# Modelling bullet trajectories on historic battlefields using exterior ballistic simulation and target-oriented visibility

## Trajectory modelling on historic battlefields

For as long as archaeologists have investigated battlefields and fortifications they have encountered ammunition component evidence, in the form of arrow-heads, bolt-heads, shot, cannon-balls, shell fragments, bullets, and cartridge-cases. In some instances it is possible to assign ammunition components to one side in the battle or the other, on the basis of their type and size. The markings and deformities of a projectile may indicate whether it was fired or dropped, the weapon type, and the approximate range of the trajectory. The orientation of a conical or pointed projectile may suggest the direction from which it was fired.

There have been few attempts to quantitatively model weapons trajectories on historic or prehistoric battlefields. Prior to the advent of GIS technology in archaeology, trajectory modelling was strictly qualitative (Richmond 1968: 32-33 and figs. 2, 14, 18; Ferguson 1977: 65; Harrington 1978: 124). Since at least the 1990's, however, military GIS applications have had the functionality to calculate a 'weapons fan' – essentially a viewshed from a firing point, buffered to the weapon's maximum effective range – which models the areas of the terrain where a target is both visible and within range (Guth 2003). The fan model of course assumes that the weapon is being controlled in a direct-fire mode.

Benson (2000) undertook what was perhaps the first quantitative study of bullet trajectories on a historic battlefield. He used cumulative weapons fan modelling to locate the firing point of a set of five .40-calibre Sharps bullets at Little Bighorn – he calculated viewsheds from each bullet find-spot, buffered them to the Sharps rifle's effective range, and intersected the results. While his project was indeed an innovative application, what he in effect did was apply a cumulative weapons fan technique not to model capability from given firing points, but to model a firing point from given projectile finds. This is invalid for three reasons. First, it assumes that all five bullets were fired from the same point. Second, in buffering to the maximum effective range, it fails to consider the possibility that the bullets had overshot their targets. A projectile that misses its target on a low-angle trajectory is highly likely to overshoot it and, in the absence of intervening terrain, it may travel a considerable distance beyond. Third, it fails to model the curvature of the trajectories. At medium and long-range, the curvature can be significant, as the projectiles may drop down behind a ridge or hill, out of visibility from the firing point. In such cases, the straight lines of sight that viewsheds are based on provide a poor model.

Drexler (2004: 58) also used a cumulative viewshed technique in his study of artillery positions at Wilson's Creek, but his work on canister-shot scatters at Pea Ridge took another approach. A canister round is essentially a metal case packed with several dozen small projectiles – usually musket-balls. When it is fired from a cannon it disintegrates and the contents scatter across an arc of perhaps four to six degrees. Drexler applied linear regression analysis to the suspected canister-shot scatters to model the borelines of each shot, and interpreted the intersections of these borelines as the artillery firing points.

Lacey's work on World War Two pillboxes on the Taunton Stopline developed a more advanced version of weapons fan modelling (Lacey 2003; Schofield 2005: 59). His goal was to model weapons capability from a network of defensive positions. He introduced the notion of a 'fireshed', which indicates the areas of the terrain where a target can be hit by projectiles from a given weapon type at a given location. It is similar to a weapons fan, except that it models the projectile's path and impact point (direct or indirect) rather than the conditions for a feasible direct-fire target point. He derived his firesheds by horizontally rotating the profile of a given trajectory to create a projectile height grid, subtracting this from a digital elevation model (DEM) of the terrain, and performing a viewshed calculation across the difference. Although his notion of a fireshed is very insightful and Lacey's approach is far more sophisticated than the cumulative viewshed technique, his current implementation encounters problems (Lacey 2003: 81) in adapting the given trajectory profile to model fire at targets that are significantly above or below the level of the firing point. These problems can be overcome by using exterior ballistics simulation to calculate the trajectory through any given point.

## Method

The present research aims to develop a broadly applicable approach to trajectory modelling. From one period to another, battlefield archaeology varies widely by the types of weapons used and the quality of trajectory-related evidence. The approach sought is one that can be adapted to any projectile weapon, and scaled to fit the available evidence.

The method seeks to identify possible firing and target positions on the basis of a given impact point and DEM of the site. The trajectory to the impact point is modelled from each of a given set of firing points. The firing points may be specified as a single point, a set of irregularly spaced points, or points sampled along a line segment or across a rectangular area. In the horizontal plane, each trajectory is modelled as a line segment between the firing point and impact point – at this stage in the research the potential effects of a cross-wind are ignored. The target points may be specified in the same ways as firing points, or alternatively as points sampled along the line of fire or at the intersection of the line of fire and a given line segment, such as an enemy position. Various other parameters for the calculations include the vertical offsets from the ground for the firing, target, and (in the case of impact marks on structures) impact points; and exterior ballistics parameters such as the ratio of air pressure to a ballistics standard and the muzzle velocity (MV), ballistic coefficient (BC), and drag function of the projectile. It is possible to control the resolution of the results by specifying the number of range intervals at which the trajectory is to be calculated.

Since the purpose of the modelling is to identify likely firing and target points, criteria for evaluating the feasibility of each trajectory must be established. The criteria proposed by the current research are that:

1. the projectile must travel above ground throughout the trajectory,
2. the target point must be visible from the firing point,
3. the trajectory must be 'reasonably' well-aimed at the target point, and
4. the target point must be within the effective combat range of the weapon.

These criteria clearly make certain assumptions, namely that the projectile did not ricochet off of the ground or otherwise move from its initial impact point, and that the firer was behaving rationally. The calculation yields various sets of results for evaluating the trajectory with respect to each of these criteria. In this case, these results are:

1. the projectile's minimum height above ground throughout its trajectory,
2. the minimum height above ground of the line of sight between the firing and target points,
3. the angles between the modelled trajectory and the ideal trajectory that would hit the target in the centre, and
4. the distance between the firing and target points.

By applying filters to these results, the 'feasible' trajectories can be extracted from all of the possibilities considered.

This approach is currently being implemented in MapBasic as a plug-in for MapInfo. The exterior ballistics engine is an adapted version of McTraj 4.1, a point mass model simulation first written in BASIC in 1987 by Robert McCoy of the US Army Ballistics Research Laboratory.

## Case study: The Greasy Grass Ridge episode at Little Bighorn (1876)

The effectiveness of trajectory modelling on historic battlefields may be demonstrated by a small-scale case study from the Custer battlefield at Little Bighorn, specifically the fighting in the Greasy Grass Ridge sector in the southern extremity of the monument. Much has been written about the battle, but the historical-archaeological interpretation offered by Fox (1993: 143-159) is that this episode occurred early in the engagement. The right-wing of Custer's battalion, deployed atop Calhoun Hill ('CH' in Fig. 1), was threatened by an Indian infiltration into Calhoun Coulee, to their west. Company C was detached to drive back the approaching warriors. Somewhere in the vicinity of Greasy Grass Ridge, the company encountered strong resistance and retreated, first to the southern end of Calhoun Ridge ('CR') and then back along the ridge to rejoin the remainder of the right-wing.

The artefact distribution on Greasy Grass Ridge permits a detailed hypothesis of this action. The linear pattern of Springfield cartridge-cases suggests that Company C dismounted and deployed into skirmish line. Tactics dictated (Fox 1993: 45) that the company dismount to the rear of their intended firing position and lead their horses to a safe area. The dismount point implied by this hypothesis is indeed the first point along Company C's axis of advance that is out of visibility from the Indian 'rally point.' As the cavalry deployed into a firing formation straddling the crest of the ridge, the Indians apparently moved forward in a frontal attack. If so, it seems that the Indians deliberately crossed over to the south-west slope of the ridge to minimise their exposure to the cavalry's fire (Fig. 3).

What is perhaps most remarkable about this sector, however, is two distributions of Indian cartridge-cases that are very linear and spaced in tight clusters at fairly regular intervals. These lie to the south-west of and parallel to the cavalry position. This pattern recurs to some extent in roughly half a dozen other places on the battlefield, although it is most clear in this sector. It is hypothesised that these represent Indian flank attacks on the cavalry, and that these may have been the decisive action that drove Company C into retreat.

Trajectory modelling was applied to the ammunition component evidence to determine whether it supports this hypothesis of an Indian flank attack. Following the implicit fields of fire north-eastward from the Indian positions, a number of bullets were selected as possibly being connected with this action. The study was conducted using the archaeological data gathered in the 1984/5 project, co-directed by Douglas Scott and Richard Fox, and a first-pulse LIDAR DEM of the site at 5-metre postings. A 1-metre vertical offset was used for firing and target points, under the assumption that both sides were fighting in a kneeling or crouching posture.

Field Specimen 1408, a .50-calibre bullet found approximately 600 metres north-east of the ridge, was subjected to study. An 'inverse fireshed' was calculated from the entire ridge sector to the bullet's find-spot, and trajectories were modelled from each of the .50-calibre cartridge-cases in the attack corridors (Fig. 2). The inverse fireshed is in effect the opposite of Lacey's fireshed: it models the areas from which there is a clear trajectory to the impact point. The results of these processes indicated that there was a .50-calibre case at the origin of one of the Indian attacks ('B' in Fig. 2) from which point there is a clear trajectory that virtually passes through the visible part of the Company C position and ends at the FS 1408 find-spot. Alternative trajectories (including 'A' and 'C') were ruled out.

This modelling was repeated for other bullets in the likely impact areas, and it was discovered there were several similarly feasible trajectories from Indian firing points through the cavalry positions evidenced by Springfield and Colt cartridge-cases. Many of these trajectories were 400 to 800 metres long, and it is interesting to note that none of them would have been detected by viewshed modelling – these bullets would all have overshot the crest of the ridge and dropped down out of visibility from the firing points. It is worth noting that some of the feasible trajectories are 'direct' shots aimed along the line of attack, and some are 'oblique' shots at the main body of the cavalry. There may be various explanations of why these Indian attacks and others on the site are not oriented directly at the main cavalry positions, but perhaps the most sensible is that the Indians were exercising a 'fire and movement' tactic, whereby a movement team advances under cover from a fire team. To prevent the fire team from shooting the movement team in the back, the line of attack would naturally have to be oriented at an angle to the target. The density of the cartridge-case clusters may support this. In the first two firing positions of Attack 1, there are a total of five cases, and in the first position of Attack 2 there are five. There are no more than two cases at each of the forward positions. This suggests that the fire from the initial (rear) positions was either more intense or long-lasting than that from the forward firing points.

The results of the trajectory modelling can be compared with other forms of evidence. In the Little Bighorn project, firearms identification procedures were applied to the cartridge-cases, and several sets were identified as having been fired in the same weapon (Scott *et al.* 1989: 104-113). From this, it is possible to infer the movements of individual soldiers and Indians during the battle, although the notional 'pathways' do not necessarily represent actual lines of movement – in Fig. 3, for example, two of the pathways have been curved slightly for clarity. Note also that only the pathways per-

Fig. 1 – Terrain map of the Greasy Grass Ridge (GGR) sector of the Custer battlefield, the ammunition component distribution, and a historical-archaeological hypothesis of the engagement between Company C and the Indians.

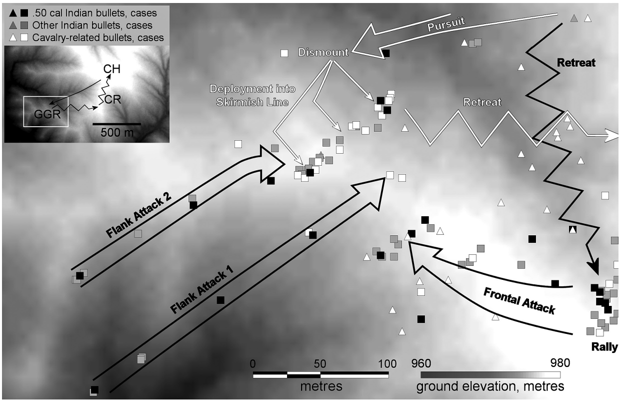



Fig. 2 – Inverse fireshed from the find-spot of a .50-calibre bullet (FS 1408) located approximately 600 metres north-east of Greasy Grass Ridge and three alternative trajectory models (A-C), in plan and profile view. In Model A the target is not visible and in Model C the trajectory is obstructed. The inverse fireshed indicates areas (white) from which there is a clear trajectory to the impact point.

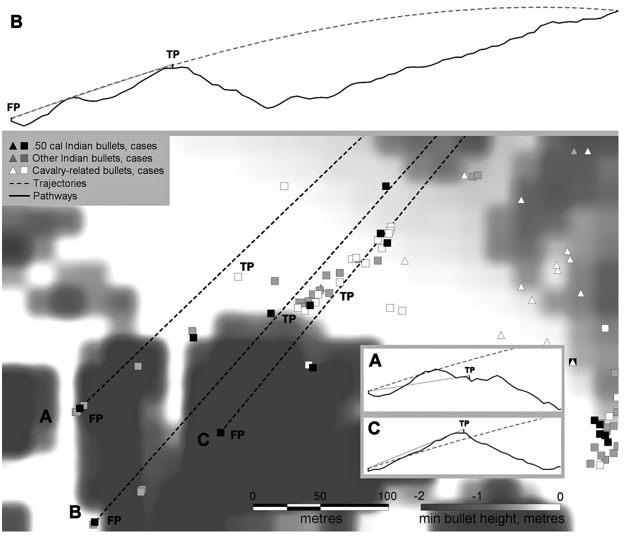
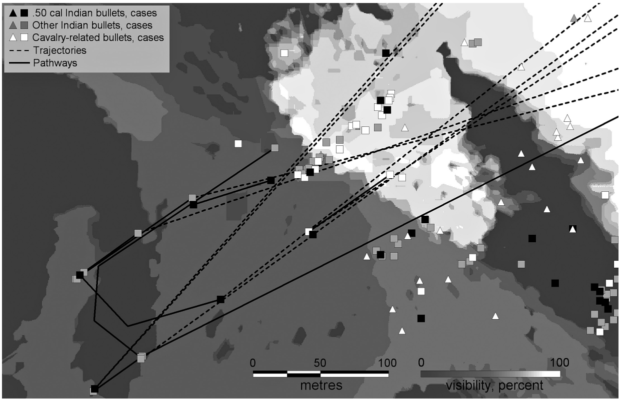



Fig. 3 – Cumulative viewshed from the Company C skirmish line, selected individual Indians' pathways, and feasible trajectories modelled from the firing points of the Indian flank attacks to bullets of the appropriate types.



taining to cartridge-cases in the flank attack area have been included in Fig. 3. On the whole, these movements support the idea of Indian flank attacks approaching from the south-west. Furthermore, the fact that two individuals participated in both attacks implies that they did not occur simultaneously. While there is no firm basis for sequencing them, Attack 1 is more typical of the flank attack patterns found elsewhere on the site – it approaches from the side and slightly to the front of the cavalry position. It seems that this attack perhaps stalled or failed, and that the Indians tried again from a position slightly north-west, where they could approach more closely before exposing themselves to the skirmish line. In the final stage of Attack 2, one pathway diverges slightly from the attack's centre-line, possibly indicating that the attackers were fanning out to pursue the enemy, or that the attack had otherwise lost tactical cohesion.

The results of cumulative visibility modelling are equally interesting (Fig. 3). It appears that in each flank attack the first two Indian firing positions were chosen specifically in areas of marginal visibility from the extreme right of the cavalry position. The Indians were apparently using the terrain for cover, and throughout their attack they were visible to no more than approximately 30% of the cavalry formation.

The correlation of the modelled trajectories with the bullet deformation and orientation data is somewhat more difficult to assess. It seems that at short-range, bullets tend to retain their orientation after impact. The cavalry bullets in and behind the position of the Indian frontal attack are almost exclusively oriented to the east, south-east, and south. However, most of bullets from the Indian flank attacks were on much longer trajectories, and hence were significantly slower and less stable at impact. Some are within 45 degrees of the line of fire, and most are within 90 degrees. Most of the bullets exhibited 'slight' to 'moderate' deformation, which is broadly consistent with the range of the trajectories. Until experimental data can be gathered regarding orientation and deformation at medium and long-range, it is difficult to weigh the significance of this data.

In conclusion, the trajectory modelling indicates that the ammunition component evidence generally supports the hypothesis. There was a failure to find any trajectories from the origin point of Attack 2, although several bullets in the likely impact areas have not been identified by type and could not be considered. Further modelling in the Greasy Grass Ridge sector and an examination of the other 'flank attack' patterns elsewhere on the site may provide additional insight into this episode.

## Future work

The archaeological record on late-19th century battlefields tends to be relatively rich. It is not currently known how effective this type of modelling will be on earlier sites, where the trajectory-related evidence is typically less clear. As more battlefield projects are carried out, the realm of potential case studies will expand, and as LIDAR DEMs for battlefields become available and rigorous test-firing of historic firearms continues, the quality of the relevant data will improve. It is hoped that the continued development and application of this approach to modelling trajectories on historic battlefields will yield new ways of studying ammunition component evidence and interpreting battle sequences.

*Acknowledgements*

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# The Archaeological Information System of the underground of Rome: A challenging proposal for the near future

## Introduction

The archaeological sites and the underground of Rome and its suburbs (*Agro Romano*) are managed by the Government Department for Archaeology in Rome (State Archaeological Superintendency of Rome-SASR); this is an office subordinate to the Ministry of Cultural Heritage and Activities which is devoted both to safeguarding the archaeological heritage and promoting scientific research in this field. In fact, a major concern of the SASR is the management of the routine and emergency excavations (about 40,000 per year) related to underground services and infrastructures (water, electricity, gas, phone and data lines) and new building sites.

Due to this particular set of circumstances, we came up with the idea of a global project, that would integrate new but inexpensive technologies to acquire, to archive and to manage all the information related to new excavations and to organize them together with those pertaining to past investigations according to a standardized protocol.

This paper describes the fundamentals of the project and discusses the results of experiments designed in cooperation with SASR specifically to test the feasibility of the standardized protocol relating to the acquisition of field information and the implementing of a first section of the GIS concerning the archaeological aspects of private buildings and areas within the territory of the Roman municipality.

## Project

The global project consists of two sub-projects, the first one (S.I.T.A.S. Romae) mainly pertaining new excavations, the second (In.Forma) related to the management of ancient maps.

### *S.I.T.A.S. Romae*

S.I.T.A.S. Romae (*Sistema Informativo Territoriale Archaeologico del Sottosuolo per la città di Roma – Archaeological Information System of the Underground of Rome)* is a sub-project which integrates different technologies (terrestrial and GPS surveys, close range photogrammetry, GIS) to acquire, process and organize data derived from excavations. At the same time, it proposes a standard procedure, to which all professionals and all companies working in this field must conform.

The S.I.T.A.S. project was developed through the implementation of a GIS employed for the filing and management of all the data collected during surveying and georeferencing of archaeological sites in the territory under SASR jurisdiction according to a standardized procedure.

Surveying and georeferencing should be based on mixed terrestrial and GPS techniques, integrated when necessary by close range photogrammetric images. The official new numeric map of Rome, scale 1:2000, should be the GIS cartographic reference.

## *In.Forma*

In.Forma (*Indagando sulla Forma di Roma*) is the second sub-project complementing S.I.T.A.S. Romae; it concerns geometrically correct georeferencing of ancient maps, mainly based on GPS surveys, by standard GIS routines. These maps are often related to archaeological sites which are now buried, but whose consistency and relatively accurate position may be reconstructed *a posteriori* without conducting new excavations.

The goal of the two projects S.I.T.A.S. and In.Forma (Fig. 1) is to standardize procedures for:

- Surveying and georeferencing archaeological finds during excavations usually carried out by public service companies.
- Production, management and updating of a spatial database of the excavations and of the archaeological sites and monuments.
- Creation of a database establishing the present archaeological significance of private buildings and areas within the territory of the Roman municipality.
- Georeferencing of ancient maps (metrically correct).

Several important advantages may be gained by the development of the two sub-projects, both for the SASR and for all the other people and companies involved:

- Archiving in a standard digital format of all information related to surveys of archaeological evidence, which will be useful for rapid consultation for scientific and technical investigations.
- Increased efficiency for supervising and documenting archaeological excavations and progressive reduction of the costs that SASR has to sustain for this purpose.
- Dynamic grouping of the streets within the Roman municipality in two classes: "positive" and "negative" streets, respectively with and without the previously discovered archaeological finds in the underground, which will be useful for planning of future excavations and for obtaining official excavation permits.
- Enhanced spatial analysis of the distribution of archaeological finds.

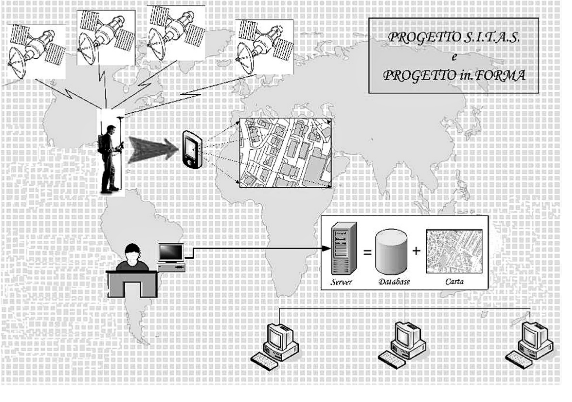


Fig. 1 – Functional scheme of S.I.T.A.S. and In.Forma projects.

## Preliminary experiments

After presentation of the project to SASR, we were asked to perform some preliminary experiments in order to test the feasibility of the standardized protocol. Three of them, carried out between December 2004 and February 2005, concerned field information acquisition and georeferencing of historical maps:

1. Use of GPS in an urban environment, in the presence of remarkable obstacles, to survey two archaeological sites and georeference their ancient maps (Baiocchi *et al*. 2001; Baiocchi *et al*. 2002) with the RTK technique assisted by the GPS permanent network of the Lazio Region, managed by the Area di Geodesia e Geomatica-Università di Roma "La Sapienza".

2. Use of a new total station fully integrated with a double frequency GPS (Smart Station® by Leica) to survey a very large monument near Rome (20 km away) in an suburban region; in this case the RTK technique assisted by the GPS permanent network of the Lazio Region was also employed.

3. Use of close range photogrammetry techniques applied to non-metric digital camera images to survey a Roman cippus of small dimensions, comparable to those of the majority of archaeological finds discovered during routine excavations.

Moreover, we produced a prototypical database recording the archaeological aspects of private and public buildings and areas in the territory of the Roman municipality, both according to the rules included in the quite recent "Codice dei Beni Culturali e del Paesaggio" (2004) and to the previous laws.

### *GPS-RTK survey in urban environment*

The aim of the experiment was to evaluate the GPS-RTK survey performance in an urban environment. In fact GPS (assisted when necessary by total station) makes it possible to determine with adequate accuracy (which may range from several centimeters to a few tenths of a meter) suitable points needed to compute the dimensions and volumes (depth w.r.t. the present ground level also) of excavations and archaeological finds (Fig. 2).

Consequently, two archaeological structures were surveyed and georeferenced; they both are located in the urban area represented in section 37410G of the official map of Rome, scale 1:2000 (horizontal tolerance 0.6 m), produced by Cartesia S.p.a.

The first structure, called Santuario Siriaco, lies near the Gianicolo hill in a closed archaeological area. Six points located approximately at the vertices of Santuario Siriaco were surveyed; a 20$^{th}$ century map of the ancient structure was georeferenced by means of the GPS survey, showing the correct position of the whole structure which is now buried or in ruins (Fig. 3).

The second structure lies inside a former public transportation bus depot near Mura Portuensi. This structure is composed of Roman era deposits, partly buried, situated about 5-6 meters underground. Fourteen points were surveyed; a kinematic survey was also taken on foot, around the area of the excavation. A map of the overall structure derived from a recent, large scale but not georeferenced survey was correctly positioned thanks to the GPS survey (Fig. 4).

As mentioned, both surveys were carried out using the RTK technique, receiving differential corrections from the (RTCM) in real time from the GPS permanent network of the Lazio Region, managed by the Area di Geodesia e Geomatica-

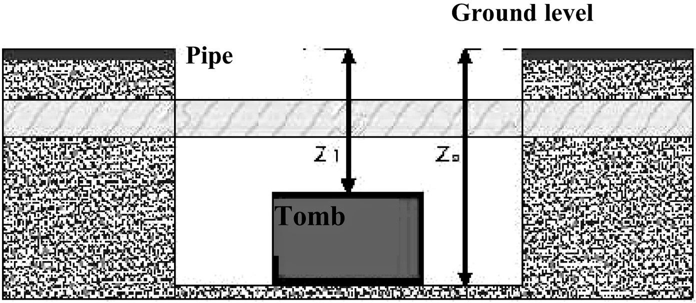


Fig. 2 – Positioning an archeological find and neighbouring underground services lines in open excavation.

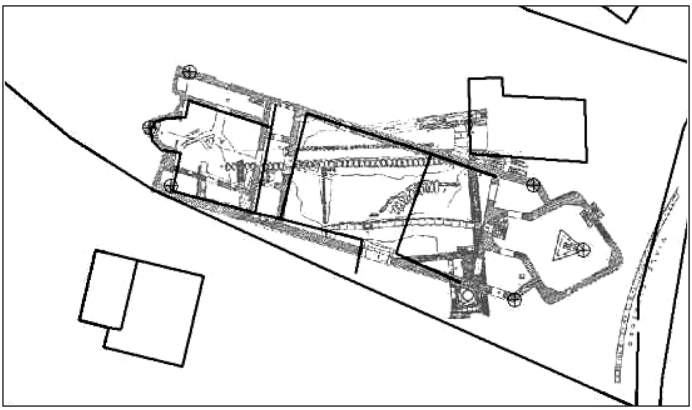

Fig. 3 – The survey of Santuario Siriaco (in evidence: the points surveyed by GPS and the XIX century map).

Università di Roma “La Sapienza”. Each point position was estimated in a two minute survey, allowing a 3D accuracy of around 0.1 m, which fits perfectly with the overall archaeological requirements.

In order to connect GPS surveys and georeferenced maps to the official map of Rome, presently available in the GAUSS-BOAGA cartographic reference system only with orthometric heights, some coordinate conversions were made:

- Ellipsoidal heights were transformed into orthometric ones applying the geoid undulations according to the ITALGEO95 public model (http://www.iges.polimi.it/) tied on four levelling benchmarks in the Rome area.
- Horizontal coordinates of all GPS points were changed into the GAUSS-BOAGA system employing the original software Trasformer (Baiocchi 2002a; Baiocchi 2002b; Baiocchi 2004) developed at the Area di Geodesia e Geomatica-Università di Roma “La Sapienza”, allowing an error transformation below 0.3 m, acceptable w.r.t. the Area di Geodesia e Geomatica-Università di Roma “La Sapienza” map tolerance.

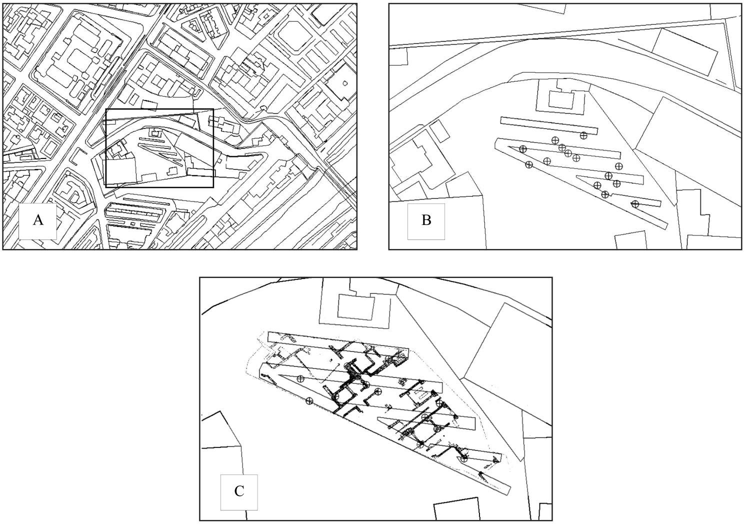


Fig. 4 – A. Portion of the map of the Roman deposits; B. Excavation trenches and GPS points; C. Map from SASR archives correctly georeferenced.

## *GPS-RTK survey in a suburban environment*

An archaeological structure was surveyed and positioned using a new total station fully integrated with a double frequency GPS (Smart Station® by Leica). The structure consists of the remains of a Roman villa in the municipality of Monte Porzio Catone (Rome province). The positioning of four points was carried out using the RTK procedure with 3D accuracy around 5 cm; a complete and detailed survey, also useful for future photogrammetric integrations, was performed in about five hours setting up the total station on these points, thus making the georeferencing of the whole structure possible.

## *Photogrammetry for high precision surveys*

The use of close range photogrammetry in the archaeological field is certainly not new, however the idea of standardizing a procedure to take, process and archive digital images using non-metric low cost cameras and inexpensive software, which can be used not only by experts but by most of the people involved in archaeological excavations, represents a significant innovation

The main intent is simply to substitute the traditional procedure of direct survey, in order to reduce the downtime during the excavation and to guarantee a uniform accuracy, which will be practically unrelated to the surveyor's skill. It should be noted that laser-scanning is not considered here because of its high costs and its extreme accuracy which is not usually required to document archaeological finds in routine excavations.

Experiments were conducted on a cippus (Fig. 5) which lies in the public gardens of Monte Oppio, just above the world famous *Domus Aurea*, near the Engineering

Faculty of the University "La Sapienza"; dimensions of this cippus are comparable to those of the majority of archaeological finds discovered during routine excavations.

The purposes of the experimentation were:

- To test the quality of a low-cost photogrammetric procedure applied to an object of archaeological value.
- To test a simple procedure for the calibration of non-metric cameras, based on the facilities of the well known Photomodeler 4.0 software (Eos System), used also for the whole photogrammetric procedure.

We compared low cost commercial cameras (Casio Exilim EX Z40; Nikon D100; Sony Cyber Shot DSC p200; Panasonic Lumix DMC-FX7) during the preliminary calibration and the Casio Exilim Ex Z40 (350 €) turned out to be the best, and consequently was used for the subsequent photogrammetric survey. Eight stations were set up and an image pair was shot from each station (one above, the other below). Mainly, two different kinds of processing were conducted: the first by adjusting the whole sixteen image block using 16 GCP, materialized on the cippus with special targets surveyed by total station; the second without GCP, performing an intrinsic block adjustment just using corresponding points suitably observed on different images.

| Survey type | RMS Average value (pixel) | Maximum residual value (pixel) |
|---|---|---|
| With GCP | 1.35 | 4.21 |
| Without GCP | 1.44 | 4.57 |
| Pixel magnitude: 0.5 mm | | |

Table 1 – Photogrammetric survey results.

In order to check the accuracy of the photogrammetric surveys, 49 natural points were also determined by total station and their relative positions were compared to those derived in the two kinds of processing.

The results confirm an accuracy at millimeter level, suited for most and maybe for all archaeological applications.

### *Database for archaeological aspects of buildings in the Roman municipality*

The purpose of the database is to document all the archaeological aspects of private and public buildings and areas in the territory of the Roman municipality, both according to the rules included in the "Codice dei Beni Culturali e del Paesaggio" and to the previous laws.

Database was designed and a prototype was implemented by Microsoft Access 2000; all the information regarding the approx. 300 aspects will be collected and organized in order to enable a simple update in real time.

In this way, SASR will be able to provide on computer support (CDRom) or online a complete and updated documentation, allowing for easy and fast consultation by SASR or public officials, private individuals and companies.

The structure of the database is simple and intuitive, with few fields to fill for the purpose of speeding up its management and update. We planned an external directory containing only the raster map for each aspect (taken from the SASR archives) so that the user can easily find its location and a series of external directories supplying all the accessory information about each Ministerial Decree, instituting an archaeological feature. The directories are connected to the database.

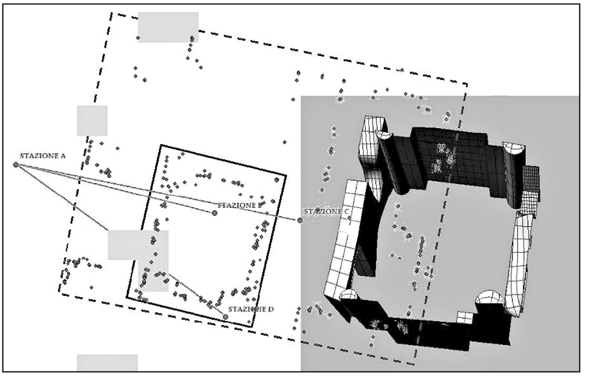


Fig. 5 – Surveyed rests of the Roman villa in the municipality Monte Porzio Catone (Rome province).

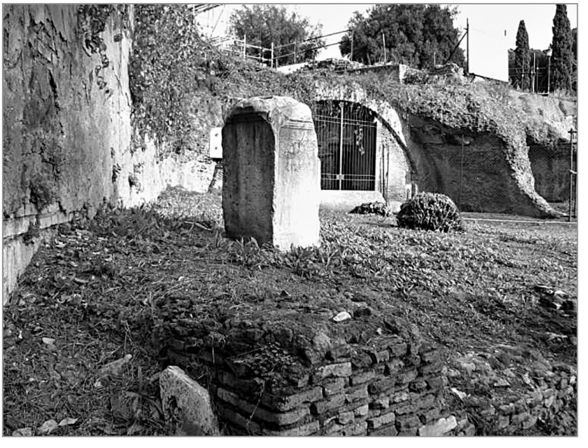

Fig. 6 – The cippus on the Monte Oppio, near Engineering Faculty of the University “La Sapienza”.

Consequently, the SASR officials will be able to manage all the documents connected to the various Ministerial Decrees (technical reports, administrative correspondence, precedent laws). The documents in the directories will be indexed and ordered according to standard codes.

There are several advantages offered by this database:

- Possibility of getting queries about features and supplementary documents in the external directories.
- Possibility of connecting the archaeological aspects database to other municipal, provincial, regional and national databases.
- Possibility of easily supplying the whole documentation related to the administrative management of the archaeological data both to the SASR and public officials, to private individuals and companies in a short time.

- Possibility of updating and complementing the database with other types of features (landscape, monumental, etc.).

*Tie alphanumeric code*

Special mention should be made of the possibility to introduce an alphanumeric code connected to the database for the unambiguous definition of the elements related to each feature. The code should consist of a standard bar code that, for each feature, responds with information of specific interest for the SASR.

The creation of an alphanumeric code for the archaeological features would allow SASR to achieve a leading position in the definition of a standard that classifies all the known archaeological features within the national territory.

## Chronology

The S.I.T.A.S. project should proceed according to the following two phases. In the first one, a stand-alone GIS will be created, in which the spatial databases will be created and the maps inserted; in this last respect, the cartographic database could be integrated by historical maps. The structure of the GIS will be organized in a few principal layers (3 to 5), in order to simplify access by the SASR employees and officials, the data input and the realization of structured queries according to their needs.

In the second phase the GIS should be transformed in a Web-GIS, in order to make all the collected and structured information available online.

Consequently, from a technical point of view, a semi-automatic update of the database will be possible through the contribution of each archaeologist working in the field who will supply all the data (qualitative and geometric) related to the excavation, using a standardized form available online.

## Conclusions and prospects

S.I.T.A.S. and In.Forma constitute a synergetic project representing an unusual application of the new geomatics techniques to urban archaeology. They will make efficient, fast, low cost and standardized archaeological data collection, archiving, management and interpretation possible and may play a significant role in improving heritage preservation and urban planning in a reality as complex as that of Roman archaeology.

A possible and expected by-product of the project is to force archaeologists to learn new geomatic techniques which certainly might improve and standardize the quality of the data they collect, manage and analyze.

Further investigations and experiments are certainly required in order to completely develop the whole project; in this respect the cooperation with SASR officials which has already been initiated is crucial.

Two main research paths have to be followed in the near future: low cost GPS receivers suited for DGPS surveys must be tested in order to assess the achievable accuracy in urban environment; open-source GIS and Web-GIS must be concerned in order to lower the designed system cost and to facilitate customizations, according to recent indications of the Ministry for Innovation regarding the e-government.

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# Nabonidus – Archaeological Data Management Software (www.nabonidus.org/)

## Introduction

A new online archaeological data management application called Nabonidus was launched to the public just over two months ago. Named after (arguably) the first archaeologist and the last King of Babylon, Nabonidus aims to help archaeologists store and share their excavation data online. Like many new tools on the web Nabonidus is free and although it is still in "Beta" it offers a good range of functionality. In this article we hope to outline the current functionality of Nabonidus, explain why we feel there is a need for such an application and reveal future developments.

## Functionality

Nabonidus is an online application for the management of Archaeological Data. It was built to make the task of gathering, analyzing and storing archaeological excavation data easy and aims to serve multiple roles in archaeological research. It can be in use from trench-side[1] to archaeological research years post excavation. Nabonidus offers users the ability to store all raw excavation data and it also offers reporting and analytic tools capable of aiding real time excavation decisions. It manages all excavation data and offers publication quality reporting. It also functions as a research tool for future generations to be able to access primary data and compare and analyze excavations.

Nabonidus provides data storage and manipulation and the capability to share and publish that data. Typologies can also be constructed for your excavation and, if you wish, matched to other sites enabling cross site referencing. This sort of functionality is offered to varying degrees in other archaeology data management software – the main difference with Nabonidus is that it is online making excavation data accessible at all times to all archaeologists and enabling the easy publication of this data to a wider audience.

## Flexibility

The Nabonidus system is flexible enough to cope with many different types of excavations. A broad survey of excavation recording methods across the world was done and rather than choosing one of these recording methods Nabonidus at-

[1] A desktop/mobile version of Nabonidus is currently in development. It is being built so that it will work in both connected and disconnected states. When excavating users can input data on their laptops or handheld devices and when an Internet connection becomes available this data can be uploaded to the online Nabonidus database making it available to the rest of their excavation team. It will be ready for a demonstration at the Berlin CAA Conference (http://www.caa2007.de/).

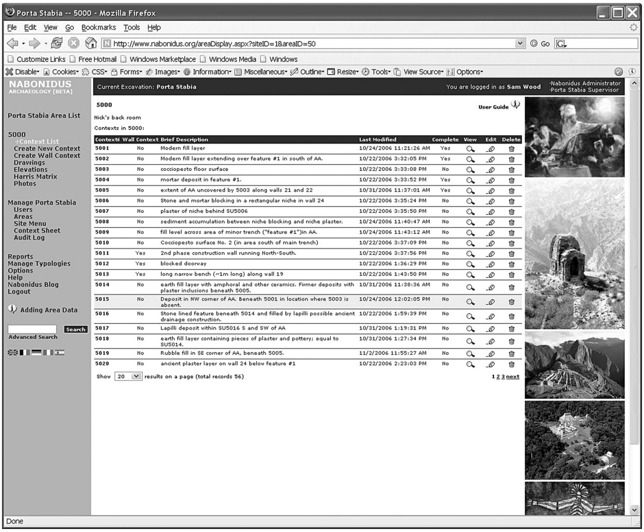



Fig. 1 – Sample context list from an excavation area.

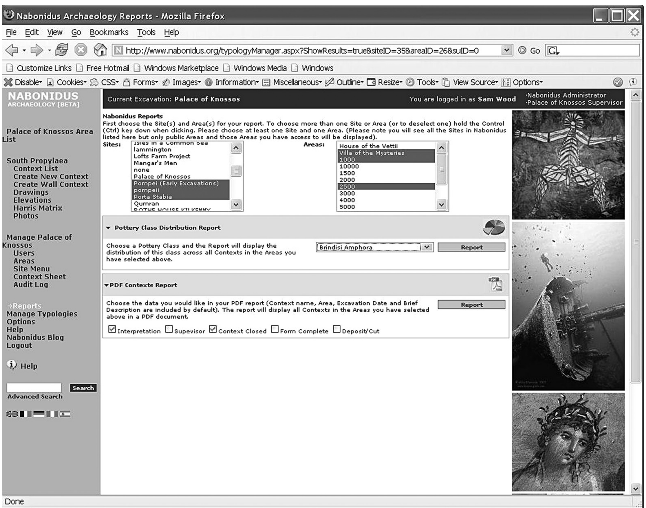



Fig. 2 – This reporting page allows users to compare multiple excavation sites. The user can request PDF or pie chart output.

tempts to incorporate them all. This does not mean that Nabonidus users have to use all of the fields offered by Nabonidus, rather it means that when they setup an excavation they have the choice of many fields for their recording forms and they also have the ability to add their own fields. These fields can be changed and added to mid-excavation as well. This seems to have worked well so far and provides enough commonality between excavations to make cross project analysis easy.

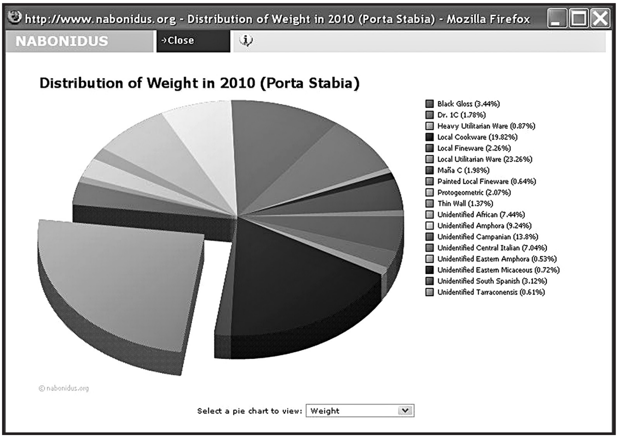



Fig. 3 – Pie Charts are created for all areas of artefact recording from broad charts like variations of metal to rim, base or pottery weight distribution in a context. Pie charts are also created for broader analysis showing pottery distributions across an area, site or multiple sites.

## Data privacy and standards

The philosophy behind Nabonidus is not to enforce any standards but rather to create a framework within which archaeologists can make their own decisions. It is hoped that as more archaeologists use a system like Nabonidus they will see the benefits of different recording systems and the benefits of cross site analysis. So standards describing archaeological data will evolve and perhaps we may even come to some agreement in the future on a standard way to describe excavation data!

## Security

Nabonidus offers multiple levels of access; from "administrator" access which allows total control over an excavation to "guest" rights where access is "read only". Nabonidus also recognizes the need for data privacy. Users are able to set their excavations to public or private enabling total security or free access to the general public respectively. This means initially Nabonidus won't have a great deal of publicly available data but as users become comfortable with the system and publish their findings this public archive will grow. This will become a very powerful and useful research archive for archaeologists.

Nabonidus also claims no rights over data entered by users-data is completely owned by excavations and can be removed at any time.

## Usability

Nabonidus incorporates a comprehensive help guide with demonstration 'walk-throughs' and instant help features. Nabonidus also supplies clear and beneficial output using pie charts, tables, Harris matrices and PDF files.

## Search

Nabonidus Archaeology has a powerful search engine. A user can search across multiple excavations or single excavations for any field – e.g. pottery class, deposit type, keywords etc. These searches could in the future be used as research tools to map distribution of artifacts, aid excavation decisions or identify an object excavated.

## Why Nabonidus?

Why is there a need for an application like Nabonidus? Archaeologists have always produced enormous quantities of data and technology can now allow archaeologists to get the maximum possible value out of that data. There are no second excavations so the information we obtain must be conclusive, manageable and most importantly useful. We are not the only concerned party but just the ones lucky enough to be first to access this raw archaeological information. There needs to be an appropriate way of managing, storing and sharing our data, Nabonidus provides that way.

The more data there is in Nabonidus the more useful a tool it will become. Obviously the archaeological community would gain access to this raw excavation data which is not an easy thing to do currently. Secondly, archaeologists would gain a new angle on the data with Nabonidus reporting tools and multiple excavation analysis. This notion of multiple excavation analysis was actually what prompted the building of Nabonidus. The ability to search across multiple excavations with just a few clicks is very compelling and could raise many archaeological questions and possibly answers.

There are also "by-products" of the development of Nabonidus. It has a typology section for pottery which could prove to be a powerful tool for archaeologists in the future. As data is collected this online typology of pottery from around the world will grow, integrating excavations from different countries, showing distribution, trade as well as being extremely useful for identifying finds in the field.

## Technical details

Nabonidus was built using the .Net Framework Version 2.0[2] and with free development tools. The actual website was built using Web Developer Express[3] and uses a Sql Server Express database[4].

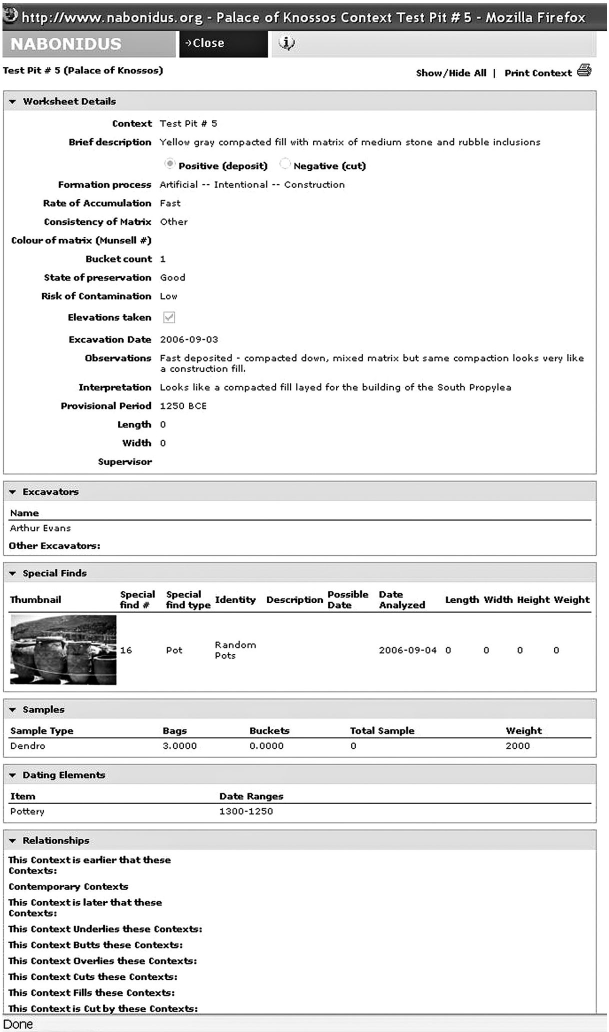
It is currently in "Beta" and will evolve and grow according to archaeologists' needs. It was architected and built on a voluntary basis by Sam Wood of the British Museum and software professionals from Ramapithecus Technologies[5].

[2] http://msdn2.microsoft.com/en-us/netframework/default.aspx

[3] http://msdn.microsoft.com/vstudio/express/vwd/

[4] http://msdn.microsoft.com/vstudio/express/sql/default.aspx

[5] http://www.ramapithecuscorporation.com/



http://www.nabonidus.org - Palace of Knossos Context Test Pit # 5 - Mozilla Firefox

NABONIDUS →Close

Test Pit # 5 (Palace of Knossos) Show/Hide All | Print Context

**Worksheet Details**

| | |
|---|---|
| Context | Test Pit # 5 |
| Brief description | Yellow gray compacted fill with matrix of medium stone and rubble inclusions |
| | Positive (deposit) Negative (cut) |
| Formation process | Artificial -- Intentional -- Construction |
| Rate of Accumulation | Fast |
| Consistency of Matrix | Other |
| Colour of matrix (Munsell #) | |
| Bucket count | 1 |
| State of preservation | Good |
| Risk of Contamination | Low |
| Elevations taken | |
| Excavation Date | 2006-09-03 |
| Observations | Fast deposited - compacted down, mixed matrix but same compaction looks very like a construction fill. |
| Interpretation | Looks like a compacted fill layed for the building of the South Propylea |
| Provisional Period | 1250 BCE |
| Length | 0 |
| Width | 0 |
| Supervisor | |

**Excavators**

| Name |
|---|
| Arthur Evans |

Other Excavators:

**Special Finds**

| Thumbnail | Special find # | Special find type | Identity | Description | Possible Date | Date Analyzed | Length | Width | Height | Weight |
|---|---|---|---|---|---|---|---|---|---|---|
| | 16 | Pot | Random Pots | | | 2006-09-04 | 0 | 0 | 0 | 0 |

**Samples**

| Sample Type | Bags | Buckets | Total Sample | Weight |
|---|---|---|---|---|
| Dendro | 3.0000 | 0.0000 | 0 | 2000 |

**Dating Elements**

| Item | Date Ranges |
|---|---|
| Pottery | 1300-1250 |

**Relationships**

This Context is earlier that these Contexts:
Contemporary Contexts
This Context is later that these Contexts:
This Context Underlies these Contexts:
This Context Butts these Contexts:
This Context Overlies these Contexts:
This Context Cuts these Contexts:
This Context Fills these Contexts:
This Context is Cut by these Contexts:

Done

Fig. 4 – Sample Nabonidus context report. It can be customized to show different aspects of a context.

## Future developments

All future development will be driven by the users of Nabonidus. Future versions will include:

- Desktop/mobile version for use onsite. We aim to build a version of Nabonidus that you can install on your laptop or mobile device and use to input data whilst on an excavation. When an Internet connection becomes available you will be given the opportunity to upload your data to the website.
- Integration with GIS applications.

- Data Import and Export functionality. We realise a lot of users currently have data in other databases and formats and would like to import that data to their Nabonidus excavation. We also realise that a lot of archaeologists have tools and applications they use to analyse their data and it would be useful for them if they could export data out of Nabonidus and into their other applications. We are working on a solution to both these scenarios.
- Survey component. An independent sheet on the same level as the context and wall context pages for the recording of survey data. The data, as with all Nabonidus data will be adaptable to individual excavation needs.
- More reporting. Distribution of pottery classes across whole areas and sites. Cross Excavation analysis. .PDF output for reporting.
- Public facing page for excavations to publish information about their dig to the general public.
- Document repository. Allow excavations to store all their documents online along with their excavation data.
- EVE – Estimated Vessel Equivalent.

Most importantly Nabonidus is currently in discussions with the Alexandria Project to enable sharing of data via web services between the OpenContext[6] project and Nabonidus. Nabonidus is also discussing with Online-archaeology[7] the possibility of connecting to their Google Maps server to enable the mapping of Nabonidus excavations.

## Conclusion

Nabonidus could be an extremely useful tool for the archaeological community. The future of Nabonidus lies with expanding its current feature set and combining with other archaeological bodies on the Internet to gain some consensus as to how archaeologists want record and publish their data. The future of Nabonidus can really only be driven by the archaeological community if they see the potential and demand for such an application. The potential benefits could be great; a centralized, online store for archaeological data, the ability to easily analyze across multiple excavations and simple publishing of excavation data and findings to the general public.

Nabonidus will be guided by the archaeological community. If you have any questions, comments or suggestions visit our blog http://www.nabonidus.blogspot.com/ or email administrator@nabonidus.org.

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[6] http://www.opencontext.org/

[7] http://www.online-archaeology.co.uk/

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*Landscape Archaeology and GIS*. By H. Chapman, Stroud, Tempus, 2006.

*Paesaggi archeologici e tecnologie digitali. Laser scanner e GPS*. Edited by S. Campana and R. Francovich, Firenze, All'Insegna del Giglio, 2006.

*Trainings Offerings and Needs in Europe on ICT Applications to Cultural Heritage*. Edited by F. Niccolucci (http://www.epoch-net.org/index.php?option=com_content&task=view&id=167&Itemid=258).