A 3D Laser Scanner model as virtual database for integrated analyses

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Abstract— **Some recent experiences of integrated analyses based on the use of 3D laser scanning and related 3D models will be presented. In the first place the idea of a 3D model as a multi-purpose virtual database will be focused in relation to specific case studies where the contributions of surveyors, historians, engineers and restorers are tightly related to one another. Applications will concern monuments, historical buildings and landscapes.**

Index Terms—**3D laser scanner, 3D modelling, integrated procedures**

I. Introduction

THE Research Centre D.I.A.P.Re.M. (Development of Integrated Automatic Procedures for Restoration of Monuments), affiliated to the Department of Architecture of the University of Ferrara, deals with advanced technologies, in particular 3D laser scanning, aimed at three-dimensional surveys of architectural monuments and sites. In the first research projects the Centre was mainly involved in surveying archaeological sites and architectural monuments with the purpose to obtain 3D complex digital models to be used also as solid models for structural analyses; moreover, the laser scanner technology has always been proposed and used in the presence of complex architectures for which the use of traditional techniques and methodologies may turn out to be difficult.

The more recent experiences carried out by the Centre intend to explore the extension of such technologies and methodologies from the single artefact to wide urban sites and landscapes especially for what concerns the rapid and accurate acquisition of metric and morphological data. Usually these sites are surveyed by means of conventional techniques and methodologies aimed at the restricting the number of metric data to be acquired and representations; on the contrary, the proposed procedures are based on a synthetic approach which provides any type of representation by using the same surveyed date, however complex the site may be.

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The rapid and precise acquisition of thousands of points per second is the main feature of laser scanners; by means of this technology it is possible to provide and manage data bases including not only basic information on buildings and monuments, like metric and morphological data, but also a wide variety of information on urban areas. The methodology related to the 3D laser scanner, usually defined "quantitative survey" or "high density survey" to underline the possibility of collecting a large amount of data, allows to postpone some steps of the usual "survey planning" to the phase of data processing in the Lab, thanks to the degree of flexibility of the metric model acquired. The application of this technique in the field of urban survey, where precision and accuracy are required to define morphological and volumetric models of the context as well as macroscopic physical alterations of the features of the areas, takes advantage of the studies carried out on the conservation, enhancement and management of the historical architectural Heritage.

Moreover, 3D data bases of urban areas, because of the large amount of data acquired, can be strategic to researches in complex fields characterised by the interaction of multiple aspects and the coexistence of different problems.

The complexity of the object to be surveyed suggests also to combine the advanced survey techniques with the traditional ones in order to obtain satisfactory results and to guarantee a continuous updating of the data base at each step of the work process.

II. Research Experiences

In November 2004 the Centre started working on the research project concerning the 3D survey of the urban areas between *Piazza Travaglio* and *Piazza Trento Trieste* in the historical centre of Ferrara. This project was the result of a partnership between the Municipality of Ferrara and the DIAPReM Centre of the University of Ferrara.

The aim of the research was to experiment a 3D survey methodology at an urban dimensional scale in order to obtain conventional outputs (plans, elevations and sections) and a 3D data base of a prescribed urban area to be used with different purposes such as improvement, enhancement and management of streets, technical plants and traffic systems of the historical centre. The implementation of such a data base turned out to be extremely useful to the Municipality of Ferrara. The work carried out within this research contributed to integrate and check the data and the paper maps already available (plans obtained by using traditional survey techniques, cadastral maps, etc.).

This agreement between the Municipality of Ferrara and the DIAPReM Centre is based on a previous 3D survey, carried out in 2003 and aimed at developing a research project concerning the acquisition and management of a 3D data base of the architectural heritage of Ferrara. The integration among survey, 3D modelling and data processing has turned out to be useful even to the structural analysis of the masonry walls of the *Sala Estense*, a theatre built at the beginning of the XX century, inside the City Hall.

Another recent experience integrated with the research project concerning the historical centre of Ferrara is the survey of the interior of the Cathedral of Ferrara, *S. Giorgio Maggiore*, within the research project named "Art and spirituality in the Diocese of Ferrara - Comacchio", promoted by the Archiepiscopal Seminary of Ferrara in collaboration with the DIAPReM Centre, with the purpose of acquiring as more accurately as possible the morphology of the interior of the Cathedral in order to provide historians and researchers in general with reliable data of the Church. Such data will appear in a book of a series entitled "The Church of Ferrara - Comacchio between art and spirituality", containing information and measured data of a number of buildings belonging to the ecclesiastical heritage. Meanwhile the 3D survey of the bell-tower of the Cathedral was carried out with the analogous purposes; this monumental complex, quite different from the usual case studies, presented many difficulties during the survey process.

III. Case Studies

Although the case studies are adjacent to one another, the Authors prefer to present them in the same order they were surveyed during the survey campaign:

a – The historical centre of Ferrara: the project regards elevations and roadways, squares and porticos placed in the nearby of *Piazza Travaglio*, *Piazza Trento Trieste* and the urban area of *Corso Porta Reno*.

The aim of the research is to survey urban and architectural environments by using 3D laser scanner techniques integrated with traditional procedures, such as instrumental and manual procedures. It will be possible to survey metric and morphological properties of the buildings at hand and to provide 3D virtual models of them to be used as 3D data base. 2D CAD representations, to be used for restoration interventions or for planning urban areas of the historical centre, can be extracted from the 3D data base.

b- The former *Bazzi* drug-store and the *Sala Estense*, placed in *Piazzetta Municipale* in a part of the City Hall. The building is very rich in decorations and mouldings and its architecture is quite complex; therefore the proposed 3D survey technology

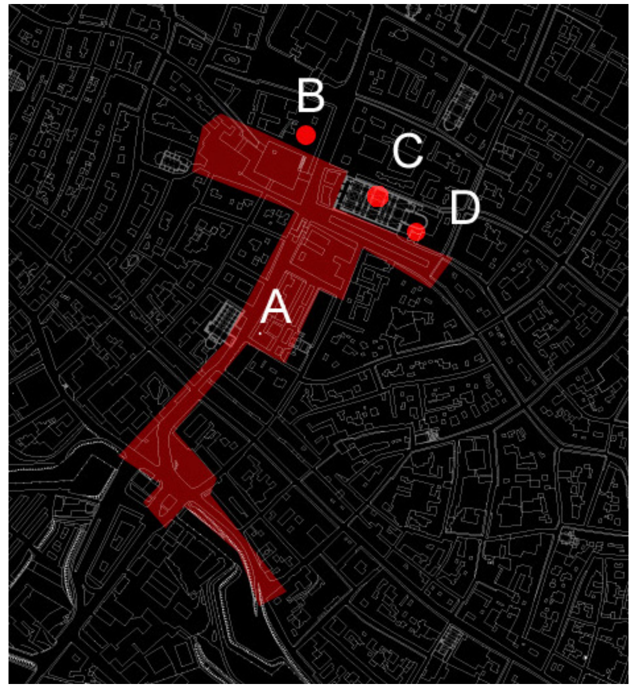

Fig. 1. Plan of the historical centre of Ferrara and case study areas in red.

proved to be suitable in this specific context.

In particular the research team set up an automatic procedure for the acquisition and the processing of all the survey data (dimension, shape, surface quality and colour) which could guarantee, at same time, the integration of conventional methods of analysis.

c – The Cathedral of Ferrara: the survey is restricted to the interior and the main façade. It is also related to a previous experimental research, completed in 2001 and regarding the main front and the elevation facing *Piazza Trento-Trieste*.

d – The bell-tower of the Cathedral of Ferrara. Although belonging to the monumental area mentioned above, it has been studied as a sole monument because of its large dimension and morphological complexity; in particular the survey of the bell-tower involved problems related to the control and reliability of all the measurement and morphological data surveyed in the past.

IV. The Instruments

The laser scanners used to realize the 3D survey of these areas are the Cyrax 2005, currently commercialized by the Leica with the name of HDS 2500, the Leica HDS 3000 and the Leica HDS 4500.

The HDS 2500 is an instrument aimed at the acquiring of metric data up to 1000 points/second; it is based on the time of flight technology (TOF) and its field of view is of 40° x 40°. The range of scan of the laser scanner is to 1 m up to 100 m with a 6 mm accuracy, but the instrument can acquire points as far as 200 m and over.

The HDS 3000 is based on the same time of flight technology (TOF) but it is updated by some very effective mechanisms, like the opportunity to put the instrument on a topographic tripod with base and level in order to scan by the exploitation of the automatic rotation of 360° around the vertical rotation axis with a frontal aperture of 135° that allows, by a complete rotation, to acquire a spherical cap with an aperture of 270°. In comparison with the stationary instruments, the ranges of time required to scan are reduced of the 35-40% for what concern both the acquisition process and the scan registration (a reduced number of targets is required). In this way it is possible to survey very narrow or foreshorten interiors.

Another feature of this instrument is the option to acquire digital photographic frames every 15° by means of a 1 mega pixel digital camera. The frames, recorded by the software, are available both to select the scan “windows” and to texture the cloud of points in order to crate a very detailed and complete model. The laser scanner takes the frames from the same point of view of the laser acquisition to avoid the parallax phenomenon.

The HDS 4500 laser scanner is different from the instruments mentioned above for the technology, the acquisition speed and the range of scan. It belongs to RADAR laser scanners and it works computing the position of the surveyed points by means of an infrared ray. Unlike the TOF laser scanners, the measure of the position of each surveyed point is not based on the time elapsed between the emission of the laser beam and its reflection by the object to be surveyed, but on the phase angle of the sent forth wave and the wave received by sensors (so it works like an interferometer). This kind of technology, in comparison with the time of flight technology instruments, has a restricted application field but allows the greatest possible speed of acquisition.

Therefore this 3D survey technology is particularly suitable to survey middling size interior and external area with a very complex morphology and where a lot of scan positions are required because of the shade areas; it is also suitable in the surveys in which a very precise angle of incidence is required.

It is not antithetical but complementary with the others HDS instruments in some work conditions; anyway, thanks to its different features, it can realize the same kind of work just with a different approach to the survey.

The range of scan is from 0,75ml up to 53,5ml; the optimal work conditions are between 1 and 25 ml.

The thickness of the cloud of points can be chosen by four different set up of resolution of the grid, that allow to create a grid of one point every 1,6 cm up to 50ml from the scan point of view. The setting up of the thickness of the grid is a contributing but not significant factor in the speed of the scanning.

The head of the instrument is a servo-mechanism (servo-motorized) so it’s able to include the 360 azimuthal degrees range, generating a spherical cap-shaped field of view with a maximum vertical angle of 310 degrees.

The speed of the data transfer is more of 500.000 points/second; this feature allows to carry out a scan station in about 7-8 minutes.

The data were geo-referenced by the optical total station Leica TCR 1101 which allowed a very precise acquisition of the targets (landmarks acquired also by the laser scanner) and of the net of points external from the object to be surveyed. The optical total station Leica allows an angular precision of 1” (1.5 mgon) and it has two sensors: the first one works without prism and using a visible red beam with a precision of +/- 3 mm (+ 3ppm), the second one works with a prism and an infrared ray with a precision of +/- 2 mm (+ 3 ppm).

By means of the integration among the laser scanner and the theodolite (optical total station) it has been possible to build up a grid of references points in order to realize the scans registration in a precise and repeatable way and to make possible a continuous updating of the 3D data base by means of monitoring and integrations.

V. The 3D Survey: Acquisition, Aims and Data Processing

The heterogeneity of the case studies, object of this paper, and the high number of experiences in the field of the acquisition by means of 3D laser scanners brought the Authors to point out a standard procedure, in which the planning linked to the survey is the first necessary step.

To bring a survey work to a successful conclusion it is necessary to consider a lot of factors: logistic conditions, complexity of the object to be surveyed, different dimensional ratio between elements, the disposal of many different instruments and techniques, the requirement to propose a “no contact” and not-destructively survey procedure to avoid any damage on monuments and structures and to avoid any inconveniences for people, and the different possible interpretative requirements of outputs. All these elements, if optimized, contribute indirectly to fasten the processing steps.

The integration among instruments, methodologies of acquisition and data processing is the only way to optimize the complex automatic procedure involved in the survey.

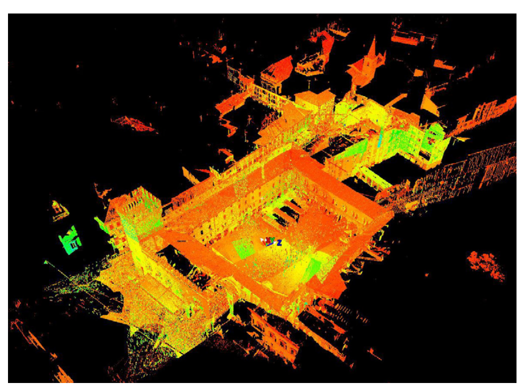

Fig. 2. 3D model in “false colours”; visualization, in the form of cloud of points, of the urban area between *Piazza Cortevecchia* and *Piazza Municipio* in Ferrara.

VI. The 3D Survey: Acquisition, Aims and Data Processing

The research project concerning the 3D survey of the urban area placed between *Piazza Travaglio* and *Piazza Trento Trieste* in the historical centre of Ferrara aims at experimenting the methodology of the 3D survey at an urban dimensional scale in order to provide effective methodologies and products to be offered to the Municipality of Ferrara.

The purpose of the survey and the high accuracy of the laser scanner impose a continuous check of the metric data; in fact, even if the area to be surveyed, because of its large extension, would be more suitable for representations at a urban/territorial dimensional scale, the large amount of the data which can be obtained after the processing suggests a sort of outputs suitable also for representations at architectural scales.

The aim is to realize 3D models of different parts of the historical centre; such models can be considered the beginning of a detailed analysis of the morphological features of the surfaces and also the first attempt to establish a relationship to other different surface specifications so as to perform an effective management of the whole urban area. In particular, it is important to set up a 3D data base of the urban environment aimed at favouring the analysis, maintenance, enhancement and management of the streets, engineering plants and traffic systems of the historical centre.

The integration between the topographic survey, carried out by means of an electronic theodolite, and the laser scanner survey allows to check the metric data; this integration is not only a development of the methodology of the reference targets net for scan registration but it is also the necessary interface to geo-reference the system and to define with a satisfactory approximation the position of the horizontal.

This technique allows to point out an automatic procedure to implement the 3D data base and to carry out the scanning with a high metric precision available also in terms of coordinates and levels system linked to the global coordinates system.

The area to be surveyed was very complex and wide; therefore the work was carried out by a team of nine people, for a total of fifteen workdays.

This first step allows to cover more than 50% of the whole area to be surveyed, but some problems linked to the scan and the integration of all the frameworks of the area, like the survey of the ground level sections and the survey of the wearing courses (because of the shade areas caused by cars or people), were found out.

These disadvantages implicated the continuous registration of small work sessions to cover the shade areas in the surveyed frameworks and the choice of the more suitable time of the day for the survey.

A subsystem grid of bench marks for each urban framework was necessary to update the data base continuously; for each street or square a reference net of datum points was singled out. These points were placed in tetrahedral shape with

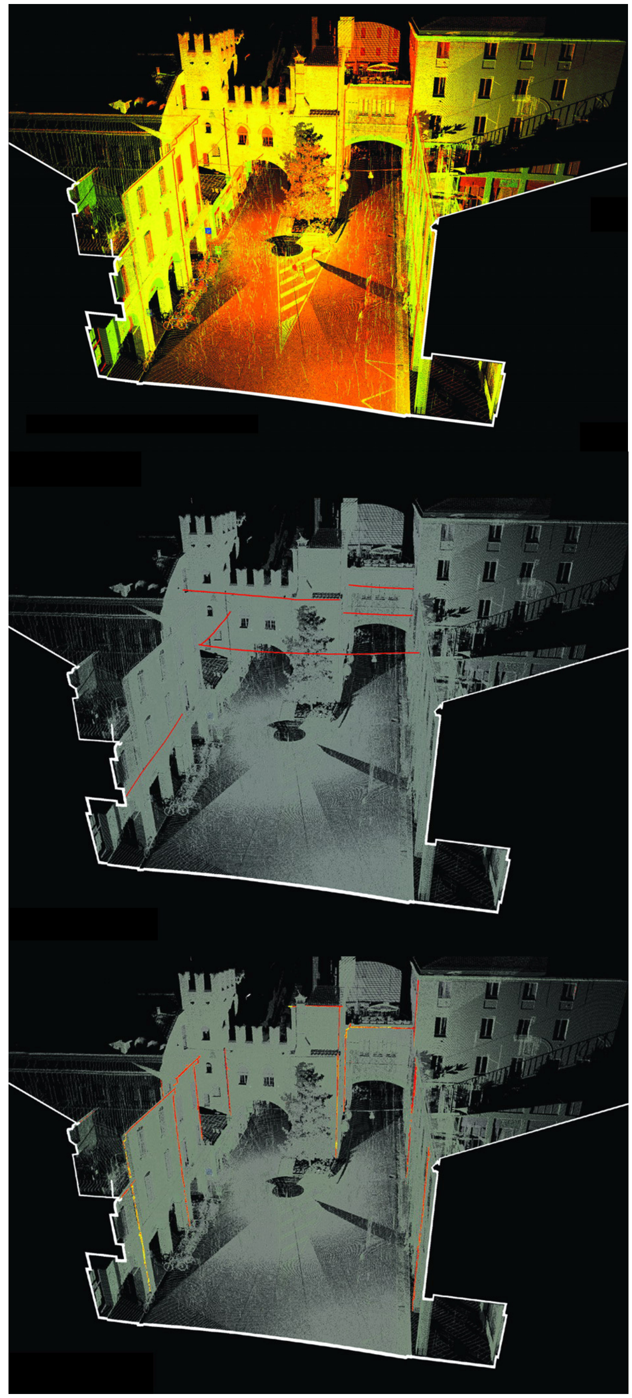

Fig. 3. Perspective sections of the model made by the cloud of points in “false” colours of the urban framework of *Porta Reno*, in Ferrara. Some subsystems of the urban area are visible, like the private and public engineering plants. The large amount of information concerns also the measures of the aerial plants.

monography and local and global coordinates. The landmarks are also used as vertexes to check the polygonals that, for logistic or morphological reasons, are open.

Up to now 40 scan stations have been defined by means of lock framing and servo-motorized instruments and the survey produced a grid of about 1 point every 2 cm, thirty topographic stations for a total of 220.000.000 laser scanner coordinates and about 370 topographic datum points.

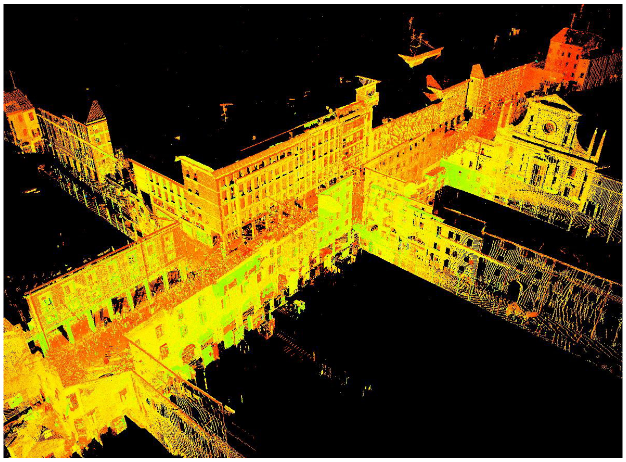

Fig. 4. A view of the “false” colour cloud of points of the urban environment of *via Porta Reno* in Ferrara.

The data managing has been set up to allow the scan registration of all the scans that compose a single urban framework (streets, squares, etc.) linked to a global system of coordinates, but the data have to be kept distinct because middling size calculators are not able to manage a such enormous amount of information. If all the data should be managed by a processors, just a short number of surveyed points could be processed by the software, inducing a reduction of the definition of the metric and morphological data, compromising the quality of the output.

While the 3D data base is an advanced instrument available to the check the metric data of the whole surveyed environment or of its subsystems, the CAD representations allow to create standard outputs like plans, urban sections and elevations; by using the same reference system for elements related to one another by means of the coordinates system, but managed separately, it is possible to manage a model with a coordinate every 2 cm, univocally referenced to others frameworks; that makes the scan registration easier.

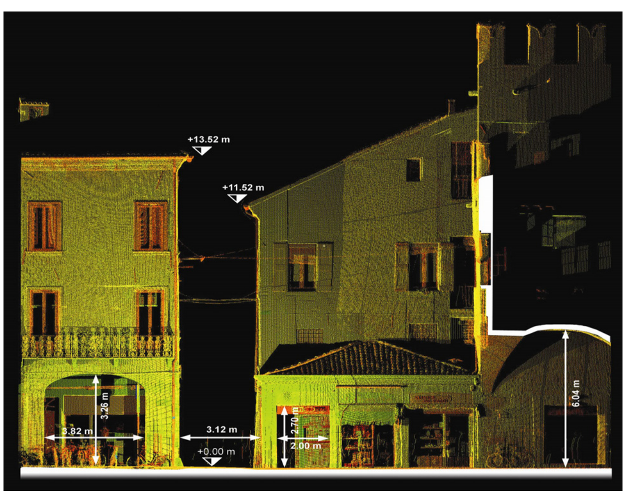

Fig. 5. Elevation view obtained with clouds of points; the urban section-plane and the metric data are visible.

VII. The 3D Survey To The Structural Analysis

The experiences of the last decades have proved that traditional techniques have become quite cumbersome in surveying, with the accuracy required nowadays, the historical-architectural heritage; moreover the necessity of providing digital data bases is stronger than in the past because of the fast development and improvement of the information techniques. That determined the need for updated survey techniques, such as the 3D laser scanner technique, able to create complex model of polygons or 3D clouds of points. Moreover, by means of specific computer codes, it is possible to reduce the complexity and the richness of data acquired in order to create digital and paper outputs to be used in restoration, urban and architectural design and structural analysis.

An example of application of the afore mentioned technologies is the survey of the *Sala Estense* in the City Hall of Ferrara; the integration among survey, 3D modelling and data processing has turned out to be useful even to the structural analysis of masonry buildings. This experimentation is aimed not only at recording data but also at carrying out an accurate analysis of the morphologic and qualitative information collected in the 3D model of the surveyed buildings.

The 3D models can be very useful to both analysis and data processing. In fact, a very realistic virtual model allows to overcome the numeric data and the trivial 2D representations unable to show the complexity of the object under investigation.

A 3D model allows every kind of geometrical check (planarity, curvatures, horizontal or vertical positions). Furthermore the 3D model can be used for structural analyses in order to check the stability of the structures, to define the state of stress and strain corresponding to the surveyed geometry and to verify the effects deriving from progressive damage or from the onset of new damage.

The procedure of acquisition based on the integration of laser scanner and topographic surveys allows to overcome the gap of the mentioned above techniques, if exploited one by

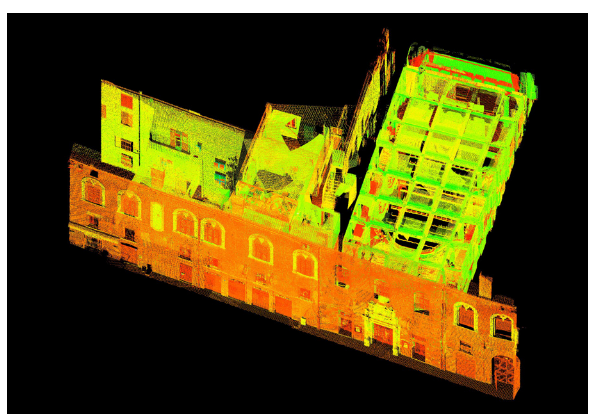

Fig. 6. Axonometric view of the main front and of the interior of the *Sala Estense* in Ferrara.

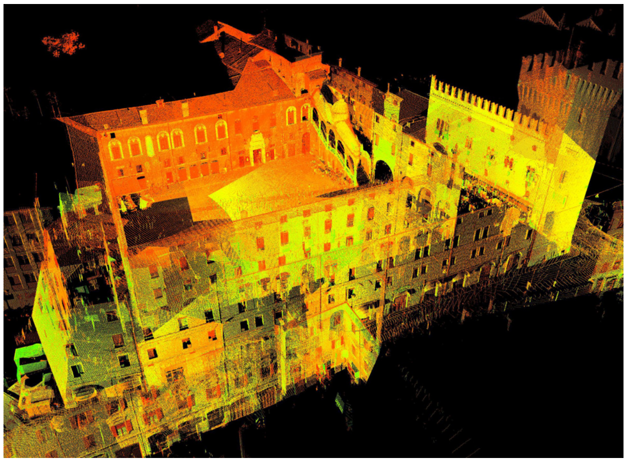

Fig. 7. Contextualization of the *Sala Estense*, belonging to the City Hall; thanks to the topographic system, this survey has been related to the recent 3D survey of the urban areas of the historical centre of Ferrara.

one, and to use the 3D model directly as a solid model for FEM (Finite Element Method) structural analyses.

After a direct analysis of the actual conditions of the monument, the data acquisition began by means of a 3D laser scanner survey.

The large amount of the acquired coordinates cannot be directly used to build up the FEM solid model (processor is not able to process this enormous amount of data). Therefore it is necessary to simplify the acquired geometry and build up a computer model which can be reliable from a geometric point of view and managed by the processor.

One horizontal section of the *Sala Estense* every 50 cm, up to 8 m in height, was defined.

The sections are imported by the modelling processor linked to the computer software and used as “medium” for the FEM solid model.

The sections imported into the computer software are made of a grid of lines connected with the brunch points that define the finite elements of the mesh.

The mechanical properties, the constraint and load conditions are prescribed to these elements; the correspondence between the inputs, the actual properties and the boundary conditions of the object have to be checked.

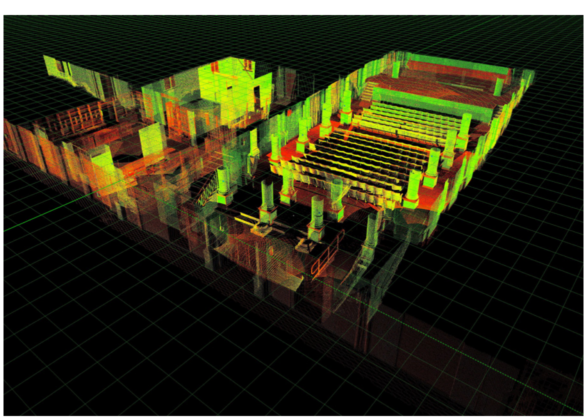

Fig. 8. Horizontal section of the cloud of points of the *Sala Estense* in Ferrara.

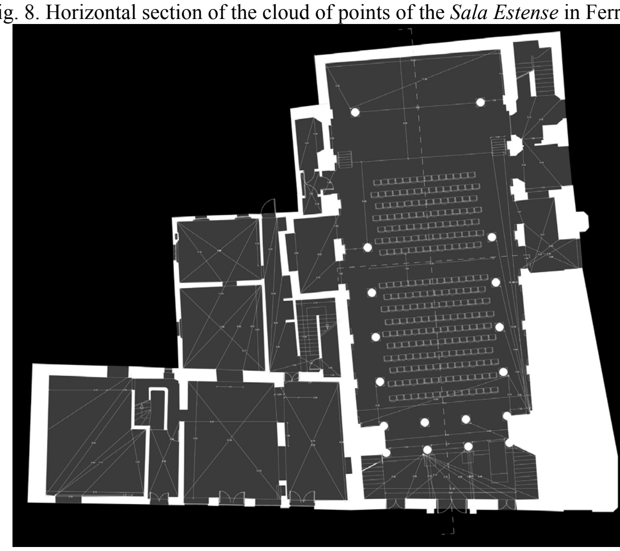

Fig. 9. Plan of the *Sala Estense* obtained by the model.

The FEM model is such as to simulate the interaction between the structure and the ground.

A linear static analysis was carried out to study the mechanical behaviour of the whole building under the self weight and the external loads.

Moreover, analyses of single parts of the building were carried out in order to point out the mechanical behaviour of some structural elements under specific boundary conditions.

One of the most stressed parts of the building is the left side of the main front where a differential settlement is occurring; this is probably the cause of the main cracks surveyed.

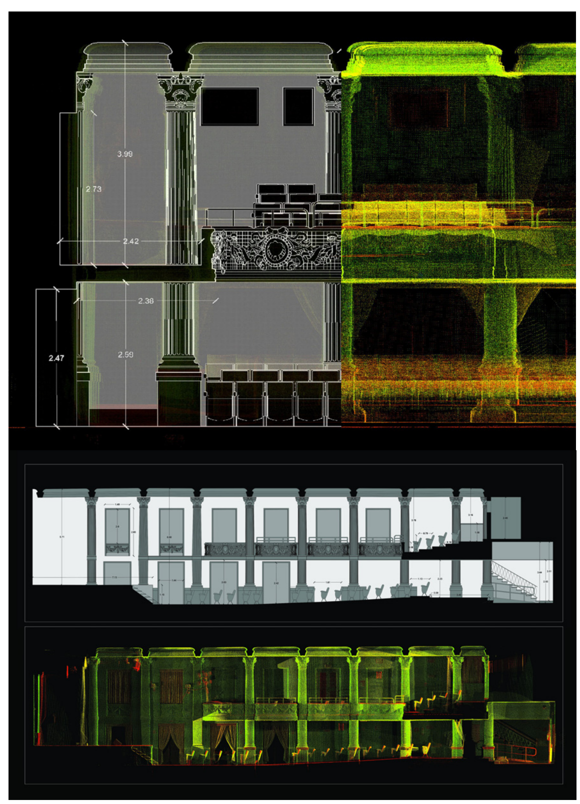

Fig. 10. Detail and sections obtained by the cloud of points.

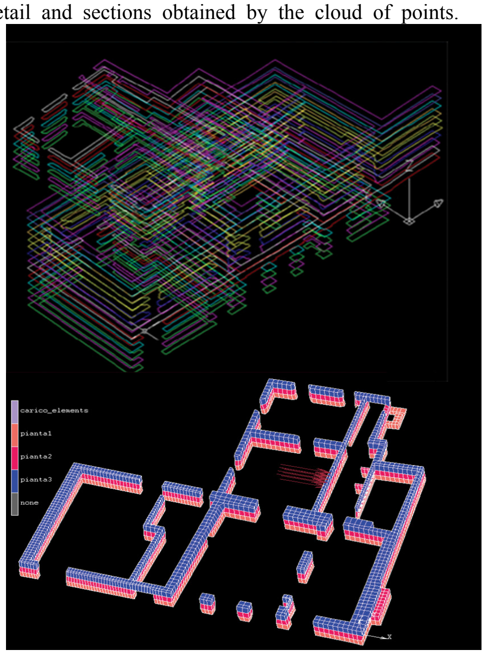

Fig. 11. Basic solid model for FEM analysis.

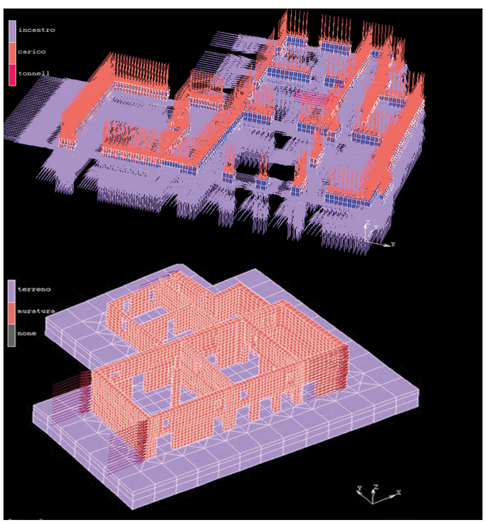

Fig. 12. Load conditions applied to the model.

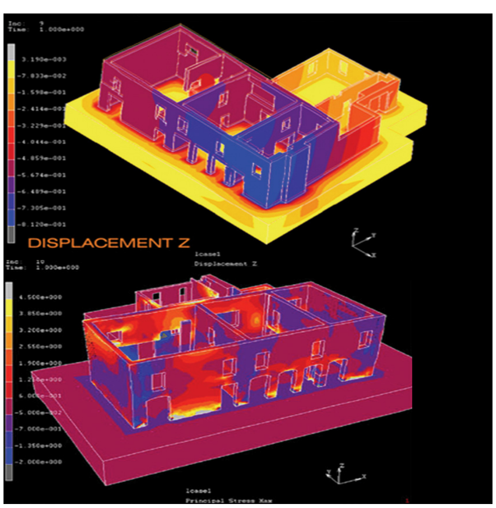

Fig. 13. FEM visualisation of deformed configurations

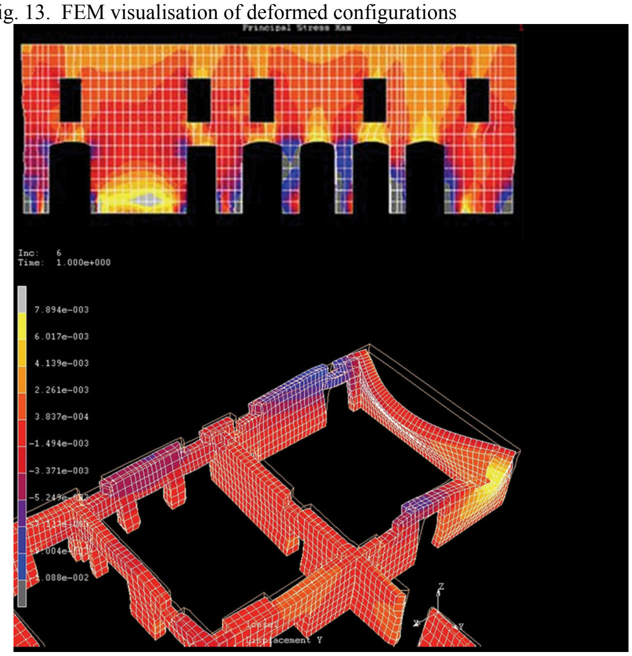

Fig. 14. FEM visualisation of states of stress and strain

VIII. The 3D Survey for The Historical-Architectural Analysis

The aim of the 3D survey of the Cathedral of Ferrara was to acquire the internal morphology in order to provide scholars and historians with reliable data of the monument.

The large dimensions of the church and the required dimensional scale of representation (1:200) suggested a detailed dimensional survey of the whole architecture as well as of its many decorations.

Moreover, a survey carried out with so many and different purposes requires several dimensional scales of research in order to meet the requirements of all possible researchers.

The integration of high precision 3D laser scanning, like the radar scanning, and the topographic survey turned out to be the best solution from many different points of view, from the acquisition and processing of a large amount of data to the speed in carrying out the survey.

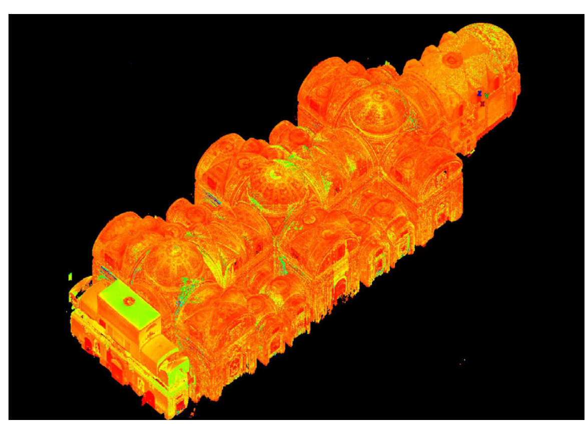

Fig. 15. Axonometric view of the Cathedral of Ferrara in the form of cloud of points

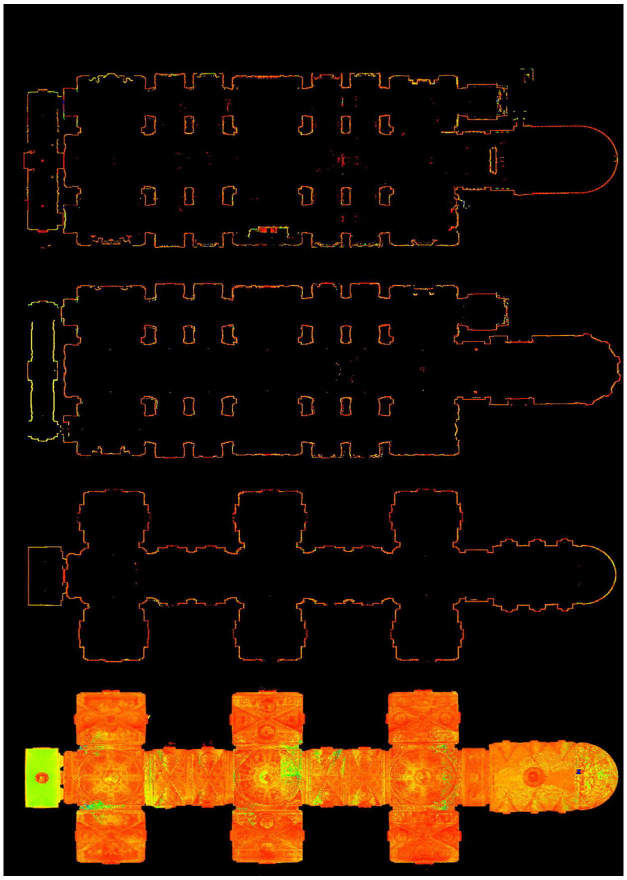

Fig. 16. Morphologic changes shown at different levels of the 3D cloud of points model.

A team of four operators carried out the survey and produced an output with a detail scale of one point for each centimetre, with an amount of 17 hours of work and for a total of 34 scan stations and 24 topographic stations; a cloud of 53.000.000 points was surveyed.

The setting up of this 3D data base for the recording of the surveyed morphological and metric data will allow a subsequent insertion of new 3D metric data, obtained by laser

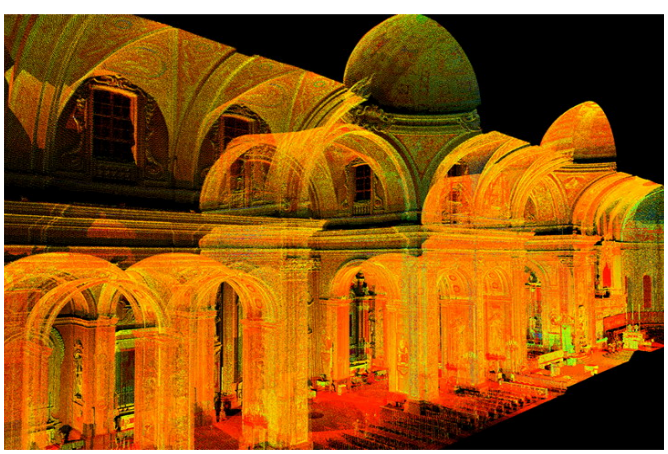

Fig. 17. Perspective section of the main dome.

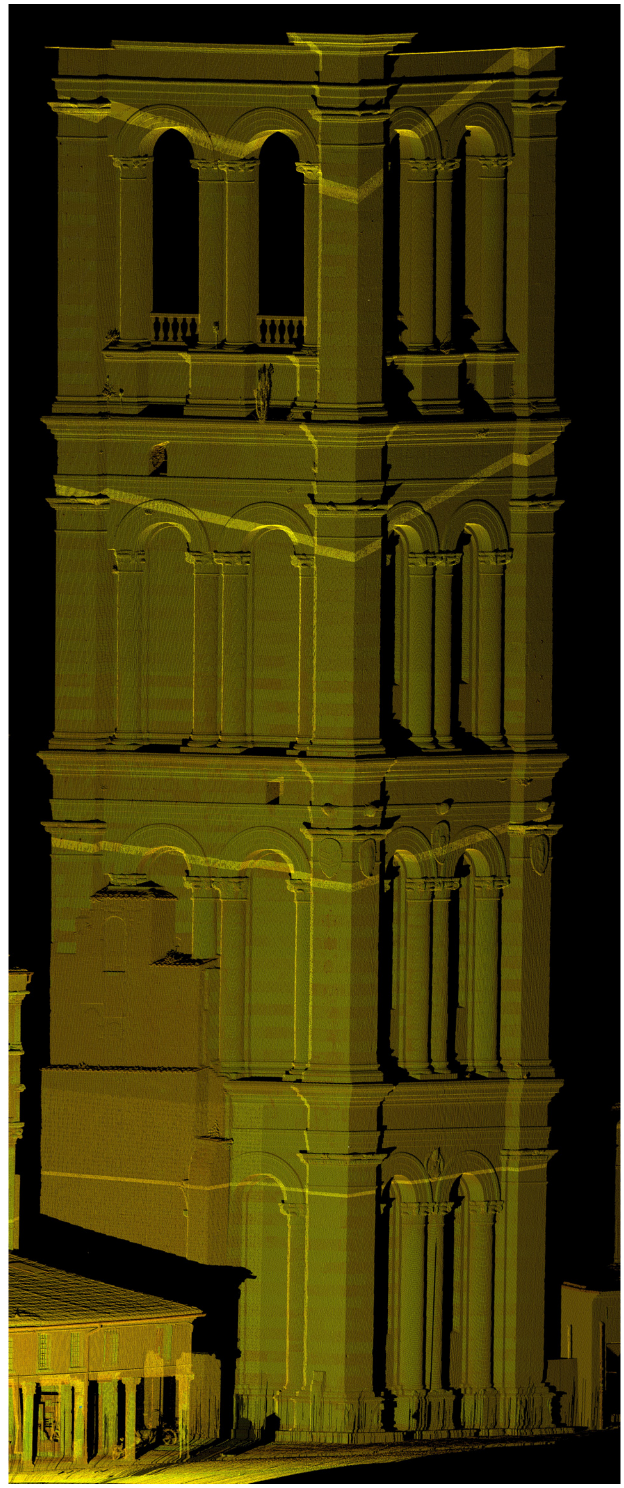

Fig. 19. Representation of the bell tower without perspective distortion.

scanner and concerning the exterior of the Cathedral acquired in different times; these data, thanks to the integration with the topographic survey, will be linked to one another and to the entire context by using the net of bench marks employed in the others surveys.

In particular, the property of being a 3D data base allows to ask for metric data in any part and location; in fact, thanks to the integration with the optical total station, it has been possible to link previous 3D surveys of the side elevation and of the main front with the model and to link to the same system the complex survey of the bell tower of the Cathedral.

This procedure allowed not only to obtain 3D morphologic data but also to link all the different clouds of points acquired separately in order to arrange the metric 2D representation and to guarantee the morphologic and metric quality of this complex object.

IX. Conclusion

The high number of experiences produced in the last years confirmed and strengthened the firm beliefs of the research team of the DIAPReM Centre.

The high innovation provided in the field of the metric survey by the information and computer science favoured new knowledge opportunities which were unthinkable a few years ago; nevertheless, these innovative techniques, like the 3D laser scanner, cannot be the solutions to all problems and uncertainties related to the metric surveys and interpretations: the integration with other techniques is mandatory to fully develop the potentialities of the 3D laser scanning, to improve the procedures, to guarantee a continuous and reliable control of the enormous amount of data provided by the clouds of points, to look for new added values. Only if based on integration of techniques, procedures, different skills and complementary expertises can a methodology satisfy nowadays the complex requirements and needs expressed by Private and Public Administrations interested to preservation, enhancement and management of the Architectural and Urban Heritage.

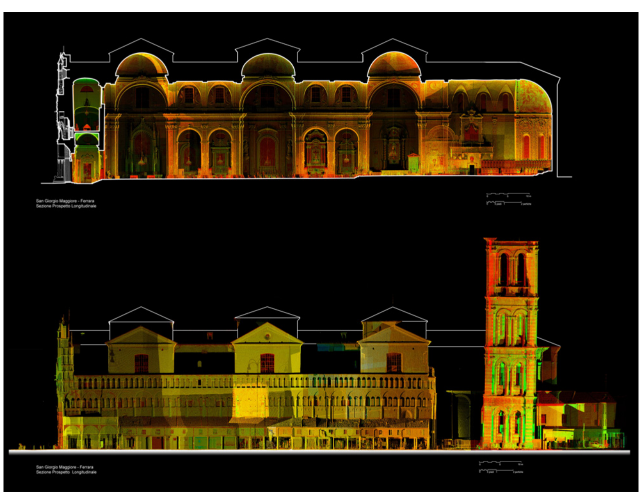

Fig.20. Representation of section ad elevation of the referenced frameworks, obtained by distinct 3D laser scanner surveys.

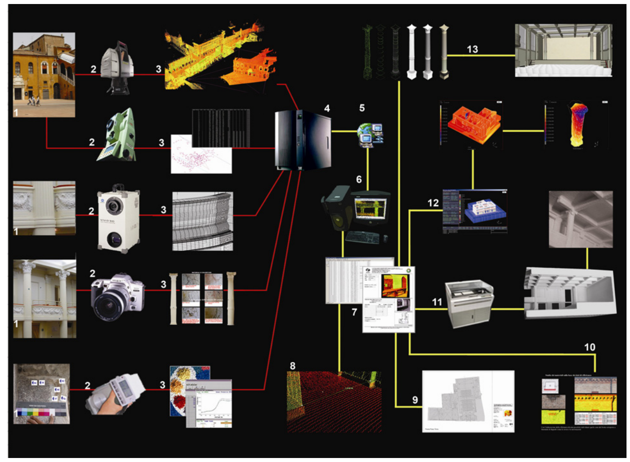

Fig. 21. Acquisition, modelling and data output scheme.

Steps of the acquisition procedure:
01 object to be surveyed
02 instruments
03 acquisition
04 data filing
05 Internet connection
06 data processing
07 forms of the data base
Steps of the processing:
08 the model allows to ask for metric data
09 paper scaled outputs
10 analysis of the photographic and spectrophotometric data to examine the conservative conditions
11 3D printing of the model or of parts of the model
12 data processing to the structural analysis
13 data output to three-dimensional modelling and representations

References

[1] BALZANI M., SANTOPUOLI N., Grieco A., Zaltron N., “Laser scanner 3D survey in archaeological field: the Forum of Pompeii”, in atti *International Conference on remote sensing archaeology*, Beijing, Cina, 2004.

[2] BALZANI M., CALLIERI M., FABBRI M., FASANO A., MONTANI C., PINGI P., SANTOPUOLI N., SCOPIGNO R., UCCELLI F., VARONE A. – “Digital representation and multimodal presentation of archeological graffiti ad Pompei”, in *The 5th Internatonal Symposium in Virtual Reality Archeology and Cultural Heritage, Eurograhics Symposium Proceedings*, a cura di Y. Chrysanthou, K. Cain, N. Silberman, F. Niccolucci, VAST (2004).

[3] Alessandri C., Fabbri R., Giunchi E., Malvezzi R., Russo M., *Tecniche moderne per la riscoperta di tecnologie antiche*, Paesaggio Urbano, 5, 2002, 61-67, Maggioli Editore.

[4] Alessandri C., Di Francesco C., Monzini C., *Modelli virtuali 3D come banche dati per l’Architettura: un’applicazione al fascicolo del fabbricato*, Dossier, n.4, 2001, 23-26, Maggioli Editore.

[5] Alessandri C. et al., *Una procedura integrata per il rilievo e l’analisi strutturale*, a cura di M. Balzani, l’Ufficio Tecnico, n. 5, 2004, ISSN 0394-8293, Maggioli Editore, 28-32.

[6] Balzani M., Santopuoli S., *Dal restauro al rilievo. Un percorso metodologico per una banca dati tridimensionale dell’Arco di Traiano a Benevento*, in “Paesaggio Urbano”, n. 5/2004, pp.24-36.

[7] Balzani M. , Alberti A., Betocchi M., Fabbri M., Santopuoli N., *Diagnosi di un eclettico castello*, in “Paesaggio Urbano”, Rimini, Maggioli Editore, n. 4/2003, pp. II-XVIII.

[8] Balzani M., Pellegrinelli A., Perfetti N., Russo P., Tralli S., Uccelli F., *Laser scanner nel rilievo dei vicini: applicazioni verifiche e test di*

precisione, in “Bollettino della SIFET (Società italiana di Fotogrammetria e Topografia)”, 2002, pp. 17-32.

[9] Alessandri C., Fabbri R., Giunchi E., Malvezzi R., Russo M., *High Technology and Structural Insight in the Wooden Composite Beams of the Renaissence Architecture in Ferrara*, in corso di stampa in Vol.3: “Interaction between Science, Technology and Architecture in Timber Construction Elsevier”, Culture 2000 Project, 509-540.

[10] Mallardo V., Alessandri C., *Arc-length procedures with BEM in physically non-linear problems*. Eng. An. Bound. Elem. 28(6), 547-559, 2004 (Engineering multidisciplinary, 5, 63)

[11] Balzani M., “La facciata di San Carlo: nuove tecniche di rilievo”, in *Giovan Battista Aleotti e l’Architettura*, a cura di C. Cavicchi, F. Ceccarelli, R. Torlontano, Reggio Emilia, Edizioni Diabasis, 2003, pp. 93-102.

[12] M. BALZANI, “Rilievo tridimensionale con laser scanners 3D. Sperimentazioni per l’architettura e i beni artistici”, in *Frontiere del Rilievo – Dalla matita alla scansione 3D*, a cura di Riccardo Migliari, Strumenti del Dottorato di Ricerca in Rilievo e Rappresentazione dell’Architettura e dell’Ambiente, Università di Roma “La Sapienza”, Dipartimento Rappresentazione e Rilievo, vol. 5/2001, Gangemi Editore, Roma, pp. 59 - 104.

[13] M. BALZANI, A. PELLEGRINELLI, N. PERFETTI, F. UCCELLI, “A terrestrial 3D laser scanner: accuracy tests”, in Atti di *CIPA 2001 international Symposium, Surveying and Documentation of Historc Buildings – Monuments – Sites. Traditional and Modern Methodes*, Postdam University, settembre 2001, pp. 445-453.

[14] M. BALZANI , F. UCCELLI, *Informatica 3D in un museo digitale in rete. Per gli istituti culturali l’opportunità di archiviare forme metriche tridimensionali per la documentazione e la ricerca*, in “ Paesaggio Urbano”, n. 4/2002, pp. I-IX

[15] M. BALZANI , F. UCCELLI, *Rilievo e modellazione 3D nello spazio pubblico. Il caso del monastero di San Giorgio a Ferrara*, in “Paesaggio Urbano”, n. 4/ 2002, pp. IX—XIII.

[16] M. BALZANI, F. UCCELLI, *Il Rilevo 3D per l’analisi strutturale*, in “ Paesaggio Urbano”, n. 4/2002, pp. XXII-XXIX.

[17] M. BALZANI, N. SANTOPUOLI, F. UCCELLI, *La luce laser scanner 3D Cyrax System per lo studio dei materiali e del degrado delle superfici architettoniche*, in “Paesaggio Urbano”, n. 4/2002, pp. XXX-XXXII.

[18] M. BALZANI, F. UCCELLI, *Rilievi tridimensionali per il controllo ambientale*, in “Paesaggio Urbano”, n. 3/2002, pp. 48-51.

[19] M. BALZANI, “Modellazione tridimensionale per ambiente, architettura e beni artistici”, in *Informatica per il progetto architettonico e ambientale*, “Dossier” n. 4/2001, Maggioli, Rimini, p. 8.

[20] M. BALZANI, “Una metodologia integrata per l'acquisizione e la restituzione di dati 3D e colorimetrici di elementi architettonici e apparati decorativi ai fini della loro conservazione: il caso di elementi architettonici, decorativi e parti di fabbrica del Colosseo a Roma”, in *Centro Ricerche Informatiche per i Beni Culturali*, Quaderni 10, X, 2000 a cura di G. Beltramini e M. Gaiani, Scuola Normale Superiore di Pisa, 2000, pp. 151-159.

[21] M. BALZANI, M. GAIANI, F. UCCELLI, “Reshaping the Coliseum in Rome: an integrated data capture and modeling at heritage sites”, in *Eurographics 2000*, a cura di M. Gross and F.R.A. Hopgood vol. 19, n.3,21-25 agosto 2000, pp. 369-378.

[22] M. BALZANI, M. GAIANI, L. SECCIA, N. SANTOPUOLI, *Morfologia e caratterizzazione colorimetrica e spettrale di elementi architettonici*, in “Disegnare" n. 18/19, Gangemi editore, 1999, pp.133-142.