The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2006)
M. Ioannides, D. Arnold, F. Niccolucci, K. Mania (Editors)

Project Papers

3D Laser Scanning as a Tool for Conservation: The Experiences of the Herculaneum Conservation Project

M. Brizzi,[1,2] S. Court,[1] A. d'Andrea,[1,2] A. Lastra[3] and D. Sepio[1,2]

[1]The Herculaneum Conservation Project, c/o The British School at Rome, Via Gramsci 61, 00197 Roma, Italy hcp@herculaneum.org
[2]Akhet Srl, Via Alessandro Volta 42, 00153 Roma, Italy
[3] Department of Computer Science, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA

Abstract

The Herculaneum Conservation Project (HCP) is a project of the Packard Humanities Institute in collaboration with the Soprintendenza Archeologica di Pompei and the British School at Rome. The ancient Roman city of Herculaneum (Italy), which was destroyed and buried along with Pompeii by the volcanic eruption of Vesuvius in AD 79, has a history of excavation dating back to the early eighteenth century. The project arose from a recognition of the risks to the survival of the unique and irreplaceable heritage to be found in Herculaneum. Its aim is both to support the Italian heritage agency in the protection and preservation of the site, and to extend scientific understanding and public interest and awareness. The most immediate task is to halt the widespread decay afflicting the entire site. The longer-term aim is to develop a conservation strategy which will ensure its survival, understanding and enhancement. The project aspires to learn lessons that will not only feed into the management of the site of Herculaneum, but that can enrich conservation working practices in Pompeii and elsewhere.

In 2006 trials were launched to see how three-dimensional laser scanning could help the project, not only in terms of documentation, but also as a tool for monitoring decay and informing conservation decisions, and as a source of rich but accurate visual material to illustrate areas of the site currently closed for conservation works and thereby enhance the visitor experience. In collaboration with the University of North Carolina, the Suburban Baths were chosen for trial survey work with a 3rdTech Inc. DeltaSphere-3000 laser scanner. This Roman bathing complex is remarkably well-preserved with intact wood, metal and decorative features, but the delicate nature of these architectural features together with a variety of grave conservation problems throughout the structure mean the area is currently closed to visitors. The 3D survey work was carried out as an analytical basis for the technical/scientific studies that are underway in this building in order to conserve it and reopen it to the public.

This paper describes the experience of the HCP team using the 3D laser scanner, and discusses the success and challenges of the work and the potential applications the results have both for the mix of heritage professionals working within the HCP team and for the wider public.

Categories and Subject Descriptors (according to ACM CCS): I.4.1 [Image Processing and Computer Vision]: Digitization and Image Capture; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

1. Introduction to Herculaneum and the Herculaneum Conservation Project

The archaeological site of Herculaneum is located just south of Naples in Italy, and contains a large part of the Roman city that was buried by volcanic material during the eruption of Mount Vesuvius in AD 79. The nature of the city's destruction has led to a remarkable state of preservation, and the site is of particular note for the survival of buildings up to a height of several storeys, often with decorative features, fixtures and fittings intact, including a wealth of organic remains (wood, food stuffs, cloth, rope, etc).

When the most ambitious campaign of open-air excavations were carried out at Herculaneum in the early twentieth century, a programme of conservation and maintenance was launched and, for an initial period this ensured that although the archaeological remains were exposed to the elements they were offered some level of protection. However, within the later half of the twentieth century these programmes began to suffer a reduction in resources and eventually failed, leaving the site in an ever more serious state of decay with every year that passed.

In 2000 Dr David W. Packard of the *Packard Humanities Institute* visited Herculaneum and was so concerned about the conditions on site that he decided to launch a project to tackle the conservation issues. In 2001 an agreement was reached between the *Packard Humanities Institute* and the local heritage agency, the *Soprintendenza Archeologica di Pompei*, which resulted in the *Herculaneum Conservation Project* (www.herculaneum.org) [GCR05; CMRW06]. The project was further strengthened by the entry of the *British School at Rome* in 2004. These three partners continue to work together to identify and tackle the causes of decay on site and to develop a long-term conservation strategy that will ensure Herculaneum's survival, understanding and enhancement. The project aspires to learn lessons that will not only feed into the management of the site of Herculaneum, but that can enrich conservation working practices in Pompeii and elsewhere (for another example of a multidisciplinary conservation project tackling issues of data management see [Won05]).

The *Herculaneum Conservation Project* is made up of various specialists representing many different heritage professions, and this allows the site's conservation issues to be tackled by a multidisciplinary team. One of the areas that is being explored by a team from the archaeological company *Akhet* is survey, documentation and information management; and it was within this area that a collaboration was formed with the *University of North Carolina at Chapel Hill* for test surveys with a three-dimensional laser scanner. The first trials with this equipment were carried out in Herculaneum's Suburban Baths, a building chosen because of its archaeological importance, its closed spaces and the serious nature of its decay.

2. The Suburban Baths

The Suburban Baths were built in the Flavian period, next to the block of houses known as the *Insula Orientalis I*, on the side that faces onto the ancient shoreline (fig. 1). This building is the second large public bath complex known in Herculaneum, where so far only a single house has been found to have private bathing facilities.

Fig. 1: *View of the Suburban Baths in context at Herculaneum.*

Herculaneum's Suburban Baths are the best conserved bath complex that survives from antiquity (fig. 2); they are entered from an open area (probably used as a *palaestra*), through a door and down a flight of stairs (H1) to a vestibule (H/A), which is laid out around four central columns that support a double series of arches. From the vestibule the usual succession of differently heated rooms can be reached: the *frigidarium* (F) with a first pool of cold water, then a room with stucco decorations (E) from where, on one side, lies the *tepidarium* (T) with its large pool heated by a "samovar" system, and, on the other side, the *caldarium* (C) that still contains the large marble basin which was swept over by the volcanic mud flow and into which fell fragments of the smashed window glass. The baths were also equipped with a *laconicum* (L), or sauna room, accessible from the *tepidarium*, and a room with large panoramic windows overlooking the sea (D), which was also connected to the vestibule.

The topographical location of the baths with respect to the main urban area of the ancient city, and the dynamics that led to its burial in the AD 79 eruption, helped to ensure the

Fig. 2: *Plan of the Suburban Baths and their location within the archaeological site.*

complete preservation of the building's structure and a large part of its wall and floor decorations, as well as its furnishings and the bath's hydraulic infrastructure and some of the wooden fittings. In fact the mass of the volcanic material did not destroy the roof vaults, but entered inside the building and filled the rooms through doors and windows with such pressure that enabled it to fill the cavities between the walls and the typical linings found in Roman bath heating systems.

This extraordinary building is without equal in surviving ancient architecture, but its very uniqueness does however present extremely complex conservation problems, due to the range of materials it contains and the multiple causes of decay. Among the decay agents, it has been recognised that the main problem that the baths face is humidity, which is a consequence of the morphological and geological characteristics of the area (for an introduction to the research

Fig. 3: *The laser scanning equipment and some of the survey team at work.*

being carried out on water in Herculaneum, both its ancient supply and drainage systems, and the problems it currently causes, see [CMTW06]). The baths are in fact saturated both by surface water that drains off the *domus* above, and by ground water as it flows down to the sea. This problem, which surely existed in ancient times as well, has led to the deterioration of some of the vault linings of the *tepidarium* and has caused the Superintendency to close the building to the public.

Over the last year or so the *Herculaneum Conservation Project*, and its specialised team led by water engineer Ippolito Massari, has been monitoring the humidity levels in the building and proposals are being developed to solve the various problems brought about by the water infiltration and rising damp that are putting the building's conservation at risk.

3. Equipment

Three dimensional modelling of cultural heritage sites and objects using a laser scanner is a fairly recent technique. There is, of course, a long history of survey using theodolites and photogrammetry. A great deal of the earlier laser scanning work concentrated on statues and other objects [e.g. LPC*00]. More recently there have been projects to create dense 3D models of exteriors and interiors of cultural-heritage buildings and sites [AST*03; EBP*04; GLSA05].

The equipment used for the survey of the Suburban Baths was a *3rdTech Inc*. DeltaSphere-3000 laser scanner, which was kindly made available by Prof. Anselmo Lastra of the Department of Computer Science at the *University of North Carolina at Chapel Hill*; and the survey data were then managed with the associated software SceneVision-3D.

The DeltaSphere was designed for surveying small to medium spaces, and is primarily used by scientific police departments for crime scene surveys. It contains an infrared laser range-finder that uses a time-of-flight technique to compute the distance to the nearest points. A spinning mirror is used to capture the range to points in a vertical slice, and a motor rotates the complete unit to capture a total of 360° horizontally by 270° vertically. The measurements are accurate to ±0.3cm over a range of 0.3-15m.

Since the number of samples captured per degree can be set over a range from 5-20, the amount of data generated is quite large. The DeltaSphere is connected to a PC, usually a laptop for convenience in the field, in order to store the data on disk. This also enables monitoring as the scan is being collected. A colour option includes a digital camera that can be mounted on the unit. Technical details of the prototype from which the commercial produce was developed are available in [NLM*01].

With this scanner it is possible to register various scans without using georeferenced points, but instead by using those areas of scanned points that they have in common. This is done by using the iterative closest point (ICP) algorithm [BM92]. The operator chooses a small number of points to obtain an initial registration, and the algorithm refines the solution by minimizing the distance between the sets of points. The scans to be registered must contain enough overlap to ensure that ICP can reach a unique solution.

Another property of the instrument and its associated software is the possibility of mapping the surveyed surfaces both with photographs taken contextually with the scan, as well as with images taken from different positions. Currently points of correspondence between the colour and range images are chosen manually, but we expect that in the future it will be possible to map colour automatically [WLH*04; HL04].

Both the automated registration and the ability to map arbitrary colour images to range samples make work in the field much quicker. The SceneVision package includes a polygonal simplification [LRC*02] module that reduces the size of the captures geometric model in order to enable interactive display on a PC:

4. Fieldwork

After training for the survey team and a brief trial period, work was divided into two phases with the creation of a 3D model as the end result. Time issues related to the restricted availability of the equipment and limited access to the bath building led to a first fieldwork phase where all the numeric and photographic data were acquired; only later in a second phase was the data processing carried out and the model created.

The fieldwork phase lasted about four weeks, during which the measurements and photographs necessary for generating the model were acquired (fig. 3). In this phase various problems arose. For example, it was necessary to set up a number of survey stations, due to the quantity and characteristics of the spaces which make up the bath complex. There are a series of quite small rooms, with high vaults, that in some cases are two floors high (fig. 4).

Fig. 4: *An example of the complexity of the building's spaces.*

Another problem that is common to any type of survey carried out with a laser scanner, is the scanner's (and the camera's) viewpoint. The increased number of survey stations necessary to cover the rooms' surfaces was caused by the presence of protruding parts of the walls (stucco or plasterwork features), rather than corners or objects within the rooms (for example, scaffolding used for conservation work in progress). It also often proved to be difficult to move the equipment in the restricted spaces (fig. 5).

Alongside the scanning in the field, photographs were taken to create the 3D model. In this case the biggest difficulties were those related to the different light levels. The bath complex is partly on an underground level made up of closed spaces with marked variations in the amount of light, due to the various light sources (small windows in the walls or ceilings). This made it particularly difficult to obtain uniform images in terms of luminosity and contrast within each of the different rooms.

The high humidity levels in the rooms (see above) and the subsequent presence of dark-coloured mould and lichens also created problems for the scanner: the reflection of the laser ray, by which the triple coordinates of every single surveyed point are registered, either did not register or was extremely weak.

Where there were black surfaces, holes appeared in the mesh of points (although it should be noted that often surfaces that seemed black, were not so for the infrared frequencies and resulted in optimal surveys). A similar problem was found in those areas of the building where there was a significant amount of water on the walls, which equally limited the rays' ability to reflect.

5. Data processing and model creation

The model of the Suburban Baths is currently being finalized using the software SceneVision-3D, which is also by *3rdTech Inc*.

The aligning of single scans, so that the entire volume of the rooms is covered, is done by using common surveyed points, as mentioned above.

The next step is to also align the individual digital images that were recorded contextually with the scan in the field. At this stage it is necessary to ensure that the model's surface points are identified and made to correspond with the same ones on the images. In this way a point cloud is created, where every pixel of the image is associated with a numeric value and colour (fig. 6).

The final 3D model is produced by creating a triangulated irregular network (or TIN) by interpolating the measurements, which are then draped with digital images. It is saved as a VRML file, which is a 3D file format that can be exported, and that is readable with various visualizers freely available on the internet (the software used can also create a high resolution 3D model in the same way, but one with a regular mesh that respects the totality of the surveyed points, instead of an irregular TIN). The VRML standard makes it possible to import the 3D model into more common 3D graphic software programs (fig. 7).

In order to guarantee realistic perception of the model, particular care was taken to reprocess all the digital images, correcting their luminosity, contrast and colour uniformity.

In general terms the data processing phase, from the alignment of the scans to the texturization, proved to be long and complex; it was necessary to change format and use various 3D modelling software packages and adequate hardware. In fact it has been calculated that for every day of data gathering in the field a week of processing is needed in the office.

Fig. 5: *Some examples of the difficulties met during the survey work.*

Fig. 6: *Above: a complete 360° scan; below: the alignment of a digital image and the application of colour onto the scan.*

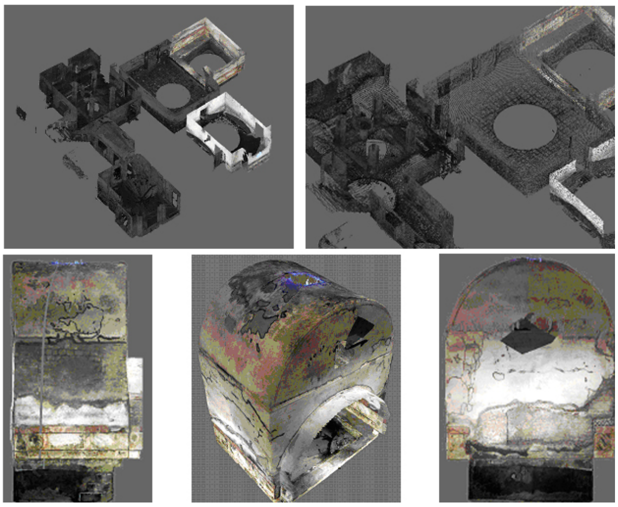

Fig. 7: *Above: views of the 3D model under construction; below centre: prospective view of a room, below left and right: two orthographic views.*

6. Results

The immediate result of creating a texturized digital model is an extremely realistic 3D virtual environment that can then be utilized as the basis for other uses (fig. 8).

The processing software contains tools that can take measurements (linear distances and angles) directly within the 3D model as soon as it is generated (fig. 9). The data are recorded as text notes that can be recalled and modified according to need. Other graphic editing tools allow linear and polygonal elements to be drawn on the model, and these can be labelled either with alphanumeric and hyperlink labels that connect to external data (files or database records). These created elements themselves can be exported in VRML format and managed separately within the graphic processing software.

Considering the normal requirements of an architectural survey, the numeric model has the capacity to totally describe a surveyed object and offer a result that is very similar to reality. Unlike traditional surveys, where only a small number of an object's points are measured (meaning that the missing and interpreted areas are greater than the data objectively surveyed), with the 3D scanner the object's surfaces enormous numbers of points are measured and represented by a mesh obtained from their interpolation. This theoretically allows an infinite number of two-dimensional projective models (plans, sections and elevations) and three-dimensional models to be created, which are not dependent on the viewpoints established *a priori*. The possibility of having available the total coverage of a building, in terms of data acquisition, changes the very idea of a survey and its scale of reference. Unlike a traditional plan where the choice of section cannot be changed, 3D laser scanner technology allows sections to be created through the digital model at any point according to what is required. This is as true for the horizontal planes (plans) as for the vertical ones (sections and elevations; fig. 10).

However, faced with these undeniable advantages the real needs of the survey archaeologist should not be forgotten, whereby the main aim of any survey is to gain critical information, whatever the nominal scale that it is done at. It is only by direct observation that an object can be defined, divided into its component parts, characterised and interpreted.

Fig. 8: *Prospective view of the model with various of rooms joined together.*

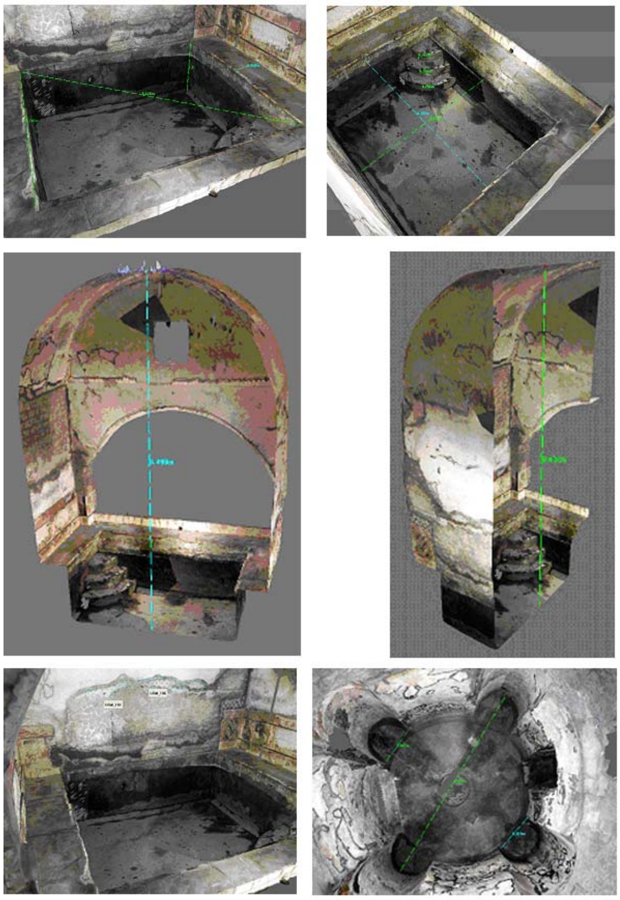

Fig. 9: *Examples of measurements and analysis of parts of the model within the management software.*

Therefore, only if the two methodologies – old and new – are thoughtfully integrated can the best results be obtained in terms of representation, comprehension and transmission of data – all by definition fundamental elements of a good archaeological survey.

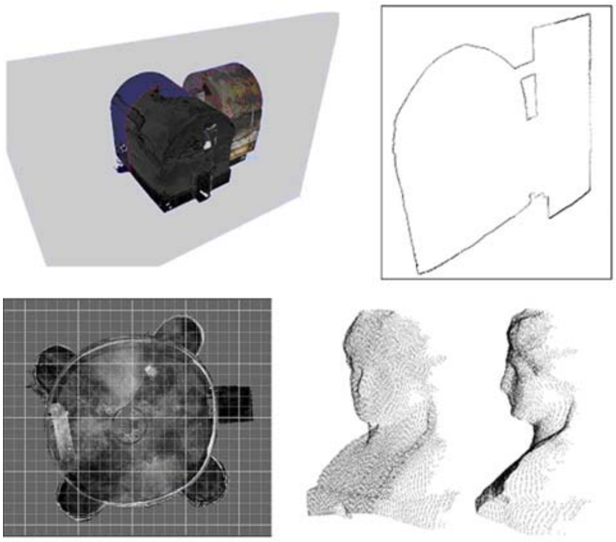

Fig. 10: *Examples of sections or plans drawn from the model.*

Another application of the model relates to data management in a 3D GIS environment for an interdisciplinary analysis of a structure. Within the *Herculaneum Conservation Project*, a geodatabase was created for Herculaneum's *Insula Orientalis I* [BDS*05]. It was structured so as to archive the graphic documentation and recording forms used in archaeological analyses and conservation interventions. In this case the 3D model was created from plans and elevations obtained with traditional methods (direct instrument survey and rectified digital photographs). The aim was to create a 3D model to which the spatial and alphanumeric information could be linked, and then managed with GIS software.

In the case of the Suburban Baths, should a similar research project be launched there, it would be possible to use the model obtained with the laser scanner for the 3D spatial basis, greatly facilitating the documentation of every single element of the building.

The use of the laser scanner offers another possible application, as by using processing software it is possible to drape the 3D model with images that were not taken at the same time as the scan.

The model can be used as a very detailed base onto which archive images can be aligned, for a comparison between the state of the structure at the time of its discovery and the current situation (fig. 11). Obviously this method can also be applied to images that were taken from various photographic campaigns, without the need of taking new scans. It is clear that this would allow an almost continual monitoring of the decorative features' and the structure's state of decay (for another example of the application of 3D laser scanning to the recording and monitoring of archaeological sites see [BCD*05]). In this context, the possibility of carrying out scans only of those areas that are subject to specific forms of decay or that need particular attention could be considered, and these scans could then go to integrate or update an already existing scan.

In fact, a modest campaign of emergency laser scanning was recently carried out by *Akhet* on spaces across Herculaneum that are both spatially and decoratively elaborate, and that are particularly vulnerable to immediate loss of archaeological features (due to the speed of deterioration and the difficulties of intervening promptly). This allowed the project to exploit the potential for rapid data collection with data processing at a later stage.

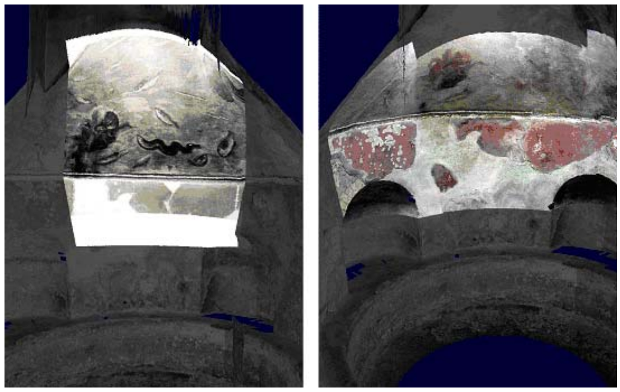

Fig. 11: *Example of the model using a photograph taken during the scan (right), compared to an archive photo (left).*

In the case of the Suburban Baths, the building's state of decay caused the closure of the complex to the public. However, the use of this technology has allowed us to create complete graphic documentation (3D and photographic surveys). It will be possible to create a virtual tour within the model, which would immediately allow the architectural spaces to be experienced and also shows the decorative complexity of the building. This is undoubtedly a huge advantage offered by this survey technique. The texturized digital model is, in fact, an extremely realistic environment that can constitute the base for any type of multimedia processing of the product (video, virtual reality, etc) in such a way as to allow a building to be enjoyed both in cases when it becomes inaccessible, as well as in the case where the archaeological site is at a distance (virtual tours via the internet, for example). The *Herculaneum Conservation Project* will be exploring the best ways to offer this potential tool to visitors to the site, and to a distant but interested public online, as part of a research and outreach programme (for example, the use of IT applications for distance learning of heritage subjects has been explored more thoroughly in the case of the ancient history syllabus in New South Wales, Australia where Herculaneum is studied by around 10,000 students a year, the majority of whom cannot visit the site in person, see [Cou06]).

7. Conclusions

The opportunity offered by the collaboration with the *University of North Carolina at Chapel Hill* to experiment with laser scan surveying was not only advantageous to the *Herculaneum Conservation Project* in terms of data acquisition and technological advances, but also because it offered a chance to employ a reflexive methodology.

The latest technology does not necessarily present the best choice in conservation, as it can be time-consuming without offering concrete benefits beyond the aesthetic. Technology can also create a certain distance between the archaeological remains and the surveyor, which does not contribute to thoughtful analysis and consideration of a structure's complex history and conservation needs. However, where technology is thoughtfully employed the benefits can be great. In this case, the *Herculaneum Conservation Project* benefited from the fact that the *3rdTech Inc*. DeltaSphere-3000 laser scanner, and related software, is a tried and tested instrument used widely by law enforcement agencies in the USA, as this offered us advanced technology that had already undergone extensive "road testing" and ensured optimum application. 3D laser scanning is being tested for its use in long-term monitoring of decay situations (even from periods prior to the project that are only documented in archive photographs), and for its ability to offer almost infinite views of the building, which will prove incredibly helpful in future conservation efforts.

From this strictly technical point of view the 3D laser scanner technology is an increasingly important tool for archaeological survey and restoration work. However, this work should also be seen in the light of the Herculaneum Conservation Project's efforts not only to be multidisciplinary in its planning stages but also in the more delicate site-works phase. Work on site notoriously requires flexibility, speed and the immediate use of analytical data in order to develop linear operations, and in these cases a 3D laser scan of an entire building complex (such as the Suburban Baths) can provide rapid data acquisition and complete data coverage. These two basic elements then become "common ground" for discussion among all the consultants, present and future.

From our point of view a 3D model offers: an extremely flexible tool that can instantly create plans or sections for the planning phase of works (for architects); an objective basis from which to monitor and evaluate static and environmental risks (for architects, structural engineers, conservator-restorers); a method for comparing past graphic and photographic documentation (for conservator-restorers, archaeologists); a three-dimensional basis for managing GIS data (for archaeologists, conservator-restorers, technical experts); a starting point for creating hypothetical virtual reconstructions (for archaeologists); an opportunity for academics and members of the wider public to "visit" a building that is inaccessible during conservation works or at a long distance (for the public).

The spirit of this initiative was to provide a practical tool while experimenting and comparing different approaches to surveying in an archaeological and conservation context. If this perhaps appears to be simply the latest 3D laser scanning project, it should also be noted that a specific effort was made to ensure that a thorough and high-quality project was carried out in order to define the limits and advantages of this tool within a multidisciplinary and symbiotic project – perhaps establishing a further point of departure for the evaluation of new technologies in this particular applied field.

8. Acknowledgements

The work described in this paper was carried out as part of the *Herculaneum Conservation Project*, and we would like to acknowledge and thank the project partners: the *Packard Humanities Institute,* the *Soprintendenza Archeologica di Pompei* and the *British School at Rome*. In addition thanks are due to all the *Herculaneum Conservation Project* team who continually offer positive input to each aspect of activity on site, and in particular to Jane Thompson and Domenico Camardo, who offered feedback on drafts on this paper.

Finally, we would like to recognise the generosity of the Department of Computer Science at the *University of North Carolina at Chapel Hill* who loaned us the 3D laser scanner equipment, and we are particularly grateful for the energy and expertise of Prof. Anselmo Lastra.

9. References

[AST*03] ALLEN, P., STAMOS, I., TROCCOLI, A., SMITH, B., LEORDEANU, M. & MURRAY, S. New Methods for Digital Modeling of Historic Sites. In *IEEE Computer Graphics and Applications* (2003), 32-41.

[BCD*05] BARNETT, T., CHALMERS, A., DÌAZ-ANDREU, M., LONGHURST, P., ELLIS, G., SHARPE, K. & TRINKS, I. 3D laser scanning for recording and monitoring rock art erosion. In *International Newsletter on Rock Art 41* (2005), 25-29.

[BDS*05] BRIZZI, M., D'ANDREA, A., SEPIO, D., DE SILVA, M. & COURT, S.: Planning a conservation project: the information system of the Insula Orientalis I. In *International Cooperation to Save the World's Heritage: CIPA 2005 XX Symposium, 26 September-1 October 2005, Torino, Italy* (2005), 691.

[BM92] BESL, P.J. & MCKAY, N.D.: A method for registration of 3D shapes. In *IEEE Pattern Analysis and Machine Intelligence 14* (1992), 239-256.

[CMRW06] CAMARDO, D., MARTELLI CASTALDI, M., RIZZI, G. & WALLACE-HADRILL, A.: The Herculaneum Conservation Project. *Oebalus 1* (2006).

[CMTW06] CAMARDO, D., MARTELLI CASTALDI, M., THOMPSON, J., & WALLACE-HADRILL, A.: Water supply and drainage at Herculaneum. In *Die Symposiumsakten "Cura Aquarum in Ephesus"* (2006).

[Cou06] COURT, S.: The Herculaneum Conservation Project and learning initiatives. *Teaching History 39*, 4 (2006), 38-44.

[GLSA05] GIUFFRIDA, A., LIUZZO, M., SANTAGATI, C., ANDREOZZI, L. The laser scanner for archaeological survey: "Le Terme Dell'indirizzo" In *Proceedings of CIPA* (2005).

[EBP*04] EL-HAKIM, S., BERALDIN, A., PICARD, M. & GODIN, G. Detailed 3D reconstruction of large-scale heritage sites with integrated techniques. In *IEEE Computer Graphics and Applications 24.3* (2004), 21-29.

[GCR05] GUIDOBALDI, M.P., CAMARDO, D. & RIZZI, G. (2005) The Herculaneum Conservation Project. In *Nuove ricerche archeologiche a Pompei ed Ercolano* (2005), 9-18.

[HL06] HANTAK, C. & LASTRA, A. Metrics and optimization techniques for registration of color to laser range scans. In *Third International Symposium on 3D Data Processing, Visualization and Transmission* (2006).

[LPC*00] LEVOY, M., PULLI, K., CURLESS, B. ET AL. The digital Michelangelo project: 3D scanning of large statues. In *Proceedings of SIGGRAPH* (2000), 131-144.

[LRC*02] LUEBKE, D., REDDY, M., COHEN, J., VARSHNEY, A., WATSON, B. & HUEBNER, R. *Level of Detail for 3D Graphics.* Morgan-Kaufmann, 2002.

[NLM*01] NYLAND, L., LASTRA, A., MCALLISTER, D., POPESCU, V. & MCCUE, C. Capturing, processing and rendering real-world scenes. In *Videometrics and Optical Methods for 3D Shape Measurement (SPIE 4309)* (2001), 107-116.

[WLH*04] WILLIAMS, N., LOW, K., HANTAK, C., POLLEFEYS, M. & LASTRA, A. Automatic image alignment for 3D environment modeling. In *Proceedings of the 17th Brazilian Symposium on Computer Graphics and Image Processing* (2004), 388-395.

[Won05] WONG, L. From Silk Road to digital domain: managing information for a wall paintings conservation project. In *Conservation: the Getty Conservation Institute Newsletter 20.3* (2005), 21-24.