be extremely helpful to today's community. As a consequence of the entry into force of the Law on preventive archaeology (Italian Legislative Decree 195/2006), evaluating archaeological potential has finally become a key issue. It guides operational decisions during work on sites involving construction or environmental transformation: knowledge of the area's archaeological potential allows the authorities responsible for protecting the territory (Superintendencies) and for planning its development (Municipalities, Provinces and Regions) to provide more knowledgeable opinions and to immediately inform the interested persons on the chances of finding buried remains during excavations. This can all be done before opening the building site, without stopping the building works or definitely blocking any projects already under way. The Map of Archaeological Potential is an answer to the problem of finding appropriate tools for making archaeological research demands coexist with present day and future needs. The map stems from the common archaeological map and combines archaeological-historical information with data resulting from geological and geophysical surveying and prospecting, geomorphologic reconstructions, historical mapping and registers, toponymic data, and analysis of urban construction elements. Further processing, carried out on the basis of coded interpretative models, will allow us to make assumptions on the greater or lower chance of archaeological remains in areas of which we have no existing information today. In other words, the map is a predictive map. Evaluation of the possibility that certain areas may conceal archaeological remains of which we have no news is achieved by projecting knowledge regarding neighbouring areas on them, with a degree of approximation that varies according to the quantity and quality of data available. It can be said, therefore, that the Map of Archaeological Potential is a new-generation tool that helps gain knowledge of the local area and whose advantages cover many scopes of application. A further aspect must not be underestimated: the creation of a Map of Archaeological Potential is not only a vital tool to learn and safeguard archaeological heritage and to fully enhance its resources; it is also the first step to raising new collective awareness of the importance of becoming familiar with this heritage, which is imperative to any kind of archaeological protection.

Fig. 2 – The red rectangle define a 32 square kilometers area around the urban center of Pisa, Italy (copyright MappaProject – Università di Pisa).

The project

The project started on July 2011 and will end on June 2013 and it's being carried out by the Dipartimento di Scienze Archeologiche (Department of Archaeological Sciences), the Dipartimento di Scienze della Terra (Department of Earth Sciences), the Dipartimento di Matematica (Department of Mathematics) with the external collaboration of the Direzione Regionale per i Beni Culturali e Paesaggistici della Toscana (Regional Directorate for Cultural and Landscape Heritage of Tuscany), of the Soprintendenza per i Beni Archeologici della Toscana (Superintendency for Archaeological Heritage of Tuscany), of the Soprintendenza per i Beni Architettonici, Paesaggistici, Artistici ed Etnoantropologici per le Province di Pisa e Livorno (Superintendency for Architectural, Landscape and Ethno-anthropological Heritage for the Provinces of Pisa and Livorno), of the Comune di Pisa (Municipality of Pisa), of the Istituto Nazionale di Geofisica e Vulcanologia (National Institute of Geophysics and Vulcanology), of the Aerofototeca Nazionale (National Aerial Photograph Archive), of the Laboratorio di cultura Digitale – CISIAU Centro Interdipartimentale di Servizi Informatici per l'Area Umanistica (Digital Culture Laboratory – CISIAU Interdepartmental Centre of Information Services for the Humanities).

Fig. 3 – The Mappa project timeline: the project started on July 2011 and it will end on June 2013 (copyright MappaProject – Università di Pisa).

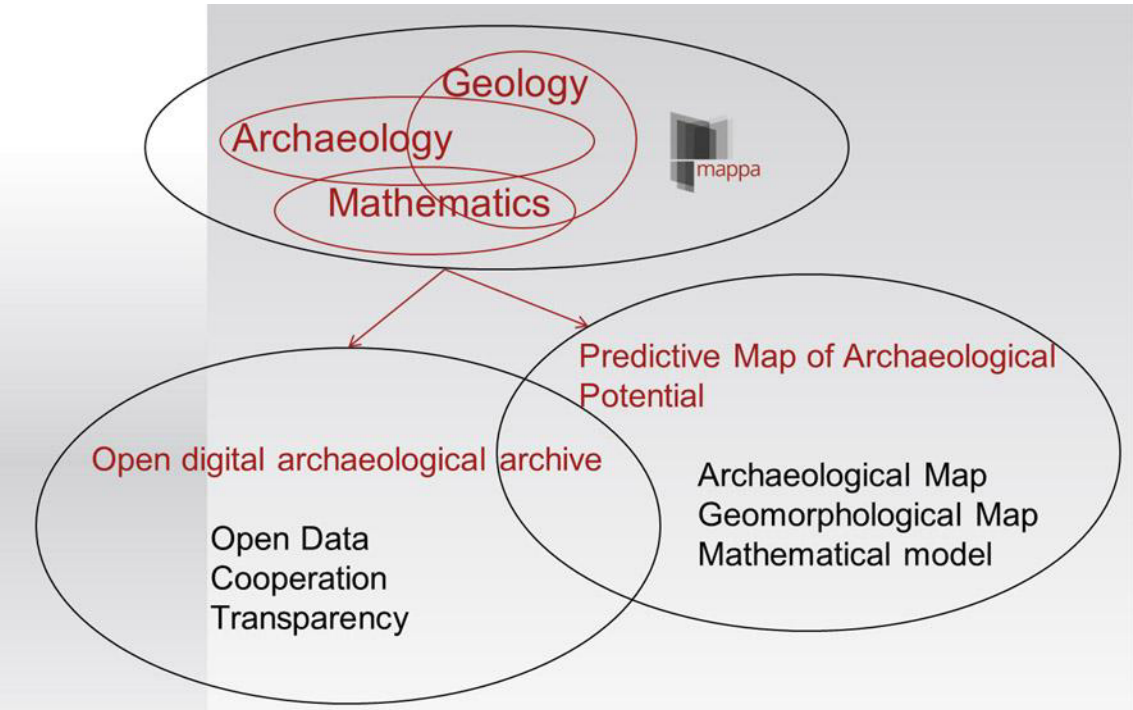


Fig. 4 – Archaeologists, geologists, mathematicians: a dynamic group of researchers who are convinced that a multi-disciplinary approach and free access to knowledge can propel innovation and research development (copyright MappaProject – Università di Pisa).

Unlike famous international examples, research dealing with these problems and their focal issues is highly disadvantaged in Italy. Although many projects have been funded over the past years regarding the introduction of highly advanced technologies, a common and systematic multi-disciplinary approach has not yet been developed which aims at "managing" buried archaeological heritage in terms of planning and safeguarding. The project intends to achieve the following objectives:

- Enhancing the development and research of archaeology by fostering collaboration with experts from different research sectors (earth sciences and mathematics). By developing a common language and observing from different perspectives, the project will especially aim at achieving a methodological development of the issues tackled in the project and at increasing the progress and competitiveness of the individual disciplinary sectors. Within this context, we seek to develop and test predictive mathematical models applied to archaeology which will have a social impact in terms of archaeological heritage protection, territorial planning and historical knowledge.
- Creating a repeatable model that may be applied to all multi-layered urban centres in order to facilitate land use decisions regarding archaeological heritage management and protection issues. This will mitigate impact on heritage and promote the sustainability of territorial planning processes. We firmly believe that university research must be at the service of civil society and provide its results in the form of exploitable tools, with effects both on citizens and on cultural heritage.
- Providing a standardised protocol of Operational Guidelines, drawn up with measurable and repeatable criteria. A further objective consists in providing local governmental and protection institutions with an integrated "package" that will make urban planning easier during the planning phases and optimise both financial resources and implementation time. The system also represents a valid tool for supporting private development projects since it facilitates archaeological impact assessment procedures and safeguards cultural heritage.
- Creating a standardised, digital and user-friendly (i.e. open data) archaeological data archiving model, which may be applied to all Tuscan and Italian urban contexts after it has been tested on samples in Pisa. The implementation of a system such as this (the only one in the country to date) will promote the communication and diffusion of the research results and the direct transfer of technological innovation via web.
- Training and professionally qualifying new R&D experts with a multi-disciplinary approach in order to develop a competitive system model. We aim to create new experts with strong specific skills but at the same time capable of speaking a common inter-disciplinary language. We firmly believe that this is a qualifying element for the professions involved in the project and for the development of a knowledge-based society that is capable of integrating topics that differ by scientific approach and method, and of developing a highly competitive system model.
- Pisa has a very special environmental context, characterised by numerous watercourses and wetlands which have frequently changed over the centuries and significantly altered the territory. For this reason, we believe that a detailed geomorphological reconstruction is of vital importance, especially with regard to the diachronic migration of natural watercourses in the urban area and identification of the artificial canals connected to them. Furthermore, it will help us interpret the dynamics of urban settlement over various historical periods (ANICHINI et al. 2011a).

The data model

MAPPA Data Model is developed to manage heterogeneous data, which drawn the urban archaeological complexity, and to develop effective predictive tools. This has led to the need to work with both topographical (geomorphologic, hydrographical, toponymic data, etc.) and urban data (archaeological stratifications, buildings, road network, hypotheses of historians and archaeologists, etc.), combining inter-site analysis and archaeological excavation GIS resources.

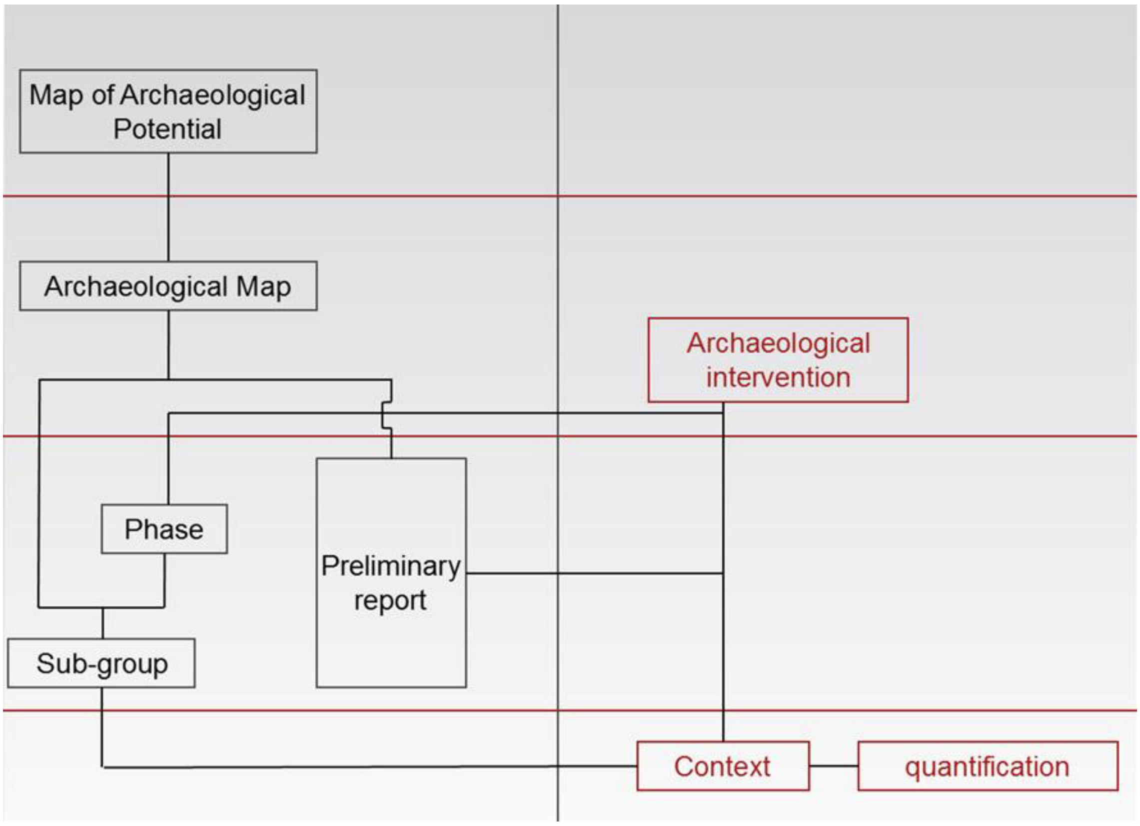


Fig. 5 – The 4 level archaeological data model (copyright MappaProject – Università di Pisa).

The archaeological data model is a 4 level model which combine raw data and interpreted data. The model goes from less synthetic data (i.e. the context level) to the more synthetic data. This model suits the Relational DataBase Management System and the GIS Geodatabase. The centre of the model is the archaeological intervention. To enable proper processing queries, it’s necessary a comprehensive geographical and archaeological data entry, according to a consistent use of geometric primitives for reproducing vector objects. As a general principle it was decided to use polygons for georeferencing all data location. Archaeological excavation data entry was based to the principles of archaeological stratigraphy, archaeological plans coming from a complete archaeological dataset or from a partial archaeological dataset have been addressed through an identical graphical representation, but using different files. Deposits and cuts are drawn as polygon, symbols as line.

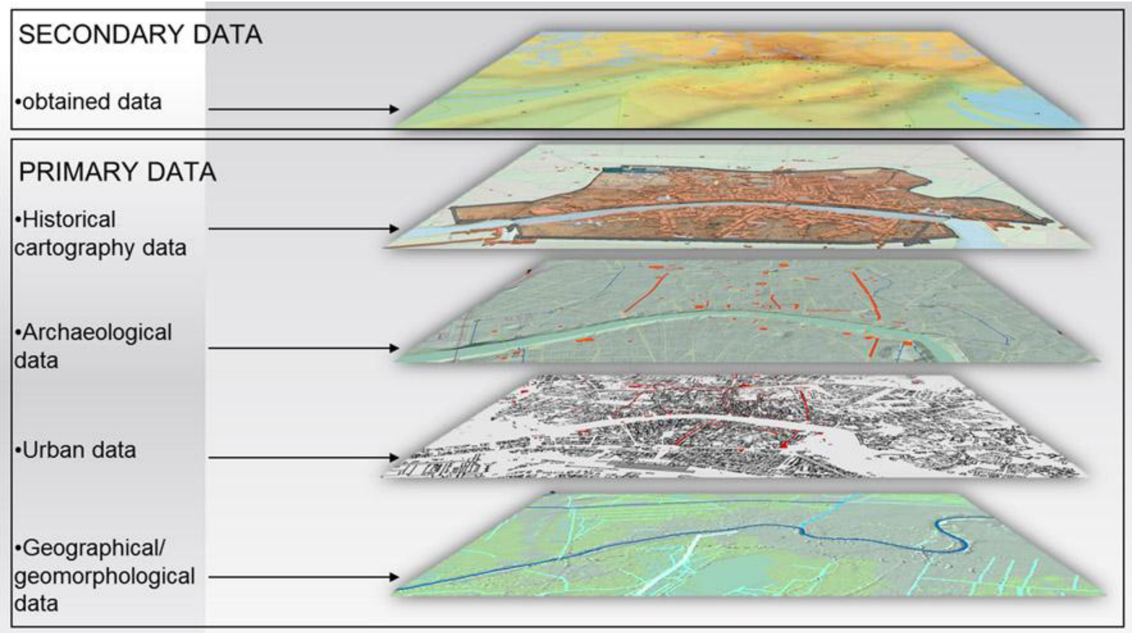


Fig. 6 – To summarize the model includes: geographical/geomorphological data; urban data; historical cartography data; all archaeological data from occasional findings to stratigraphical excavations; obtained or secondary data (copyright MappaProject – Università di Pisa).

The Data model also includes:

- ► filing of published data, of archive data and of data resulting from building archaeology, and data georeferencing and vectorisation in order to understand urban fabric development and the level of architectural heritage preservation;
- ► the collection of written, published documentary sources with the aim to locate no longer existing place names, production activities, infrastructures and topographic structures;
- ► the computerised acquisition of historical mapping to trace urban transformation throughout the modern and contemporary ages;
- ► finally, mapping of stratigraphic gaps by recording the thick network of underground environments including cellars, garages, cisterns, basement areas, underground services, as well as the portions already subject to archaeological excavations which have led to the removal of stratigraphic deposits.

Definition of Archaeological Potential

The archaeological potential of an area represents the possibilities that a more or less significant archaeological stratification is preserved. Archaeological potential is calculated by analysing and studying a series of historical-archaeological and paleo-environmental data retrieved from various sources, with a degree of approximation that may vary according to the quantity and quality of the data provided and their spatial and contextual relationships. The archaeological potential of an area is, in itself, a factor independent of any other following intervention that is carried out, which must be regarded as a contingent risk factor. The process for defining overall urban archaeological potential consists in drawing up a series of predictive maps relating to the city's historical periods. For this reason, the parameters required for the predictive definition of the city throughout its historical periods had to be defined to begin with, followed by the parameters needed for calculating the archaeological potential. This phase of the process required the contribution of the different disciplines involved in the project. In terms of subsurface geology, the criteria for determining the parameters for the predictive definition of the city throughout its historical periods basically refers to the distinction between river channel areas and extra-channel areas. The latter include wetlands and (dry) floodplain areas, in a broad sense. Paleo-depositional reconstruction of the uppermost subsurface, through *facies* analysis of a series of stratigraphic sections, will consequently allow the areas crossed by channels (prevailing lithology: sand), marshes (prevailing lithology: organic lime and clay with low consistency, peat and sand) and dry floodplain areas (prevailing lithology: consistent lime and clay, interrupted locally by thin sand layers) to be distinguished. The different settlement potential that these areas and their relations represent throughout the various periods helps predict the probable presence of settlements. This general criterion is applicable to all the stratigraphic intervals that we will be able to reconstruct, and must naturally be integrated with both archaeological and geomorphological data: geological maps define stratigraphic units and sedimentary bodies, geomorphological maps show relief forms and define the geomorphic processes responsible for their genesis, in addition to recent modifications. In order to define the values of archaeological potential on the basis of geomorphological data, therefore, it is necessary to understand, together with the archaeologists, the settlement criteria for a certain area during the various cultural phases. Generally speaking, each morphological unit (or morphotype) can be more or less suitable for settlements. Indeed, certain 'cultures' prefer wetlands, others favour flat areas, while others have a preference for topographic summits. Geomorphological surveying, therefore, must be based on a detailed definition of the morphological units of the current landscape and on the identification of their spatial position. Particular attention must be given to their extension in order to outline their limits with relative accuracy. Subsequently, with the help of stratigraphic data regarding the uppermost subsurface, the diachronic evolution of the forms must be characterised. A distinction must be made particularly for cases presenting:

- continuity, over time, of geomorphic processes, yet spatial variation of forms (e.g. river processes continue to prevail yet the position of the riverbeds changes);
- geomorphic processes that follow on from the previous due to climatic modifications and/or crustal dynamics (e.g. marshes transformed into lagoons due to coseismic subsidence);
- geomorphic processes that commence or end by human intervention throughout the territory (e.g. deforestation, reclamation, etc.).

Determination of the criteria for a geomorphological-based predictive definition must also take into account the limits of paleo-topographic reconstruction connected to the compacting of sediments and to subsidence, which tend to reduce the differences in height between the morphological units. It must also be different for each historical period and strictly relate to the archaeological data.

In archaeological terms, the following parameters will be taken into consideration for the predictive definition of the city throughout its historical periods:

- typology of finds, inferred on the basis of the interpretation of the archaeological records appropriately standardised in categories;
- quality and quantity of the archaeographic data;
- spatial relations between the finds, which allow identification in probabilistic terms of the presence of further finds in areas that have not been archaeologically investigated;

- typological relations between the finds, which allow identification in probabilistic terms of the presence of further finds in areas that have not been archaeologically investigated;
- expert judgment: the experience of experts will be a useful tool for determining the possible existence of archaeological remains since their statistic and mathematical evaluation will use knowledge which would otherwise be difficult to manage.
- land use: it is important to consider all anthropic traces – including traces that are not strictly connected to constructions or settlements, such as agricultural and/or farming practices – and to assign a different parametric value to them.
- historical data from written sources and maps, thanks to which it is possible to reconstruct the city environment, both in the presence and (especially) absence of archaeological records.

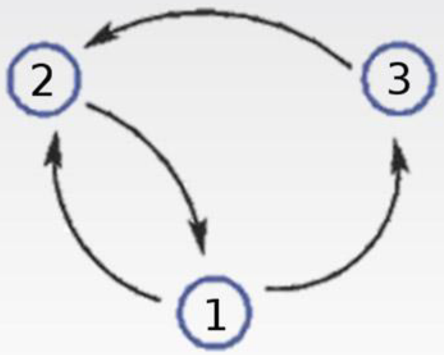
The final phase of analysis focused on defining the overall parameters that best determine urban archaeological potential and are based on a period predictive model. The following parameters were identified:

- type of settlement: the presence of settlement structures and their different typology directly contribute to determining the level of archaeological potential;
- density of settlement: the topographic concentration of the settlement directly contributes to determining the level of archaeological potential;
- multi-layering of deposits: the greater or lesser archaeological diachrony directly influences the level of archaeological potential;
- removable or non-removable nature of the archaeological deposit: the presence of a deposit that cannot be removed has a direct impact on the level of archaeological potential;
- degree of preservation of the deposit: calculated according to the presence of anthropic and natural removals and, therefore, to the presence of documented stratigraphic gaps, it directly influences the level of archaeological potential;
- depth of the deposit: this is a controversial parameter and its use alongside the other parameters mentioned above will be evaluated during the course of the project. We are quite aware that this is a highly risky issue because it appears to be strictly related to the contingency aspects of the project execution and could be confused with the calculation of archaeological risk. Instead, the parameter that will be measured is related to whether the deposit is superficial or not and to the higher or lower possibilities of it being intercepted. The depth at which we expect an archaeological deposit to be preserved could represent a valid parameter within a decision-making tool. Consequently, the depth of the deposits could inversely have an impact on the level of archaeological potential (ANICHINI et al. 2011b).

The Page Rank model

The few examples of existing Maps of Archaeological Potential are based on the statistical analysis of known data from which predictive data on archaeological potential are inferred non-empirically and non-systematically. Highly advanced mathematical theories, which are mature enough to significantly contribute in areas commonly considered as falling outside their scope of application, have never been used or have been unjustifiably used so far in many research sectors (especially in the field of historical-archaeological studies). This is also due to the general difficulty of communication between experts belonging to different disciplinary areas and, consequently, to the scarce amount of inter-disciplinary research activities. One of the approaches used in literature (probably the simplest) to predict archaeological potential consists of a predictive model capable of generating a decision rule. The input needed to determine this rule may be, for instance, land configuration (plain/slope), the presence of nearby water sources or soil type. Variants to this approach may include assigning 'weights' to the different conditions, so that more importance is given to some conditions and less to others. At the same time, significance tests may be used to evaluate whether the proposed predictive model may be associated to the presence of archaeological sites within a certain confidence intervale (CUMMING 1997; WHEATLEY and GILLINGS 2002). Models based on these rules are very easy to implement; however, they provide on/off results – for example, the presence or absence of an archaeological site – and do not go further than simply juxtaposing a number of easy rules. In other words, they do not exploit the power of a mathematical model or the computing capabilities of a computer. Literature also provides another approach for determining archaeological potential (WHEATLEY and GILLINGS 2002), based on the application of linear (or logistic) regression. This approach arises from the need to reply to questions that the above-described method cannot answer. For instance:

► How can a predictor influence the model?
► How can *continuous* quantities instead of discrete quantities be predicted?



$$\begin{cases} w_1 = w_2 \\ w_2 = 1/2w_1 + w_3 \\ w_3 = 1/2w_1 \end{cases}$$

Fig. 7 – Page rank at work…(copyright MappaProject –Università di Pisa).

Linear regression can be used to answer these questions, and is an easy approach, both in terms of its implementation and from a mathematical viewpoint. Several variants may also be introduced in the re-gressive models (single or multiple regressions, non-linear regressions, statistical regressions, etc.) (SHENNAN 1997; WESCOTT and BRANDON 2000). Although the approaches based on linear regression have the benefit of using variables to predict further variables, the model they implement is too simple and does not take into account the great complexity that must be considered when determining archaeological potential.

Based on the discussions between the mathematical team and the archaeological and geological teams, an analogy arose between the criteria used for attributing archaeological potential and the criteria used for assigning importance to web pages in search engine algorithms. When determining archaeological potential, geo-morphological and archaeological data are first integrated with an interpretation process in order to assign groups and then – through analytical work – to creata the different maps of archaeological potential for historical period. Finally, the different historical periods are 'overlapped' to reach the final result. The interpretation process of the context consists in achieving a stratigraphic categorisation from a series of archaeological and geological data, based upon the spatial and functional relations among the various finds. This process becomes further evident when determining the groups, and also with the construction of the map of potential by archaeological period. The key issue of this analysis from an abstract viewpoint is the identification of the relations that exist among the various finds, both in spatial terms and in functional terms. In other words, the presence of a particular find near another that has already been discovered could *strengthen or weaken* the probability that they will form a more complex structure, and so strengthen or weaken the archaeological potential of the area itself. This is exactly the criteria upon which page ranking algorithms are based, whereby each web page attributes importance to the web pages it points to (via a link) and, in turn, receives importance from the web pages it receives a link from. A page that has a link to other pages, distributes its importance in equal parts to the other pages and therefore gives part 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 40 billion): the result of this system of equations, after it has been solved, is the importance of each single page. 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. 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 to the others on the basis of a 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 carried 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 (BINI et al. 2011; BINI et al. 2012).

Dissemination: MAPPAgis and the open digital archaeological archive (MOD)

All data spatial data included in MAPPA Data Model will be published through a web GIS called MAPPAgis. The first release is now (June 2012) online (http://mappaproject.arch.unipi.it/?page_id=452&lang=en). Currently, it's possible to navigate the archaeological intervention layer and the aerial photography layer.

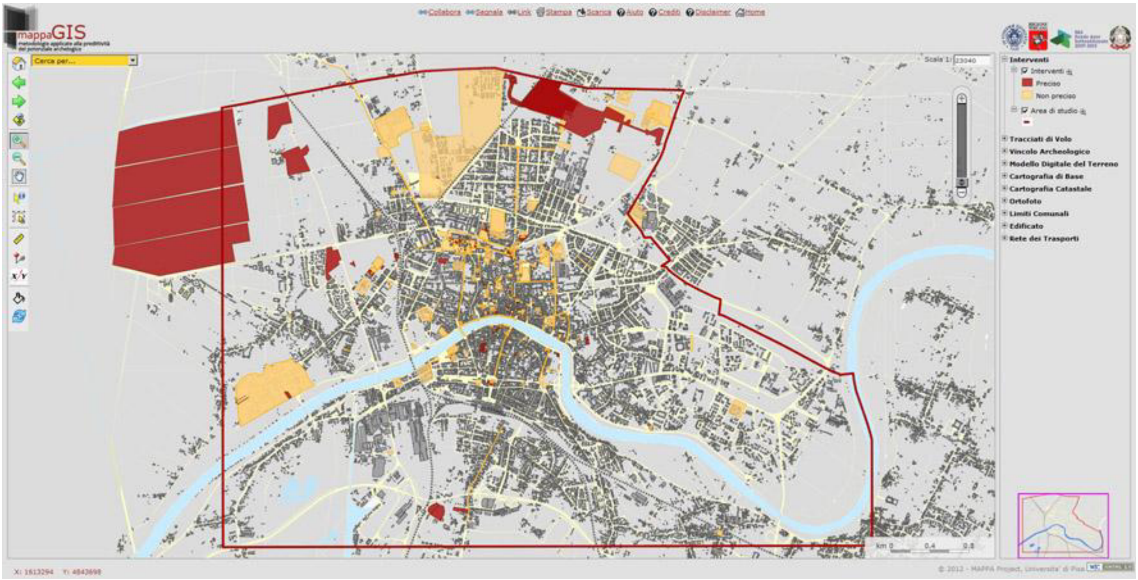


Fig. 8 – The MAPPA project web GIS (copyright MappaProject –Università di Pisa).

The archaeological data will be also disseminated as open data through Mappa Open Data (MOD) an archeological open data archive that will be introduce on June 9, 2012 at the Opening the Past Conference (http://mappaproject.arch.unipi.it/?page_id=1258&lang=en). There are currently no existing open digital archives in Italy: the greatest problem lies in making the archaeological community accept such a revolutionary instrument, which is often more intent on protecting data for future publications. Furthermore, complete research on archaeological documentation is missing in Italy: although the methodological and procedural debates were definitely closed at the start of the 1990s, technical and IT progress, alongside the growth of professional archaeology, make them highly relevant. The increasingly varied archaeological community in Italy, which includes government agencies, research institutions and professional archaeologists, makes this issue an ever more urgent matter. Indeed, archaeographic data must be created by a plurality of subjects that must actively take part in the creation of good practices and standards for collecting archaeological data. Such standards represent the professional consent to common practices and are of use when checking the compliance of working and/or organisational processes within a professional community, at least on a national scale. Data sharing depends on standards (GATTIGLIA 2009). The open digital archive intends delivering bottom-up initiatives that will involve the entire archaeological community, forcing it to change habits and to impose necessary standards. The open digital archive goes hand in hand with data publication and the protection of the individuals who have collected the data. Archaeography is a research activity, consequently sharing the raw data will be considered a scientific publication, through the use of specific copyright/copyleft licences (CC BY). Finally sharing means being able to analyse the data and generate new archaeological interpretations, allowing research to grow with a collaborative approach.

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