Conception of an Integrated System for Archaeological Excavations

Michel Fortin[1] and Bernard Lachance[2]

[1]Département d'histoire
Université Laval
Québec, Canada
[2]Centre de Recherche en Géomatique
Université Laval
Québec, Canada
Michel.Fortin@hst.ulaval.ca

Abstract

A review of the literature on the archaeological excavation process led us to realize that this process has never really been formalized. The main consequence of this situation is the lack of coherence and integrity of the data collected in the field by different actors. It represents a major challenge to a thorough and efficient analysis of all those data coming from multiple sources. Starting from there, a project was designed; it is subsidized by GEOIDE Canada and involves seven researchers coming from various Canadian universities. The objective of the project is to build an Integrated System for Archaeological Excavation (ISAE) that will allow field archaeologists to perform multi-criteria analyses from a spatial and temporal database. The development of this system can be exploded in five phases: Abstraction, Acquisition, Assemblage, Display, and Analysis. After a theoretical presentation of the system as a whole, the state of development of practical and operational functions of the system will be shown.

1 Introduction

From an epistemological point of view, one must admit that "excavation recording has never been formally standardized" (Lock 2003:79) even though excavation constitutes the methodological process at the very base of archaeology as it aims to acquire data in the field, which is so essential to all original archaeological research projects. Not only does the recording of data from a site still pose problems even after several decades of digging (Chapman 1986), but problems also exist related to ways to recover (Roskams 2000, 2001; Warburton 2003) and, consequently, to analyze data from so many different methods (Carver 2004). The whole excavation process, from data recording in the field to data analysis afterwards, especially with regard to provenance, has to be revised, in our mind, and redesigned following a heuristic approach since, among other observations, any data analysis is conditioned by the recording system originally used.

First, data collection on archaeological excavations necessitates the aid of data acquisition techniques adapted to a comprehensive recording and processing system. Second, and ideally, the processing system has to be linked to a sophisticated analytical system that would give field archaeologists the opportunity to take into account, in their analyses, the spatiotemporal contexts of the data—that is, their chronostratigraphic positions within the excavated site.

In this sort of "*chaîne opératoire*," such an analytical process of the data coming out of archaeological excavations is probably the one that poses the biggest challenge to formalization because, on one hand, it is still done intuitively by most excavators—to their satisfaction—and, on the other hand, it is always performed after the completion of excavations. In our opinion, it would be preferable to be able to proceed to a comprehensive analysis of the data while they are collected, which is in the very course of the excavation. This data analysis would undoubtedly lead to the discovery of new knowledge (knowledge discovery) about the site, which could then guide field archaeologists in the pursuit of their excavations. Such an iteration process between recording and analyzing of data could be repeated several times during excavations and would certainly contribute positively to the determination of the course to follow in order to achieve better results in the field.

With recent developments in new information technologies, some archaeologists thought they had found solutions to their data recording problems by making use of a Geographic Information Systems (GIS). Those systems can, indeed, record, up-date, process, analyze, and eventually display in various environments all types of observed phenomena with the help of spatial attributes (Kennedy 2001). Yet, to date, GISs have been used more often in archaeology for surveys, i.e., before excavations (Gillings et al. 1999), or for cultural resource management, i.e., after excavations (Berger et al. 2005; Mehrer and Wescott 2006); they have rarely been employed during archaeological excavations (Wheatley and Gillings 2002:235).

Limitations specific to GIS software restrict their use during archaeological excavations. "Taken together these limitations have served to greatly inhibit the broader application of GIS within the intra-site context" (Wheatley and Gillings 2002:236). These limitations can be summarized as follows.

1. GIS belongs to the transactional type of software (Bédard et al. 2001:65). The transactional approach refers to an exploitation system orientated toward the recording, updating, and integration of data. To accomplish these goals, some compromises are necessary, one of which is to reduce the redundancy of

data, which results in a system less optimized for analysis and decision making.

2. GIS tends to process only two-dimensional (2D) data. Several systems allow three-dimensional (3D) visualization, but very few analytical functions are available. Contrary to a wide-spread, popular belief, GIS cannot process real 3D volumetric objects. Thus, it is nearly impossible for a GIS to perform tasks related to topological or metric spatial analyses, which we consider as essential in an archaeological field situation (Pouliot et al. 2006).
3. GIS can, with difficulty, manage the evolution and temporal aspect of the data, which could be a drawback for applications in archaeology.

From our point of view, to understand properly their discoveries in the field, archaeologists should turn to an analytical system that would allow them to process their spatiotemporal data in 3D. Here, we put forward the idea of setting up a system that will formalize the whole excavation process and lead to a robust analytical system that could be used even during excavations. This system has been tested on excavations directed by Fortin (2006) in Syria.

2 The Excavation Process Formalization

Inspired by the five-step approach followed by some experts in geomatic sciences (Denègre and Salgé 1996; Longley et al. 2001) in the development of information systems, we have identified five major tasks to undertake in order to create an integrated field recording and analytical system designed specifically for archaeological excavations.

1. Abstraction: conceptualization of the whole system, from the beginning to the end, and formal description of the (archaeological) phenomena or categories of data considered relevant to the system by potential users.
2. Acquisition: descriptive (entry forms and photos) and spatial recording (measurements and drawings) of the phenomena mentioned above.
3. Assemblage: gathering and putting together acquired data in a comprehensive manner and in a form that can be easily queried.
4. Displaying: visualization (on a screen) of phenomena reconstituted from the recorded data properly assembled.
5. Analysis: data query, treatment, and utilization to enhance the understanding of the phenomena.

This sequence of tasks or steps can be followed in the order presented—for instance, before acquiring data, phenomena to be studied have to be identified (abstraction)—but several feedbacks are possible, even recommended. Thus, during the analysis it is possible that the data assemblage does not permit certain types of queries; it is necessary, then, to revise the data assemblage accordingly, making sure, in the process, that the conceptual model reflects this revision. Because of the peculiar nature of field archaeology, this interaction is to remain feasible all the time since it is almost impossible to anticipate all types of queries made by archaeologists in the production of their excavation reports or in their observations in the field.

2.1 Abstraction

Abstraction refers to the definition and formal description of archaeological phenomena being discovered in the course of an excavation as well as multiple tasks involved in the excavation process itself. To go from reality, that is the excavation, to its numerical representation, a basic component of our analytical system, different abstract models can be used since different phenomena can be considered as relevant to our analysis. Therefore, there are as many models as there are perceptions of this reality, any one as valid as the others.

Abstraction is expressed graphically by various sets of diagrams representing:

- actors who perform actions during excavations;
- processes followed by these actors to realize their actions, and
- data collected, compiled, and analyzed in the course of these processes.

To create the abstract model of the system we would like to develop, and the diagrams that would represent its multiple components, we relied on the standardized graphical notation of the Unified Modelling Language (UML) (Scott 2001), which has become the international standard (ISO/IEC 19501:2005) in Information Technology (IT). For example, the conceptual data model (CDM) (Figure 1) is a diagram that permits us to show graphically phenomena to study, and to define properties of these phenomena as well as their relationships. The CDM helps us to make sure all the data needed for our analysis will be collected and, thus, to optimize the interpretation for all discoveries, not just the most significant ones.

The CDM put forward here is organized around the concept of "excavation unit" (EU) which can be labeled differently depending on the cultural area where excavations are undertaken: lot, locus, stratigraphic context, and stratigraphic unit. The term "excavation unit" has been selected from among several because it appeared to us more generic

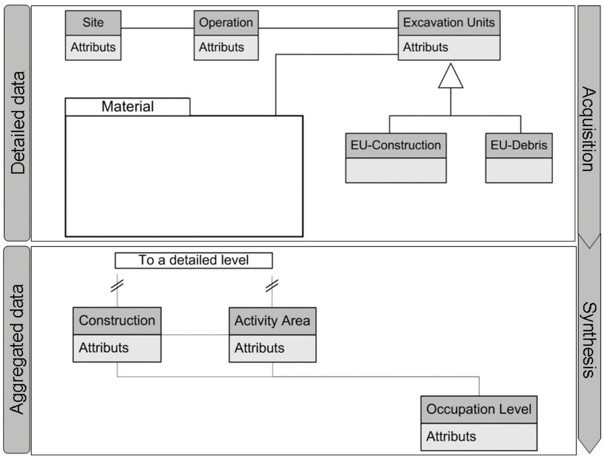

Figure 1. Schematic diagram of the Conceptual Data Model suggested for the data management of archaeological excavations.

and universal. An EU represents a volume of archaeological earth/debris which has been taken out of an excavated area, or building materials accumulated on the site being excavated and which will be eventually removed in order to dig up levels beneath. We distinguish two main classes of EU: excavation unit "debris" and excavation unit "construction."[1] "Debris" consists of a volume of excavated material that is defined by attributes about the soil matrix (color and consistency, for instance) and inclusions (mostly mineral) contained within it. "Construction" designates a loose or structured concentration of building materials that were obviously part of some construction elements in the past. This type of unit is usually kept *in situ* for a certain period of time before being removed or dismantled carefully; its descriptive attributes are the same ones as would describe a constructed feature.

Various elements of the archaeological material culture, in other words artifacts, either complete or fragmentary, retrieved from within a volume of debris or of a construction element are recorded, in our model, in an inventory/catalogue directly related to the EU class, either "debris" or "construction."

Data collected, described, and classified are afterwards aggregated. Thus, for instance, construction elements are put together in order to reconstruct original constructions, and in relating those to debris which surrounded them at the time of their discovery, it becomes feasible to reconstitutes activity areas and/or occupational levels. To achieve this aim, parameters ruling the structuring relations between different data classes have to be determined from the very conceptualization of the model. In other words, these parameters allow a user to go from the detailed data to the aggregated ones.

2.2 Acquisition

Data acquisition implies, in our system, a series of field procedures leading to the recording of excavated phenomena identified in the previous step—that is EUs (debris/construction). Data associated with EUs falls into two main categories: geometric and descriptive data. Geometric data are about the position, the shape, and the size of EU. This includes all sorts of measurements taken on EUs delineated in the field. It comprises also the type of spatial relationship an EU has with the surrounding ones, often referred to as the topological relationships (touches, intersects, contains, etc.). Descriptive data refer to a set of thematic properties to EUs such as the soil color, soil texture, inclusions within the soil matrix, and the interfaces of a unit with the units around it.

As mentioned in our introduction, the 3D representation of EU is an important component of our data acquisition system. To acquire data in a quicker and more appropriate way in view of their subsequent 3D modeling (see section 2.3, below), we located the X, Y and Z coordinates of several positions on the upper and lower surfaces of EU volumes with a RTK GPS instrument accurate to the centimeter. A total station could have accomplished the same task but it would have taken longer and necessitated a further treatment of the positions for the 3D modeling. Members of our team are also exploring the possibility of testing a laser scanner to record geometric attributes of "excavation units" (Marchand et al. 2006).

Descriptive data were noted directly in the field with the aid of a toughbook-type portable computer and recorded in a relational database. Having first experimented the INFRA system developed by Schloen (2001), we realized that we had to develop our own database. In order to facilitate the use of this database, specific software has been developed with Visual Basic.net linked to a SQL Server database.

The management of this database posed problem since we wanted to be able to modify classes, relationships, and value ranges in real-time. For that purpose, we use a database that stores only metadata. This database contains all information related to all instantiated classes. With this type of structure, it will be possible to modify the model in real-time. However, these functions have to be used with precaution since they can affect the data integrity and the analytical capacities afterwards. For instance, if in the course of excavations archaeologists decide to change terminology to record soil texture, it will be difficult, during the analysis, to link up with the former terminology. The flexibility of an adaptable model must be used advisedly. It would have been simpler to develop a static model but it would not have been compatible, as we wanted to use data from different cultural areas and also from contexts others than excavations, i.e., surveys prior to excavations. This software has been developed from the very beginning with the idea that it could to be used in conjunction with different abstract models.

In spite of the use of computers in the field, it must be understood that this will not reduce archaeologists' amount of "paperwork," so to speak. As previously, they will continue to record descriptive data, except that instead of writing them up on paper forms, they will record them in a numerical format. They will also continue to make sure that all data pertinent to excavation units have been fully recorded and that they correspond to reality. Nonetheless, the use of such a database could ease and speed their work. Indeed, the software we are developing will be an ideal tool to assure that recording rules are respected by all actors on a specific excavation. Thus, for several attributes selected to describe archaeological phenomena, the software will offer scrolling lists of descriptive terms, or values. Only preset values, envisioned in our conceptual data model and registered into our dictionary inserted into our software, can be recorded, which guarantees the data integrity necessary to achieve coherent results when querying the database later. This step is thus crucial for a refined data analysis at the end of the whole process.

Meanwhile, in order to smoothly bring field archaeologists to grips with the planned recording system, members of our team are developing a sort of "transitional" tool: a tablet PC on which users in the field could sketch EUs and write freestyle notes, as they are used to, in relation to these sketches; eventually, it should be possible to link the annotated sketches to the database mentioned above.

2.3 Assemblage

Although it may sound like an obvious thing to experienced field archaeologists, it does not seem superfluous to repeat here that when an archaeologist analyzes his data after excavations, his ultimate objective is to reconstruct the entire excavated site as it stood when it was originally occupied before it was destroyed or/and abandoned. Besides, each site has been occupied during a certain period of time and may have several successive phases of human occupation; therefore, an excavator may have numerous superposed occupational levels to reconstruct within a single site. For his superposed reconstitutions, an archaeologist has to rely on physical entities accumulated at a site that he has removed through excavations. He must, then, classify data (artifacts, constructions, and so on) according to their attribution to such or such an occupational level. Furthermore, within a specific level, he has also to try to differentiate activity areas from the data associated to this level.

To put archaeologists in a position to be able to accomplish these tasks within our system, we must first go through an assemblage step in the course of which data acquired in the field will be put together in such a logical and coherent manner as to permit displaying and analysis. It is important to note that the way chosen to assemble the data will have a direct influence on the comprehensiveness of the analysis to be performed afterwards. On one hand, geometric data will have to be gathered in order to represent adequately the full geometry of EU recorded on the site. On the other hand, descriptive data will have to be transformed in such a way as to be included in the analytical part of our system.

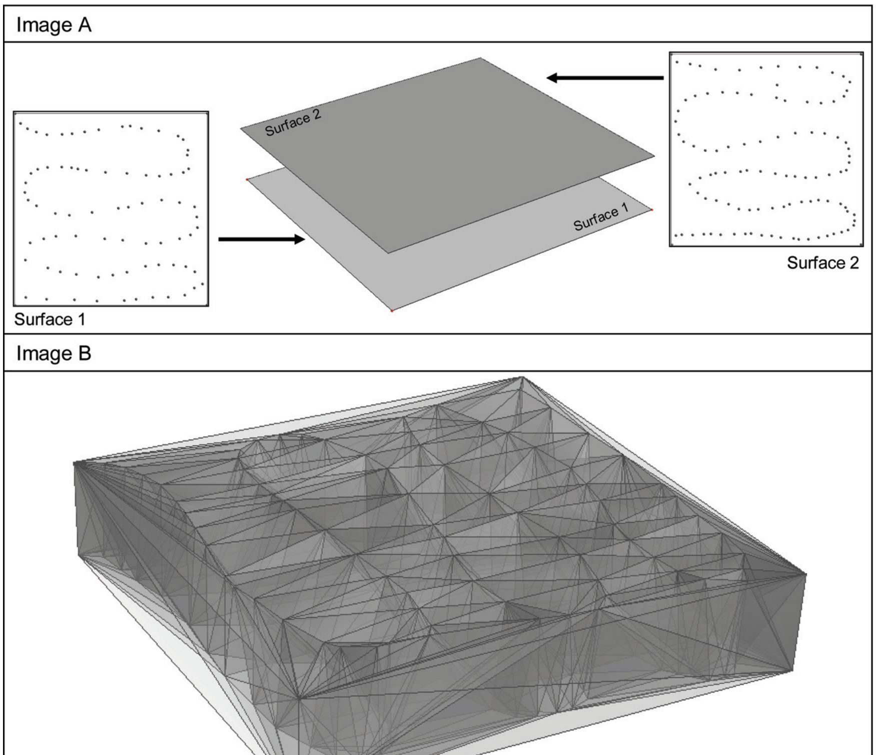

Figure 2. A) Points forming upper and lower surfaces of Excavation Unit 1. B) Tetrahedral modeling of Excavation Unit 1 with upper and lower surfaces.

In our case, the assemblage of geometric data consisted of gathering points taken with a Real-Time Kinematics (RTK) GPS in order to create well-defined entities: excavation units represented by volumetric objects that will be afterwards positioned in a 3D model of the whole site. First, points are assembled on excavation units upper and lower surfaces (Figure 2, image A). Second, these surfaces are put together to form volumetric objects (Figure 2, image B). This procedure has been realized (Losier et al. 2007) with the Gocad modeling software following an experimentation done in 2004 on the site of Tell ‘Acharneh, in Syria, the excavations of which are under the directorship of Fortin (2006). From such a volumetric object, it is possible to calculate, for instance, the whole volume or its superficies.

2.4 Descriptive Analysis (Assemblage)

In order to be able to assemble descriptive data with the aim of analyzing them, these data have to be denormalized first since they have been recorded following specifications proper to the relational database. Indeed, denormalization consists of modifying the way data are stored in the database to make them compatible with an analytical approach. The one we have in mind is inspired from On-Line Analytical Processing (OLAP) systems (Pedersen and Jensen 2001): recent works done at the Research Center in Geomatics at Laval University (Quebec city) have integrated the spatial component of the data analyzed, giving birth to Spatial On-Line Analytical Processing (SOLAP) systems (Rivest et al. 2001).

We chose this new analytical tool because it: 1) can combine descriptive and spatial (3D) analyses since EU positions are as important as their intrinsic description; 2) is easy to use: query formulation should not be a restriction to neophyte—with information technologies—user’s needs; and 3) provides quick answers—within seven seconds if we do not want to interrupt the user’s reflection, as has been demonstrated (Caron 1998).

To obtain good results, OLAP systems exploit multidimensional databases which, in contrast to relational databases, rely on the data redundancy in order to yield quick results of an analysis. Figure 3 shows the model of such a multidimensional database.

The database is entirely structured around a “facts table” to which secondary tables are added, each one representing a dimension—theme—according to which data could be analyzed. In the example given in Figure 3, the multidimensional model comprises a selection

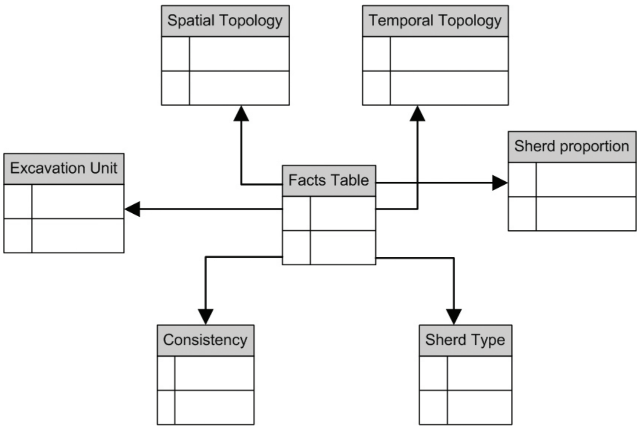

Figure 3. Example of a model associated with a multidimensional database.

of dimensions: type of sherds found in EU, granulometry and consistency of the soil matrix of the EU, identification number of these EUs, their spatial topology (touches, contains, etc.), and their temporal topology (before, at the same time, after). These constitute a set of different dimensions that a potential user could combine in the analysis of his/her data if he/she wanted to reply to a query such as: what are the EUs having a consistency X, a granulometry Y, and containing a type of sherds Z? To formulate the proper answer, the system would then call upon all the relevant dimensions: Excavation Units, Consistency, Granulometry, and Type of sherds.

Within each dimension, the system will retrieve the level of details for which the user is searching. This operation is done by the aggregation capacity of each table "dimension." The example in Figure 4 shows different aggregation levels for the dimension "consistency" of the soil matrix of an excavation unit. The term "consistency" is at the summit of the pyramid. One level below, there are five values that can qualify, generally speaking, the nature of this consistency: hard, soft, unknown, in course (of identification), and varied. Then, for each of those values, there are under-values. For instance, the consistency "hard" can be one of the following: very dense, moderately dense, or dense. Thus, in the given example, the dimension "consistency" possesses two levels of aggregation. It is this multiple-level aggregation that allows the system to navigate among the data from general to particular. By the way, it goes without saying that each descriptive term can be modified as to reflect the terminology preferred by the user.

In this context, translation rules from a relational database to a multidimensional one must be well pre-defined and, preferably, entirely automatic. This procedure is peculiar to our system since the multidimensional database is constantly in the heart of the iterative process during the data analysis. Indeed, in the course of the analysis, data recorded during excavations will be aggregated to give archaeologists a synthetic vision of the settlement which stood originally at the place of the site they have just destroyed through excavation. This reconstitution of original entities thus generates new data. For example, the aggregation of walls will create rooms; the entity "room" constitutes new data. Afterwards, archaeologists will obviously be inclined to aggregate those rooms to form a building or buildings. But to do that, newly created data—rooms—will have to be integrated into the multidimensional database since the system lies on the latter. To integrate new data to the database, a new assemblage is imperative (an iterative process).

The SOLAP system appears to us as an interesting one for the analytical part of the system we are in the process of designing. However, there is still more work to do in order to permit the extension of its analytical capacities to the third dimension and to be able to answer archaeologists' requests as formulated above. One master's thesis has been submitted recently at Laval University in search of solutions for the conception of a 3D SOLAP (Brisebois 2003), and another one is working to adapt such a SOLAP system to the context of archaeological excavations.

2.5 Spatial Analysis (Displaying)

In our system, displaying means visual representation—on the computer screen—of assembled data, either descriptive or spatial. Displaying results of a descriptive analysis is not as complicated as for a 3D spatial query, which cannot be done with any of the GIS software now on the market. Nonetheless, spatial analysis is crucial to archaeologists since it underlines the virtual reconstruction of an excavated site based on the use of spatial data.

In a way, displaying can be considered as a sort of

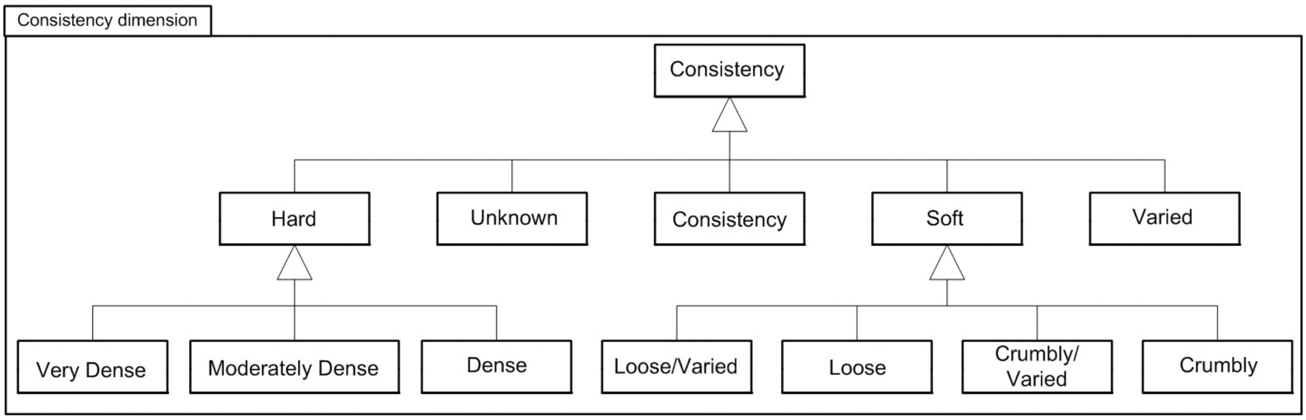

Figure 4. Hierarchical representation of the dimension "consistency."

qualitative analysis of the data since it permits the visual examination of the data from various view-angles. The visualization of EUs can certainly help archaeologists in their inference of topological relations between distinct phenomena discovered independently during excavations. If a more in-depth data examination is required, a quantitative analysis is then performed. We are particularly interested in spatial analysis because we believe it is an efficient method to discern phenomena's spatial features and to have a comprehensive understanding of them and their topological relationships.

As specified previously, for archaeologists the ultimate aim of the analysis of data extracted from an excavation is to reconstitute the type of human occupation/settlement that took place at the site (now destroyed). Thus, they have to aggregate data to be able to give them some meaning. To go back to the example above in which several walls were aggregated to form a room, one has also to attribute a function to the room. It is here that analytical tools provided by a SOLAP system become useful. With a multi-criteria query, archaeologists would know immediately all excavation units within the room as well as all inventories/catalogues of artifacts that were lying within the room and are clues to the inference of the room function.

The same type of topological, multi-criteria query could be applied to an entire stratigraphic layer of a site, as it is common knowledge that archaeologists use various clues to reconstitute all the modes of occupation represented by the stratified layers, which correspond to the chronological phases in the site occupation (Figure 5). This is, in fact, the origin of the term "chronostratigraphy" sometimes used to designate the stratified deposition of debris forming an archaeological site (Gasche and Tunca 1983; Gasche and Tunca 1984). But, at the moment, no commercial SOLAP or GIS software has the capability of performing such a quantitative topological analysis. Since information coming out of this kind of analysis is essential to the ultimate archaeologists' interpretations of their sites, we are aware that we must try to develop a specific tool for that purpose. The adaptation by one of the authors of a concept designed for geological contexts is envisioned as a promising solution to this problem (Lachance et al. 2006).

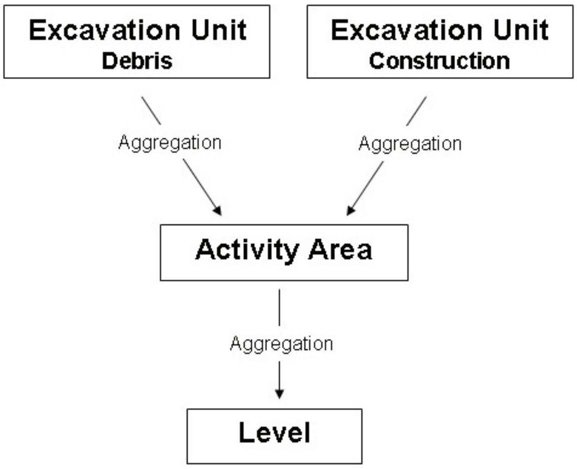

Figure 5. Data aggregation diagram.

3 Conclusion

The rethinking and redesigning of the excavation process described here, from the very acquisition and recording of the data in the field to their ultimate analysis afterwards, particularly with regard to stratigraphic position as well as their relationships to the other data, constitutes an ontological reflection on the field methodology at the origin of the entire corpus of data on which practitioners constantly base their research. Having modeled the excavation process in several of its aspects, we envision now to introduce, for fieldwork, information and geomatic technologies to improve data acquisition and, later in the process, new analytical tools that should not only permit a better understanding of the data in their topological relationships, but also to generate from the corpus of data contexts, phenomena that traditional analytical means would not bring to light.

This research project is still in progress: our objectives have not yet been reached. We have presented here a summary of the work done so far and, above all, a plan of the steps we would like to follow before this system can be considered operational by field archaeologists. Among several challenges we are facing at the moment are: improvement of 3D modeling techniques really adapted to archaeological excavations; development of the first real 3D SOLAP applied to field archaeology; setting up automated translation rules between a relational database and a multidimensional one in which will be stored data collected during excavations; and building up an infrastructure for data acquisition during excavations. The conceptualization of such an integrated system designed for archaeological excavations forced us to rethink and revise all aspects of the excavation process and to express them in an abstract model.

Endnotes

Since presenting this paper, we have decided, for clarification sake, to add into our system a third type of EU: those caused by natural phenomena. These units had originally been included, without discrimination, into our "debris" type of EU since the end results are the same whether they have been caused by human or natural phenomena. Therefore, in this article, bear in mind that EU-Debris include natural as well as man-made types of debris.

Acknowledgements

This research has been undertaken with the aid of two research grants. The first one from the Social Sciences and Humanities Research Council of Canada (SSHRC) with its program: Research Development Initiatives (RDI). This project was entitled "Development of a spatiotemporal knowledge discovery for archaeological excavations" and the research involved were all from Laval University (Quebec City) and members of the Research Center in Geomatics from this University: Michel Fortin, Jacynthe Pouliot, Yvan Bédard, and Marie-Christine Roy. The second one comes from GEOIDE, a Canadian network of Research

Centers of Excellence (RCE). The project “Geomatic technologies applied to the archaeological excavation process: from data acquisition to their contextual analysis” is pursued by the following researchers: Michel Fortin, Jacynthe Pouliot, Marie-Christine Roy, Stéphane Roche, and Sylvie Daniel (Université Laval, Quebec City), Tim Harrison (University of Toronto), Elisabeth Cooper (Université of British Columbia), and Songnian Li (Ryerson University in Toronto); Bernard Lachance is the employed research professional on this project. Both projects are directed by Michel Fortin.

References Cited

Bédard, Yvan, Merrett, T., Han, J. 2001. Fundamentals of spatial Data warehousing for geographic knowledge discovery. In, *Geographic Data Mining and Knowledge Discovery*. H. J. Miller and J. Han, eds., pp. 53-73. New York: Taylor & Francis.

Berger, J.-F., Bertoncello, F., Braemer, F. Davtian, G., and Gazenbeek, M., eds. 2005. *Temps et Espaces de l’Homme en Société Analyse et modèles spatiaux en archéologie*. Antibes: Editions APDCA.

Brisebois, Alexandre. 2003. Analyse du potentiel d’extension du concept SOLAP pour l’exploration des données spatiales tridimensionnelles. Mémoire de maîtrise, Département des sciences géomatiques, Université Laval.

Caron, P.Y. 1998. Étude du potentiel du OLAP pour supporter l’analyse spatio-temporelle. Mémoire de maîtrise, Département des Sciences Géomatiques, Université Laval, Québec, Canada.

Carver, Geoff, ed. 2004. *Digging in the Dirt. Excavation in a new millennium*. Oxord: BAR International Series 1256.

Chapman, Rupert L. 1986. Excavation techniques and recording systems: a theoretical study. *Palestine Exploration Quarterly* 118:5-26.

Denègre, J. and Salgé, F. 1996. *Les Systèmes d’Informations Ggéographiques*. Paris: Presses Universitaires de France.

Fortin, Michel, ed. 2006. *Tell ‘Acharneh 1998-2004*. Turnhout: Brepols.

Gasche, Hermann and Tunca, Öhnan. 1983. Guide to archaeostratigraphic classification and terminology: definitions and principles. *Journal of Field Archaeology* 10(3):325-335.

Gasche, Hermann, Tunca, Öhnan, eds. 1984. *Stratigraphica Archaeologica*. Ghent: A.C.T Workshop.

Gillings, Mark, Mattingly, D., van Dalen, J., eds. 1999. *Geographical Information Systems and Landscape Archaeology*. Oxford: Oxford Books.

Kennedy, H. 2001. *Dictionary of GIS Terminology*. Redlands: The ESRI Press.

Lock, Gary. 2003. *Using Computers in Archaeology. Towards Virtual Pasts*. New York: Routledge.

Lachance, Bernard, Bédard, Karine, Pouliot, Jacynthe, and Kirkwood, Donna. 2006. Design and Experiment of a Topological Structure Adapted to Tetrahedral Modeling. Paper presented at the 26th Gocad Meeting. Nancy (France), June 6-9.

Longley, P. A., Goodchild, M. F., Maguire, D. J., and Rhind, D. W. 2001. *Geographic Information Systems and Science*. Chichester: Wiley.

Losier, Louis-Martin, Pouliot, Jacynthe, Fortin, Michel. 2007. 3D geometrical modeling of excavation units at the archaeological site of Tell ‘Acharneh (Syria). *Journal of Archaeological Science* 34:272-288.

Marchand, Julien, Daniel, Sylvie, Pouliot, Jacynthe, Gauvin, Robert and Fortin, Michel. 2006. Potentiel d’un scanneur laser dans le cadre de fouilles archéologiques. Paper presented at the Symposium of the Montreal Branch of the Canadian Institute of Geomatics 2006. Montreal (Canada), October 25-26.

Mehrer, Mark W., Wescott, Konnie L. 2006. *GIS and Archaeological Site Location Modeling*. Boca Raton: Taylor and Francis.

Pedersen, Torben B. and Jensen, Christian S. 2001. Multidimensional database technology. *Computer* 34(12):40-46.

Pouliot, Jacynthe, Lachance, Bernard and Kirkwood, Donna. 2006. L’importance de la modélisation géométrique 3D lors de l’élaboration d’un SIG 3D: Exemple du développement d’une structure topologique pour une application géologique. *Revue internationale de géomatique: Information géographique tridimensionnelle* 16 (1):29-49.

Rivest, Suzie, Bédard, Yvan, and Marchand, Pierre. 2001. Towards better support for spatial decision-making: defining the characteristics of Spatial On-Line- Analytical Processing. *Geomatica* 55(4):539-555.

Roskams, Steve. 2000. *Interpreting Stratigraphy. Site Evaluation, Recording Procedures and Stratigraphic Analysis*. Oxford: BAR International series 910.

Roskams, Steve. 2001. *Excavation*. Cambridge: Cambridge University Press.

Schloen, David, J. 2001. Archaeological data models and web publication using XML. *Computers and the Humanities* 35:123-152.

Scott, Kendall 2001. *UML Explained*. Boston: Addison-Wesley.

Warburton, David A. 2003. *Archaeological Stratigraphy. A Near Eastern Approach*. Neufchâtel: Recherches et Publications.

Wheatley, David and Gillings, Mark. 2002. *Spatial Technology and Archaeology: Archaeological Applications of GIS*. London: Taylor & Francis.