Laser Scanner 3D Survey in Archaeological Field: the Forum Of Pompeii

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1. INTRODUCTION

In the last few years the problem of conservation and enhancement of the archaeological heritage, in Italy as well as in the rest of the world, has become a question of great interest[1], owing to the development of new technologies and methodologies which allow more efficient and less intrusive interventions in the architectural and archaeological heritage to be surveyed and protected.

Particulary in the field of architecture and archaeology, survey techniques based on the 3D laser scanner technology[2] have become very popular.

The development of the most widespread instrumental survey tecniques (topography, stereophotogrammetry, photographic survey aimed to digital processing up to GIS) has been considerable and has made it possible both the acquiring and the processing of a large amount of data. The 3D laser scanning represents one of the ultimate steps of the technological progress in the field of the morphological survey and it offers new and important opportunities. The continuous development and updating of such information techniques allow a wider use of them in activities related to any branch of the human and physical sciences; in particular, the Authors believe that such a progress will lead to the complete automatisation of the activities which can be managed via hypertext or GIS.

By using a 3D laser scanner technology the D.I.A.P.RE.M.[3] decided to superintend and to carry out the survey in order to draw up specific outputs to be used directly for conservation works according to requirements of the Ministery of Cultural Heritage. Moreover, while surveying, it was noted that 3D scanning methodology is applicable to different dimensional scales, not only to the survey of restricted archaeological remains and specific architectures but also to entire urban nuclei. Thus, the research project on Pompeii (Fig. 1) has become more and more interesting because it is now possible to create 3D models of the excavations based on laser scans suitably, integrated with other methodologies (topography, photogrammetry, reflectography,

[1] The interested reader may explore UNESCO's website at http://www.unesco.org/culture/

[2] M. Balzani (2001), *Rilievi tridimensionali con laser scanners 3D. Sperimentazione per l'architettura e i beni artistici*, Frontiere del rilievo 5, Cangemi editore, pp. 59-104; M. Balzani, M. Gaiani, L. Seccia, N. Santopuoli (2000) Morfologia e caratterizzazione colorimetrica e spettrale di elementi architettonici, *Disegnare* 18/19, pp. 133–142; M. Balzani, M. Gaiani, F. Uccelli (2000) Forma e Colore del Colosseo, *Paesaggio Urbano*, 1, pp. 70–71; M. Balzani, M. Gaiani, F.Uccelli, N. Santopuoli, L. Seccia (2000) Rilievi Tridimensionali e Indagini colorimetriche per il restauro e la conservazione: il cantiere del Colosseo, *Quaderni di Ottica e fotonica*, *Atti di Colorimetria e Beni Culturali*, SIOF, Centro Editoriale Toscano, Firenze.

[3] D.I.A.P.RE.M., Centre of the Department of Architecture of the University of Ferrara for the Development of Integrated Automatic Procedures for Restoration of Monuments. It aims at promoting theoretical and applied researches, publications of reports and papers, professional training and updating in specialized fields like advanced survey, monitoring, 3D modelling, structural analysis supported by computer graphics, production and management of multimedia data bases, in tight relationship with the problems regarding the conservation and restoration of monuments, historical buildings and archeological sites, the surveying and monitoring of urban areas, landscapes and infrastructures. Moreover the Centre guarantees technical and scientific advice to public and private enterprises by providing qualified and crossdisciplinary contributions which turn out to be extremely useful in tackling and solving suitably any specific problem. Further information at this regard at http://www.diaprem.unife.it.

Fig. 1: The Forum of Pompeii: view of the north side with the Temple of Jupiter.

Fig. 2: The scanner 3D has been placed at a high position to avoid the shade areas due to the presence of people. It surveys a 360° angle area.

spectrophotometry), in order to build up a digital data base which can directly accessed, consulted, integrated with the results of further researches and used for conservative interventions on archaeological sites and their enhancement.

This paper intends to summarize some significant results obtained during the research carried out at Pompeii on the monuments of the Forum. The research project aims at studying not only the architectural scale of the monuments in the Forum area (Fig. 2), but also the detail scale of each monumental component and the urban scale of the environmental context. These three different scales were taken into account when the 3D scan project was defined and a particular attention was payed to the numerous researches carried out on the Forum, expecially to the reports of the excavation works.

2. HISTORICAL NOTES

The Vesuvius eruption in 79 A.C. buried the city of Pompeii, preserving the urban structure, as it appears nowadays, nearly unchanged, with the same architectural and urbanistic organisation preserved by the different strata of lavic materials, that petrified the city in the tragic moment of the eruption.

The *Forum* is a large square built in the centre of the ancient city founded at the beginning of VI century B.C. by Italic peoples[4]. It is placed at the intersection of the two main streets of the first urban nucleus. So, at the beginning it was probably a simple open rectangular space flanked by the *Sanctuary of Apollo* on the west side. Especially since the II century B.C. it began to assume its definitive monumental configuration with its various functions of centre of the religious, political and commercial life. A "tufa" portico was built during the first development of the Forum area. When Pompeii became a Roman colony the *Temple of Jupiter*, dedicated to the cult of the Capitoline Triad (Jupiter, Juno and Minerva), was built on the north side. On the south side were the administrative buildings and the *Basilica*, seat of law court and business activities. During the I century B.C. the Forum was further enriched with a new travertine portico and other great public buildings on the east side.

Numerous monuments and statues, celebrating the Imperial household and important citizens of the political and cultural leadership, arose in the Forum area according to its central political functions. It was the main meeting place for politics and business. The Forum was the main seat not only for political, administrative and religious life but also for business and economic activities. Various shops and important buildings for commercial activities opened up along its portico.

The excavations of this area of the city began in 1813, at the end of the French occupation of Naples (1806-1815). The Basilica was first dug out, then came the southern side in 1814 and subsequently the *Temple of Apollo*, the Temple of Jupiter and other buildings on the northeastern side. In 1825 the entire square and the quarters enclosing the Forum were almost completely dug out, up to the *Forum Thermae* and *Temple of Fortuna Augusta*. The Forum was not the first area of Pompeii to be explored: the theatre quarter and most of the necropolis outside *Porta Ercolano* were dug out from one side to the another

[4] A. d'Ambrosio (a cura di) *Pompei: gli scavi dal 1748 al 1860*, Soprintendenza Archeologica di Pompei ed Electa Editore; A. Varone, *Pompei. I misteri di una città sepolta*, Newton Compton, Roma 2000.

of the city without any specific methodological plan, as usual in the first decades of excavation.

The Forum of Pompeii is an archaeological site of extreme importance. It also shows different types of restorations carried out throughout the last centuries according to different techniques and theoretical backgrounds. That makes the area a precious evidence of the evolution in the approach to problems concerning the conservation of the historical and archaeological heritage.

The present project research has concerned the survey of the Forum buildings[5]. The Basilica, law court seat, is a sumptuous architecture because of its function of representativeness of the social organisation and with various graffiti placed on its walls. The Temple of Jupiter, damaged by the 62 A.C. earthquake, as well as many other buildings of the Forum, was still incomplete at the moment of the Vesuvius eruption. Nero and Druso celebratory arches close the Forum on the north side; only the brick structure of them remains nowadays. The Macellum, the main covered market, is dated II century B.C. The Sanctuary of the city Lares, placed in the east side of the Forum, was probably built after the 62 A.C. earthquake. The Comitium, voting hall and legislative assembly seat, was damaged by the 62 A.C. earthquake. The portico, originally made of "tufa", is a sort of connection among the buildings around the square and it has been considerably modified during the imperial age. The research project concerns also the survey of via Porta Marina and of the first part of via dell'Abbondanza, the lower decumanus crossing the city from east to west.

3. SURVEY OF THE FORUM OF POMPEII

In the last few years a 3D survey methodology applied to the archaeological field has been tested by D.I.A.P.RE.M. Archaeological sites require different scales of survey in order to discover the ancient position of the finds and, on a smaller scale, to develop territorial analyses. The 3D laser scanner allows the acquisition of 3D data without any physical contact with the surface to be surveyed; an integration between the dimensional, morphological, structural, stratigraphical and colorimetric data acquired by means of traditional survey methodologies is also possible (Fig. 3).

The purpose of this integrated methodology is to create advanced digital models to be used as databases for managing the maintenance

Fig. 3: The Forum of Pompeii during the 3D surveying process: in foreground the laser scanner Cyrax 2500

[5] This project is the result of a partnership among– Superintendence of Archaeology in Pompeii – Consorzio Ferrara Ricerche (University of Ferrara Department of Architecture) and KFF – Kacyra Family Foundation.
For the Superintendence of Archaeology in Pompeii (Superintendent Prof. P. G. Guzzo and Dr. A. d'Ambrosio)
For Consorzio Ferrara Ricerche and NubLab – Modeling Architectural Surveying & Research (University of Studies of Ferrara – Department of Architecture – Via Quartieri n.8 Ferrara); Scientific responsible of research: Marcello Balzani (Director of NubLab); Coordinators of research: M. Balzani, N. Santopuoli; Responsibles of 3D Survey unit: F. Uccelli, A. Grieco, N. Zaltron; Collaboration to 3D survey: M. Berti, S. Settimo, N. Brigo, A. Papi; Topographic survey and GPS: G. Galvani, M. Crisci (Leica Geosystem); Logistic support from NubLab: V. Savoia, M. Sorrentino; Photogrphic survey: N. Santopuoli, M. Sorrentino; To the surveying operations contrubuted also a unit from Department of Architectural Planning of University of Study of Florence under the coordination of Prof. M. Bini, composed by G. Pancani and F. Tioli.
We thanks for collaboration and technical support: Leica Geosystem HDS Inc. (formerly Cyra Technologies), San Ramon, California; Leica Geosystem, Italy, Roma.

[6] C. Alessandri, C. di Francesco, C. Ronzini, Modelli virtuali 3D come banca dati per l'Architettura un'applicazione al "fascicolo del fabbricato" in "Dossier 4" 2001, pp. 23-26; N. Santopuoli, L. Seccia, Indagini spettrofotometriche e riflettografiche. Diagnostica innovativa nella catalogazione del patrimonio storico-artistico, in "Recuperare l'edilizia", 7, pp. 34–39; G.Graff, New tools for art conservation, in "Science Year" 1999 – The World Book Annual Science Supplement, R. J. Janus editor, World Book inc., Chicago, pp. 63, 67; N. Santopuoli (2001) Indagini Multispettrali sulle Superfici del Tempio Malatestiano, in "Nuovi Restauri al Tempio Malatestiano", edited by C. Muscolino, Rimini, currently under print; L. Seccia, A. M. Iannucci, N. Santopuoli, B. Vernia (1996) I mosaici di S. Apollinare Nuovo: rielaborazioni con Matlab e Image Processing di indagini diagnostiche multispettrali, in "Pixel" 3/4, pp. 5–14; L. Seccia, A. M. Iannucci, N. Santopuoli, B. Vernia (1996) Early Pixels, Image Processing vol. 8, n. 3, pp. 10–12.

interventions and the exploitation of the archeological heritage.

The project research concerning the Forum of Pompeii started in 2003: the research is the result of a partnership among Pompeii Archaeological Superintendence and the Department of Architecture of the University of Ferrara. The agreement involved also the Kacyra Family Foundation[7].

The survey of the Forum of Pompeii has been carried out by means of a 3D Cyrax 2500 laser scanner technology.

The laser scanner sends forth a laser beam directed to the surface to be surveyed in order to acquire all the points allowed by a selected grid: the result is a point cloud model which reproduces the morphology of the archaeological structure.

The use of 3D technology in archaeological field has proved the importance of a data acquisition on three different layers. The first one concerns an urban scale survey using a grid with a distance between points variable from 5 to 10cm according to the morphology of the environment to be surveyed. The second layer uses a grid with a distance between points from 1 to 4 cm, able to create point clouds of the surveyed surfaces aimed at obtaining 3D models in the standard architectural scales.

The last layer concerns the architectural details; the point cloud is created by a more refined grid with a distance between points which can be reduced up to 0.6mm, so that even the smallest details can be surveyed .

The 3D Cyrax 2500 laser scanner uses a 2nd class laser and the measure of the position of each surveyed point depends on the time of flight (the time elapsed between the emission of the laser beam and its reflection by the object to be surveyed) related to spans variable from 1,5 m up to 100 m. Up to 800 points/second can be surveyed with a 6 mm accuracy in a range of scan up to 40°x40°.

Another important 3D laser scanner feature is the opportunity to acquire the reflectance data which allow the visual recognition of the different materials of the surveyed object as well as the automatic spotting of reference targets, which are 7x7 cm square landmarks for scan registration used to assemble all the different point clouds. The target is made of three different materials: the central and the external ones are more reflecting than the middle one. (Fig. 4)

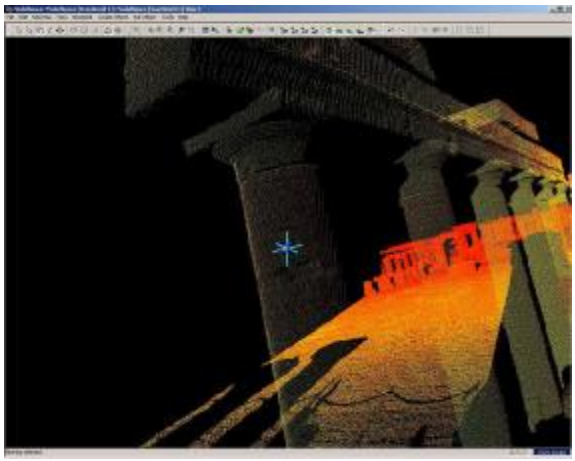

Fig. 4: "Cyclone"© software acquiring automatically a tie point (target).

Fig. 5: View of the Forum of Pompeii from the temple of Jupiter: total station and GPS station.

The laser scanner is able to place a vertex on the basis of the analysis of the three different reflectances. This technology has been integrated with the topographic survey of targets. (Fig 5) This integration allows to reduce the scan superimposition without using homologous targets; thanks to the topographic

[7] KFF (Kacyra Family Faundation) is involved in importan project researches concerning monuments and aimed to creation of 3D digital model; KFF financed the Forum of Pompei 3D laser scanner survey. KFF had been also involved in others survey project researches in important historical and archaeological sites in the world as: Tambo Colorado, Perù and Deadwood, South Dakota in Usa. In www.cyark.org, created by KFF with the help of support survey teams, it's possible to find high definition survey and pictures, DTM in ".DWG" format, an exemplification of acquired data as plants, sections and elevations in ".DWF" format (Drawing Web Format), 3D models and high definition images of scans. A plug-in for Autocad©, Cloudworx © Pro, by Cyra Tecnologies©, has been used to create the content of the website.)

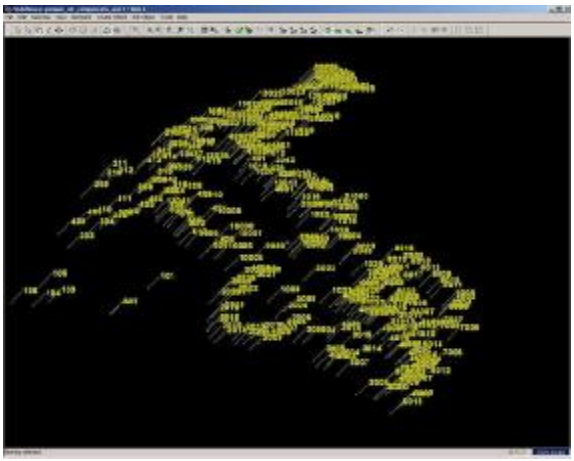

Fig. 6: Cloud of points surveyed by the TCR 1101 total station, imported in "Cyclone"© software to insert the scans in spatial co-ordinates

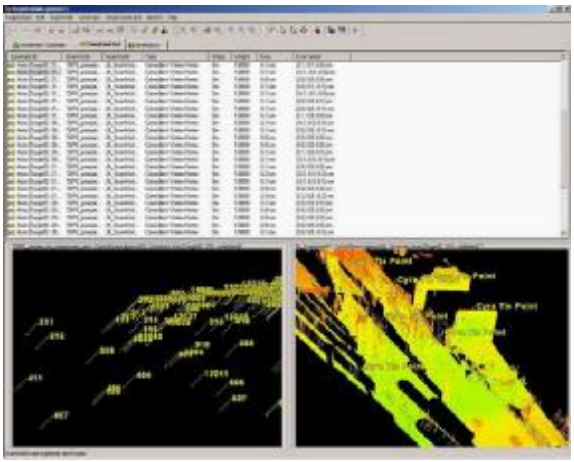

Fig. 7: An image of the registering software: part of the surveyed points and the corresponding scan.

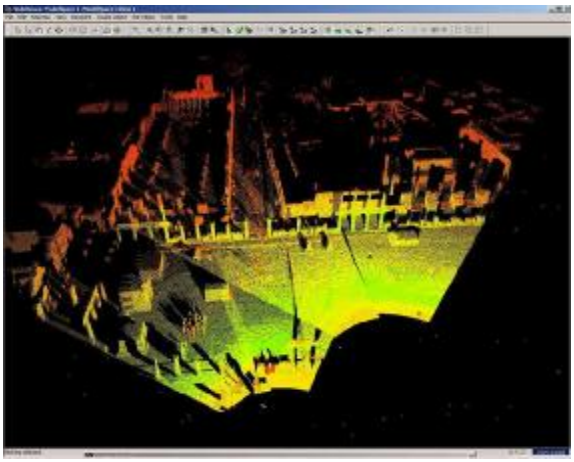

Fig. 8: Image in untrue colours of part of the 3D model, obtained by the superimposition of three scans.

survey, in fact, it is possible to materialize a cloud of targets useful to scan registration and to georeference the model in the topographical net of reference points. (Fig. 6, 7) Shade areas caused by buildings, trees, cars or people are a problem to be considered before the 3D survey setting up. It was estimated to move the scanner in order to comprise all the shade areas and to create a closed model. (Fig. 8)

The right survey methodology has to be decided by the operator; the choice has to be based on the laser scanner technology features and on the knowledge of the site and of the survey purposes.

By means of this 3D model and the reflectance analysis it is possible to study the area morphology and the materials in relation to a high resolution photographic data base set up during the survey.

In the survey of the Forum of Pompeii the 3D laser scanner has been placed higher than the Forum itself in order to reduce the shade areas and to build up the 3D model in a short time.

The work was carried out by two teams of three people each; they worked without interruptions, night and day, for a total of 129 hours. These hard work conditions, even for the climate (hot during the day and humid during the night), allowed to test the 3D Cyrax 2500 laser scanner efficiency with excellent results. The net of all reference target was materialized thanks to the topographic survey produced by the total station Leica TCR 1101 with an angular precision of 1.5 mgon. 6 bridgeheads were georeferenced thanks to a system of GPS stations (Leica GPS System 500).

The digital model has two definition layers: the urban one with a 5 cm grid and the architectural one with a 1 cm grid. The 3D model is the result of 43 scanner positions, divided into 113 scanwords with a mean of 5 targets each and a total of 468 scans. (Fig. 9)

4. DATA BASE IMPLEMENTATION

On the basis of the results obtained from the survey and 3D modelling, a 3D model of the whole area was built up with a maximum error of 6mm.

The complete 3D survey was set up in order to allow a reconstruction of the different parts of the monuments and to provide a morphological basis to be used as a reference for archaeological and historical researches, photographical data and spectrophotometric analyses.

The completeness and precision of the survey enables to: i) set up a 3D data base for the recording of the

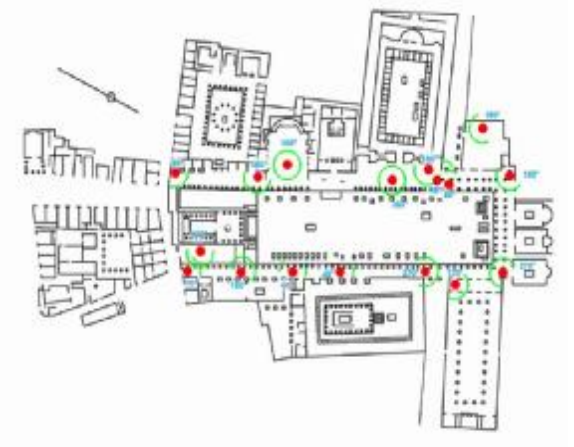

Fig. 9: Plan of the Forum of Pompeii with positions and rotation angles of the scanner.

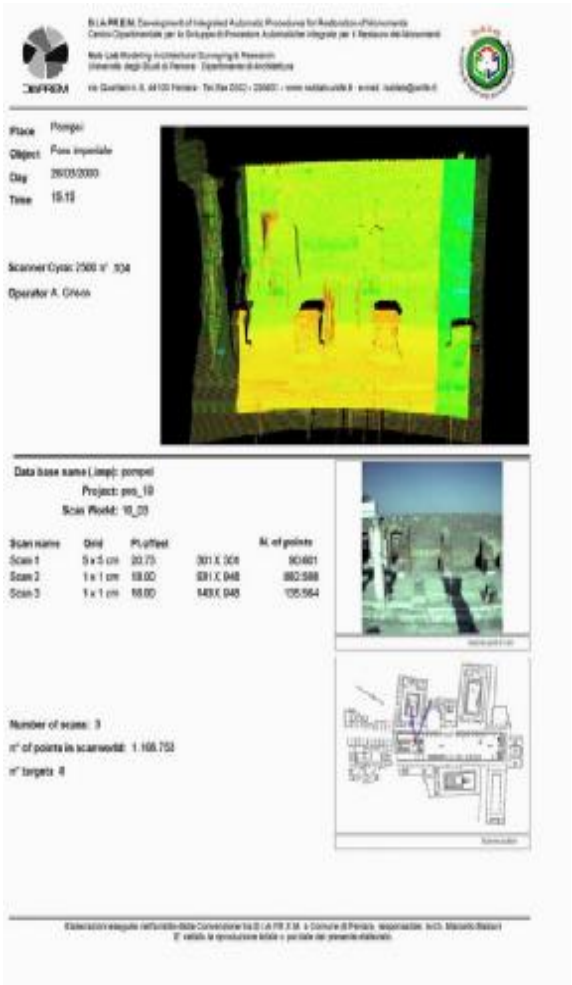

Fig. 10: Form of survey data recording, part of a database

surveyed morphological data, (Fig. 10) ii) plan the survey of the surface colour, iii) predict a first monitoring on morphology and colouring of the stone surfaces and the restorated areas.

At this point the importance of creating a 3D data base in archaeological field is evident. The right structuring of 3D data bases for architectural heritage is one of the main points of the knowledge and conservation programmes on monuments, as advised by CIPA and ICOMOS[8]. In this way (by means of this technology) 3D features of the outputs allow a suitable precision and a first morphologic monitoring in some significative areas of the fronts, mostly subjected to decay.

The solution proposed is a data recording at different layers, to be used for different purposes, from the management of the conservative interventions up to the exploitation by researchers, restorers, students and visitors.

The data base model will be set up as a hypertext with a friendly user interface in order to make the consultation via Internet as much simple as possible. Moreover the data base will be set up with an "open structure" (layout) (to allow a continual insertion of new data and sections), divided into three layers: for the Superintendences, experts and students/visitors.
The first layer concerns the non processed results of the researches and includes historical notes and reports, archaeological data, 3D scans, scientific reports, spectrophotometric data, high resolution images or other files. The second layer, addressed to archaeologists, researchers and technicians or to be consulted by scholars, is a significative synthesis of the initial data and of the ones processed; it is set up as a hypertext and the data are provided with the highest quality. The information available on this layer (texts, images, virtual model etc.) allow to scour through the time and the buildings of the Forum moreover they can be available within a written hypertext. The setting up a hypertext to be used by an Internet browser Web is an "open" method because it allows a sharing of the results among the researchers on Internet.

Finally, the third layer concerns the preparation of easy but not trivial digital tools to be used by anyone who is interested in the Pompeii site or simply wonders to know the results of research project. The instrument selected is a hypertext consultable by an Internet browser as well as for the previous layer; in this case the available data are selected in order to create a structured and intelligible *menu*.

[8] CIPA (*Comitato Internazionale di Fotogrammetria Architettonica*) and ICOMOS (*Consiglio Internazionale dei Monumenti e dei Siti*) exhort to create precise mounuments photogrammetric recording in photogrammetric survey programs.

The above mentioned three layers are effective instruments, useful to the knowledge and the exploitation of the Forum of Pompeii. The whole method guarantees a direct knowledge of the architectural and archaelogical heritage via Internet.

5. CONCLUSIONS

The research carried out has already produced numerous results concerning not only the knowledge of the monuments themselves but also the use of the 3D data base for the preservation and restoration interventions to be done. (Fig. 11) The effort of the Authors is aimed at making the use of these advanced techniques easier and more profitable by experimenting the use of more efficient instruments and by defining suitable standard protocols for the data recording.

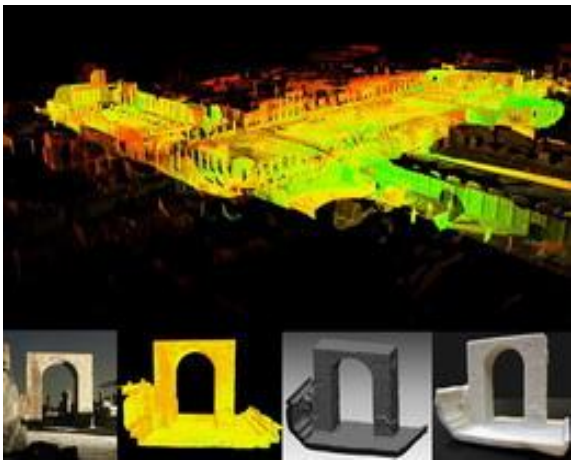

Fig. 11: The whole 3D model, after the processing of 468 scans with a miscalculation gap of 5-6 mm.

For this reason it is worth pointing out again the two main aspects of this research project, started few years ago. The first one concerns the potentiality of a 3D model of the artistic or architectural heritage at hand; in fact, by taking into account the geometric and material properties, and by inserting them into a specific software, it is possible to perform, for example, realistic simulations of philological recontructions or restorations and maintenance interventions. In this way the archaeologists togheter with the architects are able to develop crossdisiplinary researches which allow a deeper knowledge of the archaeological heritage and a proper programming of maintenance interventions. The 3D model enriched by information on material data, restouration history, physical decay and maintenance conditions, allows a *virtual* check of procedures and interventions even in the time dimension.

The second one concerns the opportunity to create solid models in different dimentional scales by means of present rapid prototyping technologies. The using of solid models in the conservation of the archaeological heritage allows both the modelling of complex shapes and the simulation of restoration interventions directly on the model in order to check the results before the actual restoration. Rapid prototyping modern technologies make the “link” between *digital* and *real* data possible.

Therefore these methodologies will contribute to the study, preservation and enhancement of the unique archaeological heritage in Pompeii. By exploiting the multimedia and internet resources the 3D models allow the archaeological heritage to be easily accessed by scholars and specialists of the field, as well as by a large number of art lovers.