Data Collection and Management for Stratigraphic Analysis of Upstanding Structures

Elisabetta Donadio and Antonia Spanò
Politecnico di Torino – DAD (Architecture and Design Dept), viale Mattioli, 39, 10125 Torino, Italy
{elisabetta.donadio, antonia.spano}@polito.it

Keywords: GIS, Masonries, Stratigraphy, Cultural Heritage, TLS, SfM.

Abstract: Stratigraphic analysis, used in principle for study of archaeological excavation, has been adapted and applied to upstanding structures with the same aim to reconstruct a building's history. Stratigraphy, as well as data excavation management, has found a useful and versatile tool in geographic information systems (GISs). Such systems allow support of this kind of analysis, which is mainly related to the reconstruction of the chronological sequence, statistical analysis, and their representation. This paper examines the process that leads to the production of information and storage in a GIS, applicable for the management of the stratigraphy of an upstanding structure. This process involves data acquisition, processing, 3D modelling, 2D representation, graphical entities, and their topological relationships, determinations, and representations. We also touch on the relationship between 3D GIS and 2D GIS; even if complex 3D archives are currently achievable, from another point of view it can be also useful for carrying out a 2D workflow aiming at achieving sharable guidelines that are valuable for specialists in Cultural Heritage conservation.

1 INTRODUCTION

The widespread use of information and communication technology (ICT) has radically improved the availability of spatial information over the Internet, and GIS tools have became powerful instruments to perform complex analyses both on thematic and geometric content.

Cultural heritage documentation is a field where GIS applications have ensued general improvements, also arisen from the increasing application of GIS to urban cartography and the consequential requirement to handle 3D representation.

In recent years, many proposals and ad hoc solutions for digital documentation systems based on GIS tools have been aimed at cultural assets (two example among others: Apollonio et al., (2012) and Katsianis (2008).

The GIS tools played a relevant role, first in the archaeological field since they enable management and analysis of a large amount of data according to basic assumptions used by archaeologists for collecting and managing site or ancient building information. Moreover, archaeological practices pay close attention to the spatial components of archaeological data. The reconstruction of past event or site changes is initiated through reading and storing of recognisable evidence related to the landscape in which they are discovered. Effectively, the great esteem for GIS tools has led to many disciplinary considerations linked to archaeological science and experiences (Scollar, 1999; Wheatley and Gillings, 2002).

In the last two decades, the community devoted to CH protection has shown an interest in new technologies of data acquisition and management. In this context, particularly GIS use has taken root.

This phenomenon is not unanticipated, since some keywords or concepts included in international conventions concerning the protection of the world heritage (UNESCO, 1972, and later) are appropriate for use with GIS tools.

The knowledge of the extent and the state of CH in a region is related to the ability of managing geographical locations. The involvement of many specialists belonging to different fields of studies and generally of stakeholders active in CH protection plans means that many different kinds of data must be collected, produced, and stored. The ability to connect diverse databases and to manage the temporal dimensions are remarkable GIS skills. The GIS tools are also widely used in CH documentation for technical reasons; orthoimages and Digital Elevation Models are easily managed and are increasingly

Donadio E. and Spanò A..
Data Collection and Management for Stratigraphic Analysis of Upstanding Structures.
DOI: 10.5220/0005470200340039
In *Proceedings of the 1st International Conference on Geographical Information Systems Theory, Applications and Management* (GISTAM-2015), pages 34-39
ISBN: 978-989-758-099-4

used in built heritage applications.

Orthoimages, which are processed from terrestrial laser scanning (TLS) and/or from digital photogrammetry techniques, represent a particularly favourable representation for different specialists since they include both metric and radiometric values. Moreover, archaeologists or other non-experts in survey techniques are autonomously able to extract data from such orthographic building representations.

2 GOALS AND OPEN ISSUES IN THE WORKFLOW OF DATA ARRANGING FOR STRATIGRAPHIC ANALYSIS

There are three main necessary phases for collecting data for a stratigraphic analysis of an upstanding structure. In the first phase, we need to choose the method for data acquisition and process, in order to obtain 3D models and orthoimages. In the second phase, we need to make the survey results available in a spatial data structure and format properly for GIS management. To do this, we frequently need data digitisation.

In the third phase, we must organise graphical datasets and all other information. To make spatial data available for queries and visualisation in connection with other archaeological, technological, or historical information, it is necessary to design a model that identifies a correspondence between spatial features and conceptual model data. The issue of this operation is related to the necessity of matching a structure based on topology with a structure that conforms to the geometric representation of the architectural structure. Therefore, the generated geometric entities must be compliant with topological data structures.

This task, representing constructive or restoration phases of buildings or sites, is usually performed to fulfil chronological plans and is widely used by the users community (e.g., Semeraro et al., 2012; Bortolotti et al., 2013).

In this paper, we favour the first two phases; therefore, some methods are discussed in the next paragraphs.

2.1 Terrestrial Laser Scanner (TLS) and Structure-from-Motion (SfM) Techniques

Today, it is well accepted that a 3D model of data derived from a digital survey using both active and passive sensors is more rapid and provides more details than using other survey systems. These models enable obtaining very useful shape documentation and thematic characterisations that are more sustainable in terms of cost and the amount of available information. However, when comparing image-based techniques with laser scanning, the former have a better chance for low cost equipment and tools.

Recent digital photogrammetric software uses algorithms derived from the computer vision community; they take advantage of *Structure-from-motion* (SfM) tools that enable estimated 3D positions of points represented in multiple images. Such systems can provide the reconstruction of objects' shapes and points' positions (Lowe, 2004).

Many other image-matching techniques have been developed earlier than SfM, such as area-based matching and feature-based matching, in order to solve the tie points (TPs) extraction; after that phase, epipolar geometry is used to process internal and external orientation and to create dense points clouds.

Section profiles or orthophotos are comparable for metric accuracy (Chiabrando and Spanò, 2013) and can be extracted to measure buildings, to examine safety conditions, and for deriving proper information for stratigraphic analysis.

2.2 Features Extraction and Automation in Digitising

Usually, some editing efforts are implemented in 3D models or orthoimages generation in order to digitise surveyed objects.

Architectural and archaeological fields usually derive drawings after the measuring phase, and the huge amount of information provided by accurate and highly detailed 3D models make the manual tracing well accepted.

Some commercial and open source tools offer solutions to support and simplify this phase. Some tools enable insertion of section planes cutting a registered points cloud anywhere in the scene space. In this way, it is possible to generate a mosaic of images representing a parallel projection of the cloud model on which extracts vectors.

Vector extraction, when manually performed, is very time consuming, and even if this is a relevant phase in reading assets, many automated or semi-automated aiding tasks and algorithms can be taken into account.

Sometimes a contours extraction tool applied on the archaeological object surface, usually represented by a DEM, can be helpful as shown in Figure 1.

The success of this method depends on the required scale of analysis and is rarely proper for masonries analysis.

More often, the algorithms that are able to recognise the radiometric boundaries can be used to process the vectorisation, usually by means of geometric constraints, such as extension, shape, or number of vertices for the recognised objects (Figure 2).

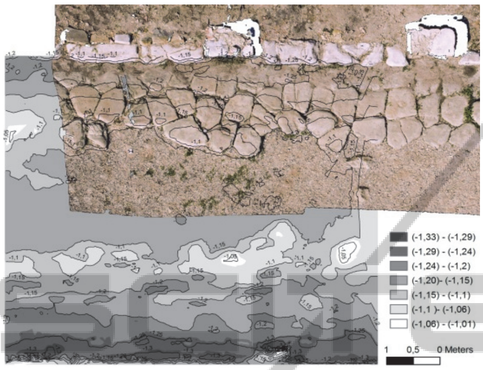


Figure 1: Vector sketches of the shape of evidence are obtained with the help of a contours extraction task (Costamagna et al., 2010).

A relevant request of process automation affects many phases and aspects of CH documentation, and occasionally some solutions are adapted from innovative applications of other sectors.

The feature extraction and matching techniques have traditionally been used in aerial photogrammetry. Many operators, such as SIFT, are widely implemented for automatic TP extraction and approximate digital surface model (DSM) generation (Lingua et al., 2009).

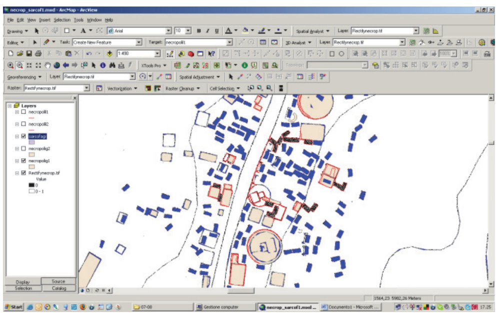


Figure 2: An example of automatic vectorisation performed by geometric constraints (tombs of Hierapolis North necropolis (Spanò, 2008).

In order to automatically extract break-lines of a surveyed object, some solutions foresee a continuous exchange of information between Lidar and Photogrammetric techniques. The result is the complete 3D description of the object through break-lines (Nex and Rinaudo, 2011).

An interesting tool, based on active contour and fulfilled specifically for a stone-by-stone digitisation aimed toward stratigraphical analysis, can be found in Drap et al., (2007).

3 STRATIGRAPHIC ANALYSIS REQUESTS: CHRONOLOGY ISSUES

The use of archaeological methods in the study of architecture aims to enrich the knowledge base, since buildings show signs of transformation, restoration, reconstruction, and demolition.

The application of the stratigraphic method to archaeology hails from Edward Harris' experiences dating back to the mid-twentieth century (Harris, 1989). The goal of archaeology is to define construction phases of the building (chronological sequences) within a relative chronology and subsequently, their settings in an absolute chronology introducing dates or periods.

The dating process starts with identification on a 3D or 2D representation of stratigraphic units (Unità Stratigrafiche Murarie (USM)) intended as constructive action with temporal autonomy.

There are two different types of stratigraphic units: positive USM, if they result from a single constructive action, and negative USM, if they result from a removal action due to human action. Some units are then defined as covering units if they cover other units, such as plasters, paints, wall coverings, and flooring.

Starting from this recognition, the analysis continues seeking temporal relationships between adjacent units and processing the stratigraphic sequences, consisting of all USM in temporal order. All of these data are recorded in a data sheet. Likewise, for the archaeological excavations, the USM are then grouped into a construction phase to be able to better study the history of the building.

The final step of a stratigraphic analysis consists of the abstraction of the relationships between units using a matrix diagram, conceived by Harris, which is a system of representation of the stratigraphic relationships that represent through a system of symbols the chronological sequence of all actions, constructive and destructive.

The stratigraphic method, which provides mapping of stratigraphic units on graphic representations and their cataloguing in a descriptive database, represents an example of a useful implementation of a

GIS. The advantage of this application is to exploit the topological relationships resulting from vectorisation (and georeferencing) of each stratigraphic unit.

4 CASE STUDY: THE NORTH FRONT OF THE SANTA MARIA CHURCH OF THE STAFFARDA ABBEY

4.1 The Cistercian Staffarda Abbey

The Cistercian Staffarda Abbey is a monastery located near Saluzzo in northwest Italy that was founded in the XII century by Cistercian monks. The abbey complex grew larger between XII-XIII centuries with a gradual decline from that date onwards (Rotunno, 2011). In 1750, the Holy See declared the autonomous abbey's role to be over, and the complex was given to the Order of St. Maurice.

Due to the modifications over the centuries, the monastery combines both Roman and Gothic architectural styles, and it includes the Santa Maria Church, the cloister, other monastic rooms (the dormitory, the refectory, etc.), the covered market, and the guestrooms (Beltramo, 2010).

Much of the complex was built in red brick and red sandstone. The church has a nave and two aisles, and is a splendid example of Romanesque-Gothic style.

Figure 3: 3D Model processed from LIDAR data.

The inside is austere, and the cross vault and the pillars (all different from one another) are decorated with alternating colours, which range from red to grey.

Externally, the overload of the roof led to the construction in early medieval sites of the flying buttresses that have improved but not solved the problem. Currently, the monastery represents one of the most important testimonies of medieval architecture in Piedmont.

The stratigraphic analysis involved in the north facade, particularly the three spans and the transept, are characterised by many visible stratifications. For example, the signs of demolition and filling of the eighteenth-century chapels and some of their decorations are still evident as well as the holes of their coverage.

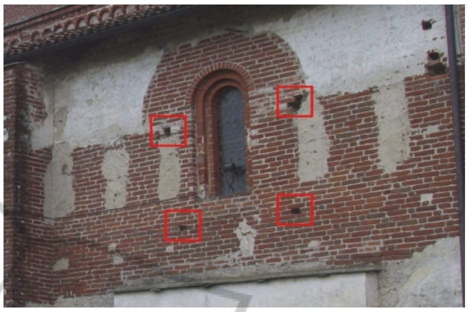
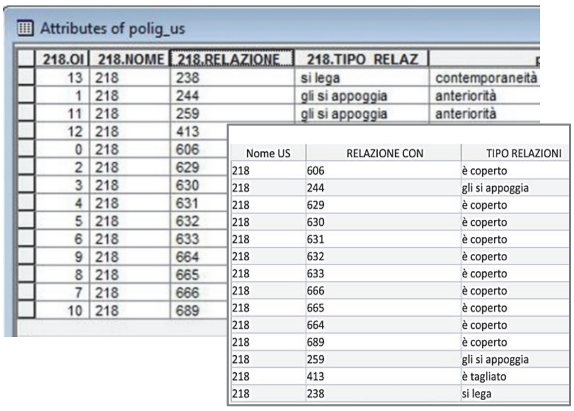


Figure 4: Holes on the masonries determined by a recent restoration.

Figure 5: Zoom-in on an example of a chapel decoration.

4.2 The Stratigraphic Analysis

The analysis has been carried out recognising and contouring units on orthoimages generated from the 3D point laser cloud. This phase led to the recognition of 74 positive USM, 22 negative USM, and 115 covering units.



Attributes of polig_us

218.OI	218.NOME	218.RELAZIONE	218.TIPO RELAZ	
13	218	238	si lega	contemporaneità
1	218	244	gli si appoggia	anteriorità
11	218	259	gli si appoggia	anteriorità
12	218	413		
0	218	606		
2	218	629		
3	218	630		
4	218	631		
5	218	632		
6	218	633		
9	218	664		
8	218	665		
7	218	666		
10	218	689		

Nome US	RELAZIONE CON	TIPO RELAZIONI
218	606	è coperto
218	244	gli si appoggia
218	629	è coperto
218	630	è coperto
218	631	è coperto
218	632	è coperto
218	633	è coperto
218	666	è coperto
218	665	è coperto
218	664	è coperto
218	689	è coperto
218	259	gli si appoggia
218	413	è tagliato
218	238	si lega

Figure 6: Attribute data tables implemented in GIS.

The next step consisted of the identification of the temporal relationship between each unit and its adjacent units. In order to archive and link this kind of descriptive information, an attribute database has been created.

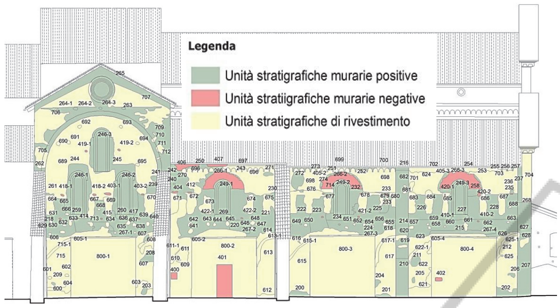


Figure 7: Example of a data thematisation: in green positive USM, in red negative USM, in yellow covering units.

In 2D or 2.5 representation GIS projects, the coordinate system cannot be the original system of the laser model that coincides with the topographical reference system. Necessarily, the graphical vector dataset representing the front façade is projected onto a vertical plane measured by xy coordinates. The original coordinate system must be shifted and turned for each face of the building that is analysed and represented; corresponding features in different drawing projections that represent the same real elements can be connected by a relationship.

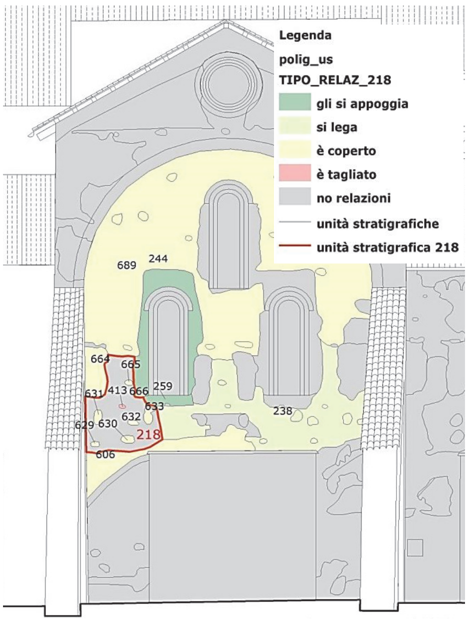


Figure 8: Result of a select by attribute query about the 218 USM. The system allows highlighting all the USM that have a relationship with it and to thematise features based on the type of relationships they have.

The implementation of features representing USMs and the related chronological relationships allow generation of several useful thematisations.

It also allows querying the data by location or attributes, depending whether it is proper to take advantage of topological relationships or when it is better to use attribute data.

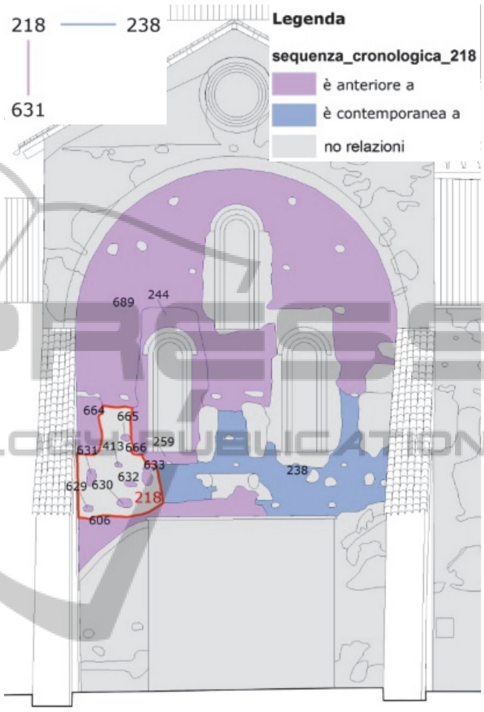


Figure 9: Harris matrix processed using GIS attribute selection.

5 CONCLUSIONS AND PERSPECTIVES

Despite the fact that this sketchy experience is based on 2D representation GIS, it shows two evident positive points. The first is that a powerful analysis for a CH conservation plan is achievable through well-known functionalities among GIS users. Later, but even more relevant, the use of many graphical frameworks, each representing a drawing projection of the building (plan, fronts, and cross sections), offer the chance to manage the entire complex of the building. Architects and archaeologists are used to using different 2D representations in studies of 3D spaces or objects. Further, by means of exploiting the capability to connect different features representing the same real elements, they can enhance their analyses.

In addition to the easy to use tools, another profitable issue for the CH documentation community is the low cost systems. The increasingly common use of open source tools, such as PostGis, is placed side-by-side to commercial tools, such as the popular ESRI products even among the CH preservation plans.

The development of 3D GIS (i.e., systems where the same importance to the (x,y,z) coordinates is assigned) is attractive in the CH conservation community. The 3D management, both in data visualisation operations and in data retrieving or editing operations, offers the achievement of specialised analyses.

In some cases, open source framework and advanced ad hoc systems for some relevant contexts are used (e.g., Coralini et al., 2010)

A very interesting specialised system has been developed for the Shawbak project. A 3D GIS allows management of both photogrammetric models and 3D shape restitution of built structures in spatial archive as well as processing and automatic visualisation of the Harris matrix with clusterisation of geometric elements (Drap et al., 2012)

A section of the scientific community, which has been working on information systems for CH preservation, started to investigate the benefits of switching from a 3D content model to historic building information modelling (HBIM) to support conservation plans (Oreni et al., 2013). Furthermore, studies comparing the advantages and disadvantages of both BIM and GIS approaches are available (Saygi et al., 2013).

In both cases, BIM or GIS adoption, there is the need to enhance the automatic digitisation tools starting from orthoimages and points models, since only more sustainable and easily approachable procedures can represent an effective strategy for basic and common use in CH conservation plans.

REFERENCES

Harris E. C., 1989. *Principles of Archaeological Stratigraphy. Academic Press*; 2nd edition (Jun 15, 1989).

Scollar I., 1999. *25 years of Computer Applications in Archaeology*, in L. Dingwall, S. Exon, V. Gaffney, S. Laflin, M. van Leusen (Eds.), *Archaeology in the Age of the Internet*, *Computer Applications and Quantitative Methods in Archaeology 1997,* BAR International Series 750, Oxford, 5-10.

Wheatley D., Gillings M., 2002. *Spatial technology and archaeology: the archaeological applications of GIS*, Taylor and Francis, London.

Lowe D., 2004. Distinctive Image Features from Scale-Invariant Keypoints. *IJCV*, vol. 60, number 2, pp. 91—110.

Drap P., Durand A., Nedir M., Seinturier J., Papini O., et al., 2007. Photogrammetry and archaeological knowledge: toward a 3D information system dedicated to medieval archaeology: a case study of Shawbak Castle in Jordan. In *Proceedings of the 3rd ISPRS, International Workshop 3D ARCH*, pp.1-8.

Katsianis M., Tsipidis S., Kotsakis K., Kousoulakou A., 2008. A 3D digital workflow for archaeological intra-site research using GIS, Journal of Archaeological Science 35 pp. 655-667.

Lingua A., Marenchino D., Nex F., 2009. Performance Analysis of the SIFT Operator for Automatic Feature Extraction and Matching in Photogrammetric Applications, *Sensors*, *9*, 3745-3766; doi:10.3390/s90503745

Beltramo S., 2010. *L'abbazia cistercense di Santa Maria di Staffarda,* l'Artistica editrice, Cuneo.

Coralini A., Guidazzoli A., Scagliarini Corlàita D., Toffalori E., 2010. VISMAN-DHER Project: Integrated Fruition of Archaeological Data through a Scientific Virtual Model, In *Euromed 2010,* pp. 409-421.

Costamagna E., Chiabrando F., Rinaudo F., Spano' A., 2010. Very close nadiral images: a proposal for quick digging survey. In: ISPRS Archive, vol. XXXVIII/5, pp. 155-160. - ISSN 1682-1750.

Nex F., Rinaudo F., 2011. LiDAR or Photogrammetry? Integration is the answer. In: *Rivista Italiana di Telerilevamento*, vol. 43 n. 2, pp. 107-121.

Apollonio F., Gaiani M., Benedetti B., 2012. 3D reality-based artefact models for the management of archaeological sites using 3D GIS: a framework starting from the case study of the Pompeii Archaeological area, Journal of Archaeological Science 39, pp. 1271-1287.

Drap P., Merad D., Seinturier J., Boï J. M., Peloso D., Vannini G., Nucciotti M., Pruno E., 2012. An Information System for Medieval Archaeology Based on Photogrammetry and Archaeological Database: The Shawbak Castle Project, In *Euromed 2012*.

Semeraro G., Pecere B., Mianulli A., 2012. Applicazioni GIS alla ricerca archeologica: Il santuario di Tas Silg a Malta, In *SCIentific RESearch and Information Technology*, Vol. 2, Issue 1 (2012), pp. 83-104, e-ISSN 2239-4303, DOI 10.2423/i22394303v2n1p83

Bortolotto S., Castiglioni A., Cattaneo N., Massa S., 2013. Complex Archaeological Sites: An integrated stratigraphic framework for progressive knowledge acquisition and representation. In *Built Heritage 2013 Monitoring Conservation Management,* pp. 719-728.

Chiabrando F., Spanò A., 2013. Points clouds generation using TLS and dense-matching techniques. A test on approachable accuracies of different tools. In: ISPRS Annals, Volume II-5/W1. pp. 67-72.

Oreni D., Burmana R., Georgopoulos A., Cuca B., 2013. HBIM for conservation and management of built Heritage: towards a library of vaults and wooden bean floors, In *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-5/W1, 2013.*

Saygi G., Agiugiaro G., Hamamcıoğlu-Turan M., Remondino F., 2013. Evaluation of GIS and BIM roles for the information management of Historical Buildings, *In ISPRS Annals Volume II-5/W1.*