10.20378/irb-56109

Interaction Design for Stratigraphic Analysis in Archaeology

Barbara Rita Barricelli, Stefano Valtolina
Department of Computer Science
Università degli Studi di Milano
Via Comelico 39/41, 20135 Milano, Italy
{barricelli, valtolin} @ di.unimi.it}

Abstract. Stratigraphic analysis, as defined my Harris in his Matrix approach, constitutes one of the most diffused analysis methods in archaeology. After a long collaboration with Archaeologists and other domain experts, we developed a second version of ArchMatrix, a system for graph-based interaction with excavation data. This system aims at solving the challenges that affect the archaeological practice given by its peculiar distributed environment. This position paper presents an overview of the research domain, the ArchMatrix system and the results of the preliminary usability tests with the end users.

1 Introduction

Archaeology is the study of human history by means of the analysis of signs left by mankind in the world. Everything that is buried underground tells us a story about how the human presence evolved over time. Archaeological excavations allow not only to find artefacts but also to understand different historical phases that succeeded in history leaving traces that can be studied through stratigraphic analysis. There are many common points between geology and archaeology because they both study the transformations of the soil during the years by observing the stratigraphies, i.e. by analyzing the sequence of soil layers. Such layers are originated by erosion and backlog phenomena that correspond respectively to creation and destruction of soil that have led to radical transformations of the environment. In geology, the various sequences of layers can be sorted in chronological order according to their vertical underground position: a layer lies on another more ancient layer and its rocks can be dated by analyzing them and assigning them to specific historical periods. Archaeology deals with stratigraphic analysis in a slightly different way: there is no analysis of rocks but of the different components, called stratigraphic units that can have human or natural origins. Such stratigraphic units can be seen as “positive”, if they are related to backlog activity (e.g., pavements, walls) or “negative” if they are originated by a destruction activity (e.g. excavations). The analysis of the relationships that

exist between the various units constitutes what is the archaeological stratigraphic analysis that was formalized by Edward C. Harris [1]. The archaeological domain is characterized by strong social and organizational factors and the successful development of our research in this area proves once more the validity of the Human Work Interaction Design framework [7] that strongly relies on the influence of environment and context on interaction in working places.

This paper presents the evolution of a research and design work performed in the last 3 years that we published in its early stage of development in [4]. We designed and developed ArchMatrix, an interactive system aimed at supporting archaeologists in archiving, managing and studying the findings collected during archaeological excavations. The design of the system followed a participatory action design research [6] and was based on a first prototype developed with technologies and languages that are today obsolete. The new system offers better performances and according to the results of the evaluations, solves all the issues highlighted during the evaluation of the first prototype.

2 Challenges in Interaction Design for Archaeological Practice

The process followed by archaeologists on excavation sites is made of seven main steps:

1) Detection of the most recent stratigraphic unit, that is the one that covers all the others and that is not covered by any other units.
2) Definition of the limits of the most recent stratigraphic unit and of its (physical) relationships with other units. This is one of the most important phases of excavation and is strictly related with the personal and subjective evaluation made by the archaeologists. This task needs to be done in a highly controlled environment to preserve its integrity and to avoid external contaminations.
3) Written, photographic, and graphical documentations of the characteristics of the soil before its exploration. Keeping track of the original status and successive modifications of the environment allows the archaeologists to analyse their findings even later their discovery and to preserve information about their original conditions.
4) Choice of the most suitable tools to be used during the exploration of the stratigraphic units to be removed. Large machines or small tools can be used.

5) The actual excavation of the soil.
6) Documentation of everything that has been detected, excavated, discovered. It is a highly challenging task because it needs a very deep precision by the archaeologists and everything that will be inserted in the post-excavation documentation will be used to interpret the findings and its quality will deeply influence the final results. The post-excavation documentation has to be focused on both vertical and horizontal plane of excavation.
7) Analysis of the collected data. Once the excavation site and its documentation are complete, this will be stored in a safe place and everything that has been found will be "indexed" by the documentation referring to the stratigraphic unit that it belonged to.

What makes this application domain very challenging is its distributed nature: many different tasks are performed in different places, by numerous teams of researchers and archaeologists and very often in multidisciplinary contexts involving experts in different domains (e.g., chemistry, geology, and historian). Moreover, excavation sites offer an uncomfortable work environment, most of the time very dusty and in some seasons and locations very sunny and hot. These specific environmental characteristics affect the use of mobile devices, especially for what concerns the visibility and legibility of screens. In the last years, we studied the archaeologists practice on the excavation sites to find out how to address the open problems and how to design the most suitable interaction and user experience for such a peculiar work environment.

In particular, we explored the graph metaphor as a visual strategy for enabling a fast and effective interaction. In archaeology, graph visualization systems have to face the problem of facilitating the exploration and analysis of a vast amount of data by means of visual methods and tools able to support needs of a wide array of different research communities involved in the study of an excavation such as archaeologists, architects, geologists, chemists, and biologists.

Information visualization strategies are applied in archaeology for assisting domain experts in the examination and interpretation of the stratigraphy of excavation sites, and identifying both natural and cultural strata. During the excavation of an archaeological site, when a stratigraphic unit is detected, the archaeologists fill in a proper form to keep track of its properties and the relationships among the unit and other units are made explicit. Three types of relationship could exist: active, passive, and neutral. Active relationships are a) covers, b) fills, c) leans, and d) cuts; passive relationships are a) is covered, b) is filled, c) relies on, d) is cut; neutral relationships are a) is equal to, and b)

binds. Once all the properties and relationships' data are collected in the form, the archaeologists represent the stratigraphic unit in a drawing on paper that will be used in successive data analysis. At the end of the excavation campaign, all this material is collected and studied for creating the correspondent Harris Matrix. The resultant Harris Matrix enables the archaeologists to determine the chronology of the various units (an example is shown in Figure 1). The rectangles represent the stratigraphic units, while lines are used to indicate the existing relationships among them (e.g. "copre" means "covers", "taglia" means "cuts", "riempie" means "fills"). After the drawing is complete, the archaeologists determine the historical age to which the stratigraphic units belong to. The Harris Matrix gives information about the temporal collocation of the units, while the analysis of the materials found in the unit allows to retrieve exact dates. The next activity is the detection of the overlays, i.e. logical levels that are constituted by the stratigraphic units that belong to the same historical period.

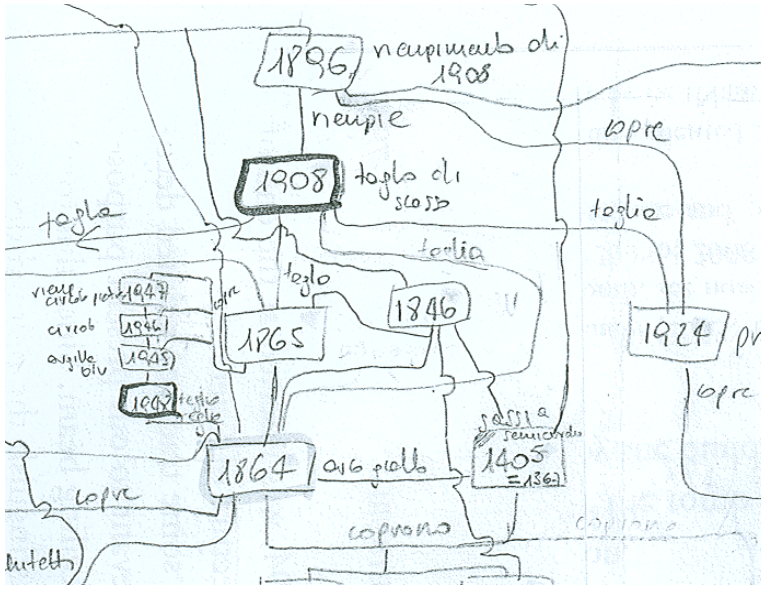

Figure 9. A section of a Harris Matrix diagram.

This work is usually done using paper-based documents, and the more the data grows, the more the consultation becomes challenging. Moreover, the more stratigraphic units are added, the more the Harris Matrix to be drawn becomes big and becomes extremely complicated to be modified and extended. Given these difficulties, the main disadvantages that arise from the use of a non-digital approach is the impossibility of properly diffuse the knowledge that is gathered through the archaeologists' activity performed on the field, the difficult of keeping the Harris Matrix documents up to date. In fact, to give permissions to modify the Matrix to more than one person is not

so simple, and new problems arise when many people have access and modification permission to the same resource. Visual interactive systems represent therefore the best choice to support archaeologists' activities and collaboration.

3 ArchMatrix Visual Interactive System

In 2012 we designed a visualization system named ArchMatrix with the collaboration of a team of archaeologists that was involved through the application of participatory design's principles. A set of evaluations on the system highlighted the presence of several usability problems that needed to be solved and its use in time pointed out the need of some changes to enable collaboration between the members of the teams.

Given the technological advancements happened in the last years and an evolution of the archaeologists and the other stakeholders in the management of data through a graph-based interaction, we decided to redesign the system by involving the experts again and to redevelop the system by using the most recent technologies and languages. A screenshot of one of the principal view of the ArchMatrix system is depicted in Figure 2.

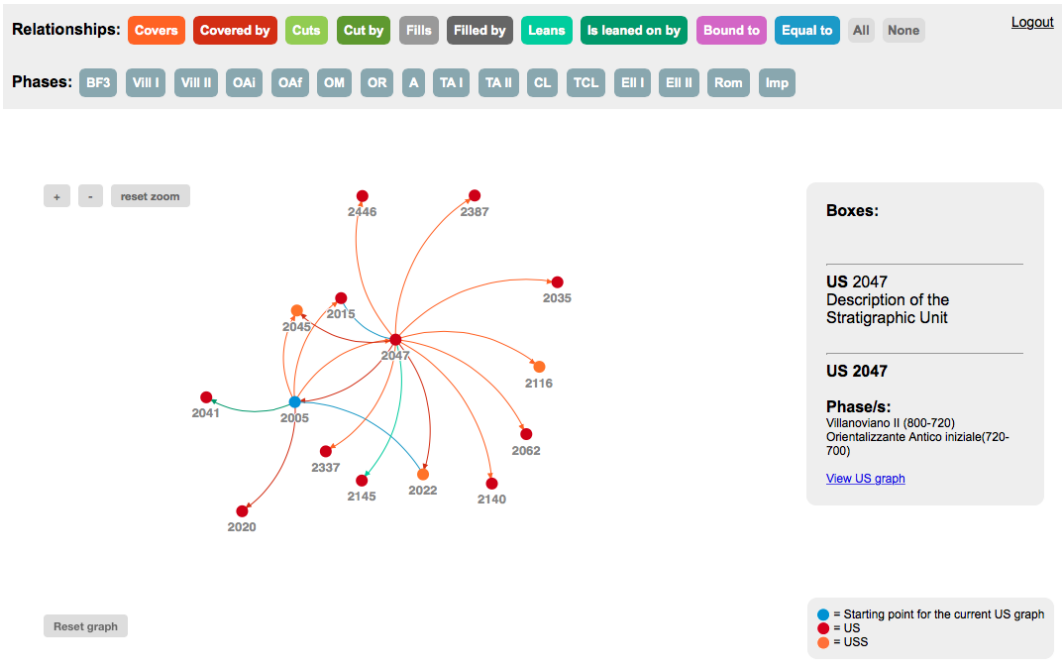

Figure 2. Harris Matrix visualization in the ArchMatrix system. The relationships of a selected stratigraphic unit are shown by means of a graph-based metaphor.

This new version of ArchMatrix allows its users to perform specific queries on the stratigraphic units data and to discover and analyse relationships

between them. An important feature that completes the digitalization of the Harris Matrix traditional method is the possibility of classifying the stratigraphic units according to specific time period. This allows the archaeologists to discuss with the other members of the team about the provenance and dating of findings.

It is through the discussion feature, implemented as an annotation tool, that ArchMatrix becomes a system for supporting collaborative analysis of archaeological excavation sites and related findings.

The graph-based interface gives the opportunity to update the information related to the stratigraphic units without having to deal with databases and complex textual interfaces.

From a technical point of view the graph provides researchers with a visual representation of the stratigraphic units highlighting geometric, topological and temporal relationships. Stratigraphic units are necessary to detect the relative chronological sequence of the entire excavation site but they also produce a number of supplemental data that are not included in the classic tool used for stratigraphic visualization. To support the complex and interdisciplinary decision-making activity at the base of the archaeologists' work, ArchMatrix can be used for visualizing and handling graphs through which researchers can define queries and algorithms able to explore stratigraphic units and the knowledge retrievable from excavation database or other knowledge sources such as data from geographical systems. This solution allows archaeologists to develop new opportunities for their investigation (both individual and collaborative), to increase their knowledge, to improve their traditional working practices and to develop new ones.

4 Evaluation

As a first preliminary evaluation we performed a usability user test followed by a questionnaire (SUS [2] and CSUQ [3] standards). The 4 participants were experts in the application of the Harris Matrix method and demonstrated to be able to use the system in a quite easy way. SUS questionnaire result was 83/100, while CSUQ reported a 4/5 on all the metrics (use of the system, quality of information, quality of interaction, and overall evaluation).

We tried to investigate about the problems that were highlighted during the evaluation of the first prototype of ArchMatrix and we noticed that in this second version all of them have been successfully solved. The problems that affected the first prototype were mainly related to navigation. In this version, the quality of the navigation approach has improved and the users demonstrated that is quite easy and fast to find all the information in this new

prototype. The annotation tool that allows to keep track of the motivations of changes made by the users has been very positively received and responds to the comments and requests gathered during the evaluation of the first prototype. An interesting outcome from the final unstructured interviews done in this evaluation, is that the archaeologists do not appreciate to see the term "graph" used in the system, even if they perfectly know that the visual structured used for the US/USS representation is in fact a graph: they find it confusing to use the term "graph" and the term "(Harris-)matrix" to intend the same thing.

The system is currently under testing by the archaeologists and we are collecting feedbacks and analysing research results (in terms of both qualitative and quantitative data). Only a long-time use in practice will point out any possible problems with the system.

5 Further works

Further studies aim at exploiting the ArchMatrix to support domain experts in defining simulations based on 3D reconstructions of archaeological evidence that no longer exists according to probabilistic hypotheses and inferred interpretations. By exploiting data of repositories containing 3D models of archaeological fragments and by integrating them with the representation of the stratigraphic units offered by ArchMatrix, this new service will provide a sophisticated recommendation system (RS) able to support researchers to carry out hypotheses simulations of 3D reconstructions. Traditional RS such as: Collaborative Filtering Systems, Content-Based Systems, and Hybrid Recommendation Systems [5], can be used for designing a dynamic support in terms of recommendation strategies that combine metadata representation of the distributed archaeological evidences, the domain experts' expectations, wishes and competences.

Specifically, this service will enable hypotheses simulations starting from analyses of 3D fragments and models collected according to similarity relationships about their semantics, context of provenance, chronology, geometrical compatibility or other metadata. A distinguishing recommendation approach that will be used concerns the use of learning algorithms to identify relations between the features of the integrated contents that may prove, as well as indications suitable to the inquirer. Thanks to the massive use of metadata, the archaeological simulation may be homogeneously identified through a vector of parameters (the metadata representation). In addition, thanks to the feedback of the previous users, a score can be associated with each composition of vectors in simulations. This

enables a dynamical decision tree procedure where, according to the current choice of the user, the service will propose branches of decision trees that may lead to satisfactory completion of the simulation, possibly listed in a monotone ranking. The results of this activity will be the creation of virtual reconstructions of original archaeological objects defined according to probabilistic hypotheses depending on the features of the combined fragments (e.g. chemical composition, chronology, semantics) and the comparison with other 3D models coming from different contexts.

Acknowledgements

The authors wish to thank the Archaeologists and other experts who collaborated with us in the design and evaluation of ArchMatrix and Alberto Faleschini for his work during his Master Degree Thesis.

References

[1] Harris, E. C. 1979. Principles of Archaeological Stratigraphy. Academic Press, New York, NY.

[2] Brooke, J. 1996. SUS: a "quick and dirty" usability scale. In *Usability Evaluation in Industry*, P. W. Jordan, B. Thomas, B. A. Weerdmeester, and A. L. McClelland, Eds. Taylor and Francis, London, UK, 189-194.

[3] Lewis, J. R. 1993. *IBM Computer Usability Satisfaction Questionnaires: Psychometric Evaluation and Instructions for Use*. Technical Report 54.786. IBM.

[4] Barricelli, B.R., Valtolina, S., Marzullo, M. (2012). ArchMatrix: A Visual Interactive System for Graph-based Knowledge Exploration in Archaeology. Proc. AVI 2012 (pp. 681-684), ACM Press.

[5] Ricci F., Rokach, L., Shapira, B. Introduction to Recommender Systems Handbook, Recommender Systems Handbook, Springer, 2011, pp. 1-35

[6] Bilandzic, M., Venable, J. (2011) Towards participatory action design research: adapting action re-search and design science research methods for urban informatics. Journal of Community In-formatics 7(3).

[7] Orngreen, R., Pejtersen, A.M., Clemmensen, T. (2008) Themes in Human Work Interaction Design. In: IFIP International Federation for Information Processing, Volume 272, pp. 33-46.