GEOMETRIC MONITORING AND INTEGRATION OF GEODETIC SURVEY TECHNIQUES TO IMPROVE THE KNOWLEDGE OF THE HISTORIC BUILDING

C.Bacigalupo*, L.Cessari**, G.Fangi**
*scientist, **senior scientist C.N.R.-Istituto per le Tecnologie Applicate ai Beni Culturali
Via Salaria km.29,300 - 00016 Monterotondo St. - Roma – Italy
E-mail: : baci(or cessari)@mlib.cnr.it

***professor Università di Ancona - Facoltà di Ingegneria
Dipartimento di Scienze dei Materiali e della Terra - Via Brecce Bianche - Ancona - Italy
E-mail: fangi@popcsi.unian.it

Commission V, Working Group WC V/5

KEY WORDS: : Domes, Measurement of defects, Photogrammetry, Monitoring., 3D simulation

ABSTRACT

Today the study and the preservation of the ancient building is of interest for many disciplines. The question addressed by the study of the architectonic heritage oscillated between historic questions and more technology problems related to the ancient structures. In both cases the "scientific survey" plays a key role in the operated-knowledge that is the building analysis.
The analysis and the geometric measurement in historic buildings represent the main diagnostic tool to define their state of conservation and to plan restoration. In case of complex structures, the accurate monitoring and survey of the morphology help the understanding of the static situation related to original materials and design dimensions. These data are important in order to generate virtual models and to simulate the evolution of deviations.
The final goal is the development of a systematic approach to the study of an ancient building, where the contributions of the different scientific disciplines are integrated. The cross check of the results obtained with different techniques, the use of interdisciplinary diagnostic tools and feed-back actions on the obtained information will provide a complete information system of the monument.
In this work we presente the results of a campaign of data collection survey on some dome like structures which suffer of serious static problems. The integration of the different methods of survey performed with laser distantiometers, traditional geodetic instruments and digital photogrammetric techniques is very important to reproduce the geometric pattern of these structures, with greataccuracy.
We obtained dimensional and geometrical measurements on the thickness of the walls, morphologic defects, variations of the axes and of the lying plane of the domes. These are very important to programme any operative strengthening.
The whole geometric data obtained in the continuous form was used as a bases for the digital reconstruction and simulation in 3D CAD.

1. INTRODUCTION

In the present work we report results of studies, research and documentation work carried out on the monuments of Samarkand performed within the framework of the INTAS Project "Preservation, restoration and protection of the Timurid monuments at Samarkand (Uzbekistan)".
The aim of this project was a survey and research plan for the documentation of the history, architecture and degradation of some Timurid monuments in this Uzbek city. This scientific project was an attempt of a systematic approach to the study of historic buildings combining several modern techniques for surveying, cataloguing data and making a diagnosis of the state of their conservation. The analysis and the geometrical measurement of defects in historical buildings represent the main diagnostic tool to define their state of conservation and to plan restoration.
The Timurid architecture is interesting because it is characterised by domes of particular features.
A real breakthrough in the survey of these special examples of architecture has been the introduction of laser technologies.
In case of complex structures, as simple or double vaults and domes, accurate monitoring and survey of morphology help to understand the static situation related to original materials and design dimensions. These data are important in order to generate virtual models and to simulate the evolution of deviations.

2. DOMES: STRUCTURAL TYPOLOGY TO BE MONITORED

Among primary architectonic forms, the dome, even in its elementary forms, represents the building type that is three-dimensional *par excellence*. For this reason, the structure and the geometry of the dome is unsatisfactorily represented by means of plane sections alone, while they can be adequately described used mathematical equations. This is why a survey and its exact rendering of vaulted and domed geometry call for an adequate number of points with three-dimensional coordinates to be known. An exact geometric reconstruction of domes represents a tool of fundamental importance in understanding the design and constructional pathway followed in making complex structures, the stability of which depends indeed on the materials and building techniques used, but above all on the shape and thickness of the dome itself. Furthermore, the analysis and accurate geometric measurement of any strains enable us to define the state of conservation and hazard level, and to make provision for any consolidation action.However, the range of dome typologies and morphologies utilised throughout the world over the centuries is so extensive and interrelated that it cannot be kept within the bounds of artificial categories. This leads to the need for specific studies and analyses aimed at evaluating the building processes and the stability problems encountered by the various types of dome.

2.1 The case of the Timurid dome

Without doubt the first to be invented and some of the most interesting owing to their widespread nature are the self-supporting dome structures. Invented in the Mediterranean region, the distinctive feature of this form of roof covering vis-à-vis trilithic constructions is its static innovation. Numerous examples of such structures, built without the use of centered supports were constructed in the classic era and can be found in numerous Greek, Roman and Near Eastern sites. During the Western medieval period ranging from the 9th to the 15th century, when Europe was abandoning the Roman and Byzantine tradition of domed roofs, in most of the East, and particularly in Persia, vaulted buildings were becoming standard for both large and small buildings. As the Sasanian, Islamic, Mongol and Timurid empires expanded, dome techniques and forms spread from the heart of the Persian area to the regions of Central Asia and southward towards India.

The main features of these structures are the construction of self-supporting domes without the use of supporting centine experimentation and spread of double-domed systems; development of geometric forms producing dome forms exerting no thrust on supports and with reduced oblique force components. At the same time, building methods and materials were developed and suitable materials used to construct self-supporting structures by means of the arrangement of concentric rows of fired bricks bonded with quick-setting gypsum mortars. Experiments were carried out on special techniques involving the inclusion of rows of bricks outside the structure to provide a support for the rest of the structure.

The custom of covering civil and religious buildings with double domes reached its peak with the experimentation carried out in the Timurid era (14-15th century) and has left us with a heritage of prestigious monuments ranging from the Gur-i Amir mausoleum and the Shah-i Zindah necropolis at Samarkand, which still represent an object of study as well as of conservation. The formal, dimensional and construction relations between the outer curve and the intrados of the inner roof covering raise questions that still remain to be answered completely. A number of answers may be found in a 15th century book by the Persian treatise writer Ghiatt al-Jamshid Kashani who describes the methods used to calculate all the geometric surfaces utilised in architecture and the systems used to design arches and vaults. This historic text provides evidence that the use of the outer dome, almost always majestically shaped on top of a tall, large diameter drum was the result of the determination to heighten the symbolic and celebrative value of the building. In some cases built first while the inner dome, which was of more human proportions, was built when all the necessary elements were available, not least the necessary funds. Furthermore, protected from weather hazards, the master decorators could serenely proceed with the execution of the rich pictorial and ceramic ornamentation of the vaulted surfaces.

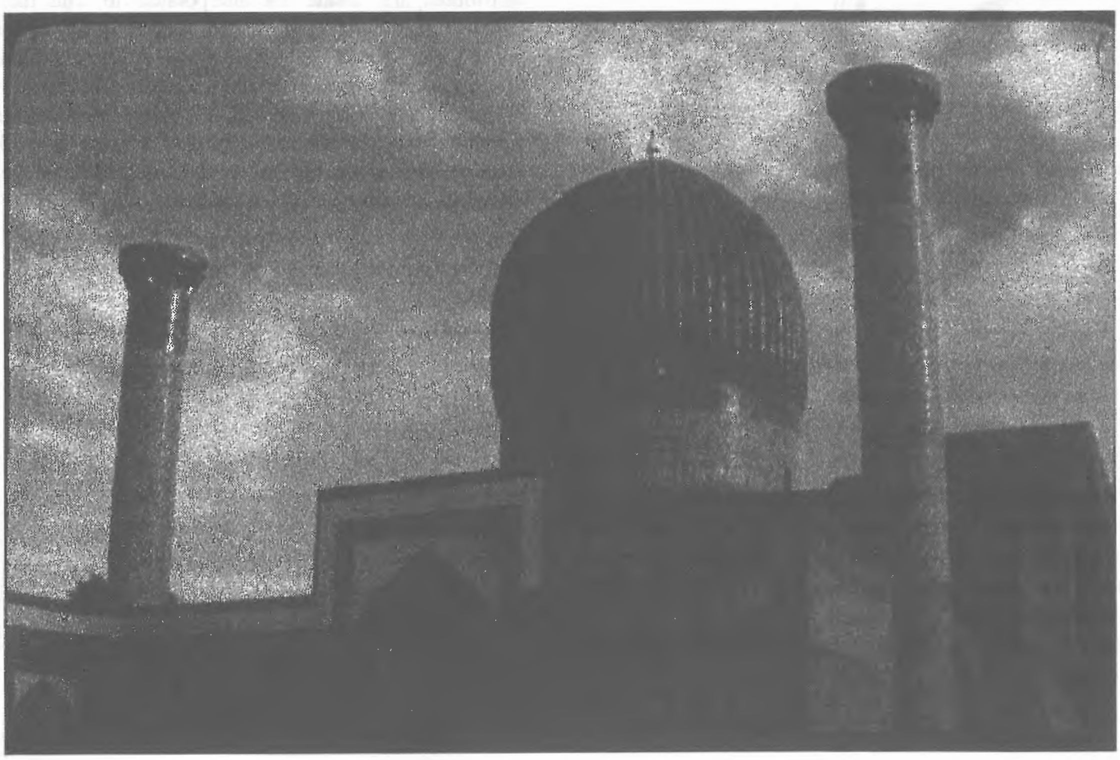

Fig1 The Gur-i Amir mausoleum and its monumental double dome

3. THE CASE OF THE DOME OF THE GUR-I AMIR MAUSOLEUM

The most famous monument of this period, the Gur-i Amir, i.e. the Timur's tomb is located in the Southwest quarter of Samarkand.
The early structures were a khanaka with a domed mosque, a two-storey madrasah and a square-shaped courtyard fringed by a roofed gallery. All the sides of the courtyard had arches and pilasters in rhythmic order and four minarets rising at the corner (this layout was identified during archaeological excavations). In the 1404 a mausoleum was built on the crypt of the Muhammed Sultan, Tamerlan's grandson. The geometrical shape was an octahedral prism surmounted by a double dome on a cylindrical drum.
The inner dome over the sepulchral chamber is similar to the other of the same period, with a traditional octagonal squinch zone of transition. The exterior dome rises on a high drum. One third of the externaldome, collapsed approximately in 1905, was rebuilt and redecorated in 1950.
During the survey of the inner volume between the two domes, we surveyed 13 counterforts, helding the masonry of the dome. The outer surface of the external dome is decorated with 64 ribs lined with glazed polichrome tiles

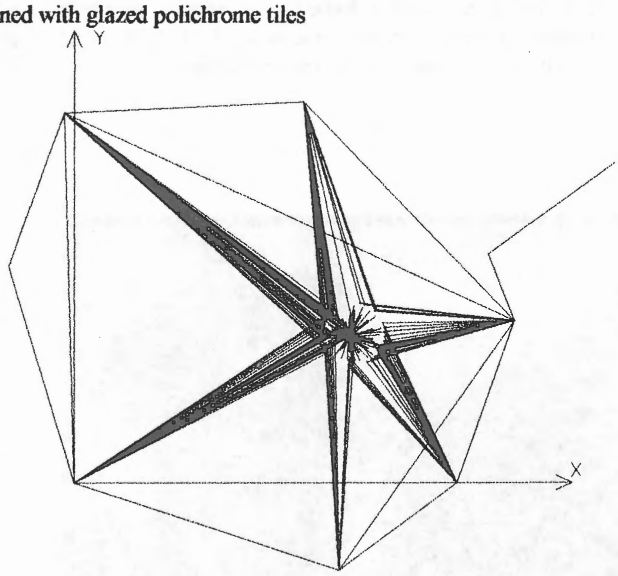

Fig 2 Control network

During our survey of the intrados of the external dome, we could not see any remains of the central pillar made of fired brick standing on the top of the inner dome. But there are some wooden tension bars hanging from the counterforts and anchored to this disappeared pillar.
Such a structure could be seen in the case of the coheval dome of the Bibi Khanum mosque.

4. THE GEODETIC SURVEY

A geodetic network was laid out in the Gur-i Amir mausoleum. This network consisted in 8 station points: 7 for the closed traverse outside the mausoleum, and 1 in the inner volume between the two domes: i.e. the intrados of the outer vault and the extrados of the inner vault.
140 internal points were necessary to survey the volume between the two domes.

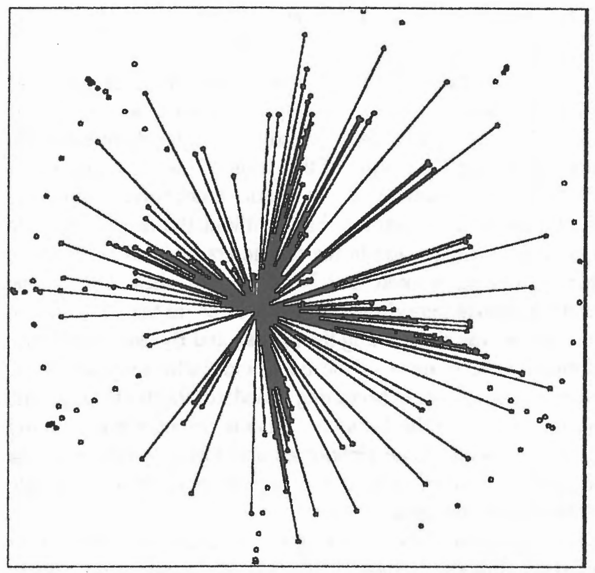

Fig 3 Interior points of the upper dome

In order to investigate the shape of the plotted surfaces, a numerical analysis was worked out.
We started by considering a theoretic and deformation free dome with perfect ribs. Some points fall outside this theoretic surface, some inside. At the dome base all the points, regularly distributed, are "inside" the interpolated rib. This fact might be due to the interpolation method, and it is known as "border effect". The zone of the surface whose points are outside, led us to suppose that some deformation of the whole structure occured. We could not entirely survey the dome because the lack of suitable room for the photographic survey. In addition, the southern side of the cupola is partly occluded by the ivan and therefore the lower part is not visible.

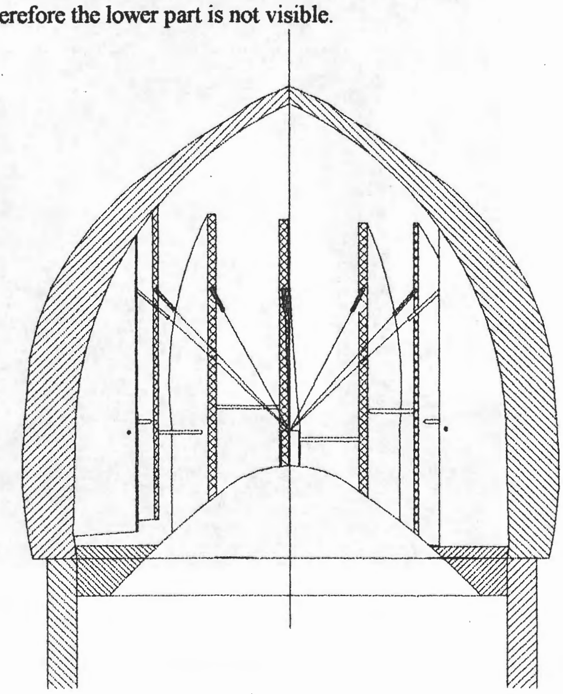

Fig 4 Vertical cross section of the double dome

The photographic coverage was arranged in a non-stereoscopic way. Due to the particular shape of the monument, and the available room around it, the stereo-taking would be much more difficult. The very particular pattern of the ceramic tiles helped in finding suitable control points. Again the plotting was performed by PhOX photogrammetric System. It resulted only in a digital output, being the 3d co-ordinates and their accuracy list. We estimate the accuracy in the order of few (one-two) centimetres.
The evaluated points were 651. Again the plotting resulted only in a digital output. All the images were regarded as non metric images.
This work allowed us to appreciate the deviations of the main meridian rib and the trend of the centres of the circumferences passing through the mean dome. The radius of the circular parallel of the cylindric drum varies from 7.03m at the base to 7.15m on the top, 4.12m being the elevation difference. At the base all the dome points, regularly distributed, fall "inside" the interpolated rib. This fact may be due to the interpolation method used. There is an area of the dome surface where the points measured fall outside the mean cylinder. This fact is surely due to deformation. The plane co-ordinates of the centre of the base ring (X=63.086; Y=33.649; Z=25.302), interpolated as a circumference, almost coincide with those of the top point of the dome (X=63.142; Y=33.620; Z=37.40). The difference in elevation is 12.10 m. The thickness of the dome wall is decreasing: from 0.84m at the base, to 0.35 of the top (we do not take into account the decreasing thickness of the ribs).

4.CONCLUSIONS

The study of damages and deformations of domes are usually complicated for their surface and their location in the monumental complexes. This work shows that digital photogrammetry is an ideal tool to record every information.
The speed up and the completeness of a larger set of points in the survey and the ideal geometrical configuration (the operator is at the centre of a sphere: i.e. spatial irradiation) represent a real change with respect to previous applications.
The disadvantages arising in the case of the domes considered as "difficult" geometrical shapes, become advantages in the spatial irradiation technique (all the points are detectable). The large number of the measured points profitably substitute the lack of iperdetermination.
The integration of geodetic and photogrammetric techniques enabled the monitoring of the structural disruptions.
The monitoring relies on the comparison of the present geometric state of the building with the ideal geometric shape of the design (symmetry, lack of discontinuity, flatness, verticality of planes and lines, sweep of overlapped domes, constant thickness of the walls).
There are no doubts that the fact of getting an exact rendering of the apparent envelope will allow us to georeference the information gathered by means of the prospecting described above.
The whole geometric data obtained in the continuous form were used as a bases for the digital reconstruction and simulation in 3D CAD.

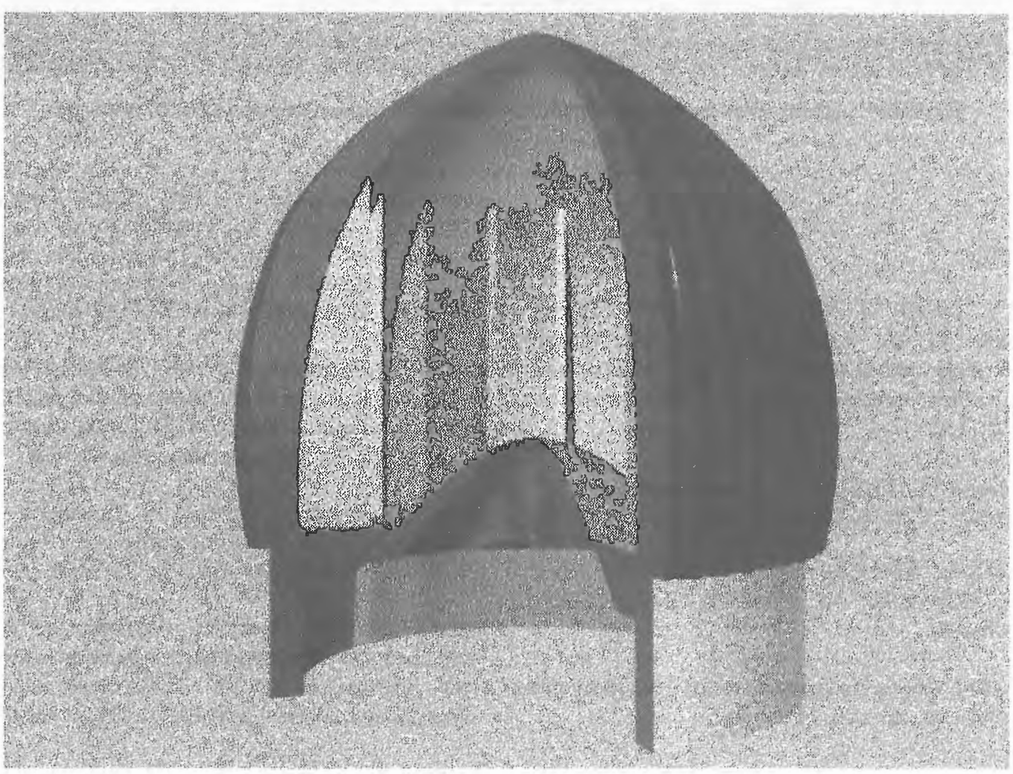

Fig 5 The 3D CAD reconstruction of the double dome

The final objective is to obtain a three-dimensional model of the surveyed roof accompanied by data on the covering materials used and their static behaviour in order to be able to simulate any occurrence of damage and any effects of consolidation action.
Presently we are working to put all information (geodetic data, raster and vectorial products) in a advanced system in order to get a total visualisation. The softwares used are by Advanced Visual System (Boston, Massachusetts).

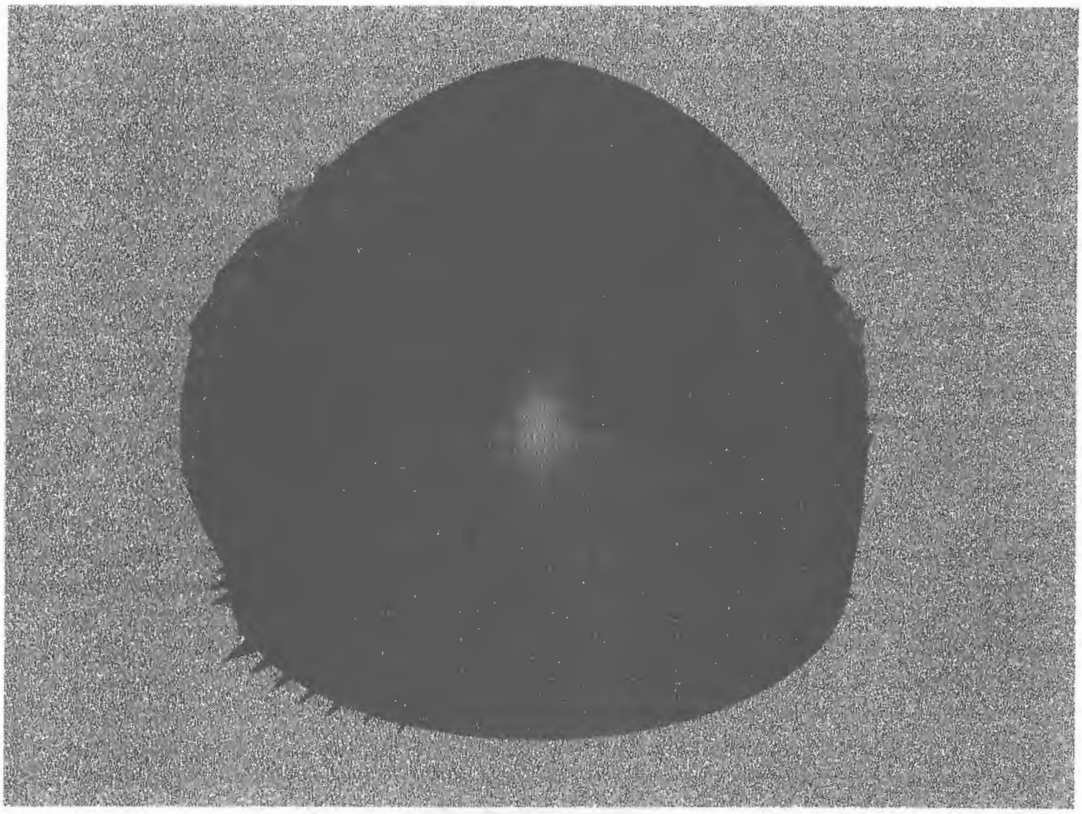

Fig 6 The CAD model of the outer dome of Gur-i Amir with the deviation emphasized ten times

7. REFERENCES

Bacigalupo C., Cessari L., Fangi G., 1997. Digital photogrammetry for the documentation of the Islamic architecture. A study case: Shahi Zinda complex at Samarkand (Uzbekistan), in Proceedings of Studies in Ancient Structures, Istanbul, pp.125-134.

Bacigalupo C., Cessari L., Fangi G., 1997. Integrated systems of geometrical survey for the monitoring of dome structural problems, in Proceedings of Structural Studied Repairs and Maintenance of Historical Building, San Sebastian, pp.93-102.

Bulatov, M.S., 1978. Geometric Harmony in the Architecture of Central Asia, 9th-15th centuries, Moscow.

Cessari L., Bacigalupo C., 1995. Integrazione di sistemi fotogrammetrici per l'analisi del costruito, in Atti del 1° Colloquio Internazionale "La Fotogrammetria per il Restauro e la Storia", Milano, pp. 191-193.

Cessari L., Bacigalupo C., 1995. Digital Photogrammetry In Building Analysis, in Proceedings of 1st International Congress on: "Science and Technology for the Safeguard of Cultural Heritage in the Mediterranean Basin", Catania, Siracusa, November 27-December 2. (in press)

Cessari L., Francaviglia V., , 1995. Integrated plan of action to safeguard the Timurid monuments of Samarkand (Uzbekistan), in Proceedings of 8th CIMTEC-World Ceramics Congress, Ceramics in Architecture, Faenza, pp.425-436.

Fangi G., 1992. Potenza e flessibilità di tecniche fotogrammetriche non convenzionali nei rilievi architettonici, XXXVIII Convegno nazionale SIFET, Stresa.

Fangi G., 1995. Tecniche alternative di fotogrammetria architettonica. Esperienze di triangolazione aerea con camere non metriche, in Atti del 1° Colloquio Internazionale "La Fotogrammetria per il Restauro e la Storia", Milano.

Nemetseva N.B., Shvab Iu.Z., 1979. Ensemble of Shah-i Zindeh, Tashkent.

Pugachenkova, G.A., 1976. Architecture of Central Asia: 15th century, Tashkent.