Practical comparative evaluation of an integrated hybrid sensor based on Photogrammetry and Laser Scanning for Architectural Representation

C. Balletti*, F. Guerra*, P. Vernier*,
N. Studnicka**, J. Riegl**, S. Orlandini***

* Laboratorio di fotogrammetria – CIRCE
IUAV Università degli Studi – S. Croce 1624 – 30135 Venice – Italy
**RIEGL LMS Gmbh
***Microgeo S.r.l.

KEY WORDS: Photogrammetry, Architecture, Integration, Modelling, Laser scanner, Orthoimage, Multi-scale

ABSTRACT:

In architectural surveying aimed to restoration and to conservation, close to the traditional two-dimensional vectorial representation in orthogonal projection, raster representation has gained considerable importance. Among all raster representations, the most widely-used is the digital orthophoto.
The application of laser scanners as a new instrument for terrestrial survey together with firmly attached, high resolution and close range calibrated digital cameras, has permitted to obtain in straightforward way not only orthophotos but even to produce more sophisticated elaborations such as 3D orthophoto or solid image. These representations allow to get a vector representations via digitalizing in a single image.
In the paper we will describe in detail a survey procedure that is based on an integrated photogrammetric – laser scanning system manufactured and marketed by Riegl LMS GmbH (high performance 3D imaging laser sensor + high resolution digital camera). A newly developed software allows to automatically extracted 3D orthophoto and so-called "solid images" from the hybrid data set (registered scan data and digital images) which can be subsequently used to easily create vector drawings by means of 2.5D digitalizing.
This procedure is considered as an alternative approach to traditional digital close range photogrammetry, usually carried out in the activities of the photogrammetric laboratory of CIRCE – IUAV, to produce the well-known final representations: vectorial drawings and orthophoto.
Considering that these products are in Italy the ordinary requests of a survey final user, such as architects or more generally restoration technicians, the authors have done a comparison not only on the achievable accuracy but also on time, costs and resources consumption that are necessary in real applications following the two procedures: the classical one based on traditional photogrammetry, and the new hybrid system approach based on photogrammetry -laser scanner integrated system.
As test field the Arena of Verona has been chosen, such as significant application for the comparison just for the big amount of data collected by the photogrammetric laboratory of CIRCE during the photogrammetric survey campaigns (still in progress), and moreover for its own characteristics of an archaeological and architectural survey combination.
The objective of the research is to offer the possibility to a surveyor to choose the best solution for representations productions, demanded by architects, restorers, etc., considering both accuracy and representation requests.

Introduction

Can laser-scanner survey be an alternative to topographical-photogrammetrical survey?
If not, how much and to what extent can this new methodology replace or bolster the "old" method?
To answer these queries, we tried to understand if the hardware and software available today for laser-scanning can obtain a satisfactory result according to the current canons of architectonic representation, which calls for not only the use of vectorial drawings in orthogonal projections but also raster images and 3D models.
It was decided to carry out the survey of a single object by using the two different methods and compare them in each individual phase. The test area was a portion of the exterior façade of the Arena of Verona, consisting of three *arcovoli* (archways) on the south side: the XXXI, the XXXII and the XXXIII which represent an area functional to topographical-photogrammetrical survey. It was a test area significant in terms of dimensions in order to not oversimplify the problems while still maintaining complete control over the procedures.
The purpose was to evaluate the techniques from an operating perspective and therefore there is the need to keep closely to the operating and professional practice of survey.
The essential point is that while photogrammetric survey of a monument such as the Arena is a completely controlled technique, for which the times, costs and obtainable results are known, laser-scanning has been applied only experimentally and there is no case theory so generalized to be able to effectively design a survey whose instrumental support is based on the 3D scanner.
To be able to accurately compare only the scanning and rectification techniques, we decided to keep the topographic reference system common, made up of topographical local system and detail nets.
We analysed the operating methods of the two methodologies on the field and the procedures for controlling and handling the data in the laboratory, highlighting the procedures common to both techniques, the ones logically similar and those that are completely different.
We then compared the vector and raster representations obtained, to evaluate the differences in the results and attempt to identify the causes of the differences.
Finally, we evaluated the resources (times and costs) necessary for carrying out the survey using both techniques, to highlight any economies made possible by the use of laser scanner methods.

Laser scanning and photogrammetry

Laser scanning has already shown its outstanding advantages in acquiring 3D information on an object's surface in many different applications within the past few years. For laser scanning, a highly collimated laser beam is scanned over a predefined solid angle in a regular scan pattern. While scanning, the distance to the object is measured by measuring the time of flight of the laser signal with high precision. Different commercial systems are available with a broad range of specifications. The specifications differ in measurement range, field-of-view, measurement accuracy, data acquisition speed, robustness, compactness, and transportability. The primary output delivered by a scanning laser system is a *point cloud* representing a sampled replica of the object's surface. The point cloud is composed usually of a very large number of points or vertices and, for most of the systems, each vertex corresponds to a single laser range measurement. As for many applications the user is not only interested in geometrical information, but also in additional information on the object's surface, the point cloud is frequently complemented by additional vertex descriptors containing information on, e.g., surface reflectivity or surface color. Almost all laser scanners provide, beside the geometry data, also information of the signal strength of the echo signal, commonly addressed as intensity data. Some laser sensors provide with every laser measurement also color information by converting the ambient light in the direction of the laser beam into an RGB (red-green-blue) triple. The geometrical data and the additional vertex descriptors are acquired synchronously and sequentially and the spatial resolution of the additional data can thus not be higher. In order to have texturing data with a higher resolution than the laser data, high resolution digital cameras can be used additionally.

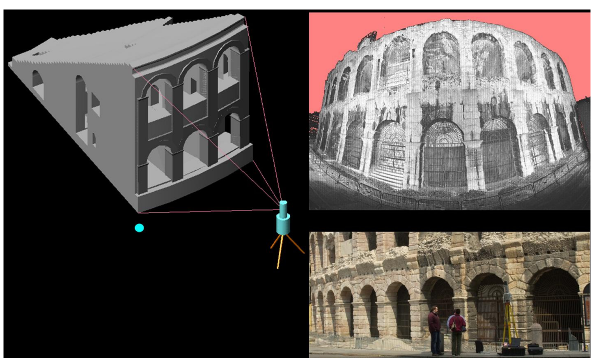

fig.1 Posizione dello strumento per l'acquisizione dei punti

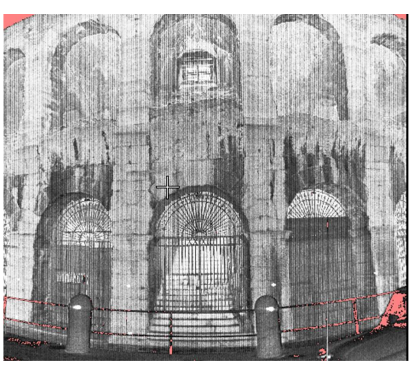

fig.2 La nuvola di punti

In principle, texturing 3D models generated from laser scan data with image data is well-established and many of the 3D data processing packages provide at least some means for texturing the surface of a 3D model. However, using images of a camera without prior knowledge of its position and orientation requires, for example, manual definition of tie points in both the scan data and the image to calculate the image parameters. Integrating a high-resolution calibrated camera into a laser scanning system provides a very efficient, convenient, and powerful system for automatically generating accurately textured high-resolution 3D models. This combination forms a *hybrid sensors* which is composed of a high-performance long-range laser scanner with a wide field-of-view and a calibrated high-resolution digital camera firmly mounted to the scanning head of the laser scanners. As for every image taken with the camera the position and orientation of the camera is measured with high accuracy within the scanners own coordinate system, scan data and image data can be combined in a straightforward way without the need of user interaction.

fig.3 LMS-Z 360i and phototheodolite.

Utilization of this new type of hybrid data in the field of Cultural Heritage (particularly architectural and archaeological field) can be tackled according to a *reductive* approach, namely attempting to obtain the traditional products more rapidly and thus more economically, or from a *propositional* approach, attempting to generate new tools for description and representation of complex forms. This challenge involves not only surveyors but also other professionals who base their work on the results of metric survey, such as restorers, structural engineers, and historians.

In order to satisfy the demands of detailed feature extraction, e.g., on ancient walls, *RIEGL* offers now a unique solution by combining laser scanning and close range photogrammetry, thus making use of the respective advantages of both. The system used for the experimental investigation is a *RIEGL* LMS-Z360i laser scanner with a digital camera, model Nikon D100. It is a portable rugged terrestrial sensor, intended for the fast acquisition of high-quality 3D images even under difficult environmental conditions (Riegl 2004).
The crucial idea behind this combination is not to regard those as competitive but complementary technologies: The most impressive result of laser scanning is the definition of surfaces, whereas the strength of photogrammetry lies in its capability of recognizing edges. The accuracy of the details is caused in the high pixel density of the photo camera, the accuracy of the whole scene comes from the laser scanner.

The secondary results derived from the hybrid data are a coloured point cloud, a decimated mesh textured with the high resolution images, an orthophoto and the possibility to digitize the data in the so-called mono plot method.

Operating methods for surveys of the three archways

The main operating differences of the two methods used for survey are described in the table below.

	Topography-Photogrammetry	**Laser-scanning**
Marking	Survey of the test area requires 6 stereoscopic models and the marking must be made to cover the entire object. This survey technique requires an aerial platform is necessary.	Only a few points on the lower part must be marked to orient the scanning and only a single scan is necessary to cover the test area. In this case, the survey is done at street level.
The sights	The sights used for topography and photogrammetry are sights that can be collimated and recognized in the images.	The laser scanner sights are the same as topography and photogrammetry but are supplied with a reflecting part to allow automatic extraction of the coordinates of the targets from the point clouds.
Setting up the instrument	The principal characteristic is the verticality of the primary axis, made possible by the thoric level present in the instrument.	Only the spherical level of the base is used to set up the instrument.
Topographic support	The framing grids are the same. There are 32 support points, located across the entire survey area. The points are distributed uniformly across the stereoscopic overlap areas of every model. In the event of interlinking models, the points are located in the overlapping area of the models. In the same way, in the event of triangulation to independent models it is necessary to put the transition points in the overlapping areas of the models.	The framing grids are the same. The reflecting targets consist of 8 known coordinates and 4 unknown coordinates located only at the level of the campaign range. The targets are positioned not only on the object but also in the surrounding area and are visible in the various scannings, thanks to the speed of acquisition and the possibility to survey with a very large angular range (360° in horizontal). This enables us to forego marking inaccessible areas. Instead of reinforcing the system of the models-scannings with points located on a vertical plane is reinforced with points on a horizontal plane.
Stereoscopic images	To cover the area, 12 photograms are necessary to form 6 models: 3 high models to carry out with an aerial platform and 3 low models to carry out from the street level. The images are defined as "normal"	Terrestrial scannings
Scannings	It corresponds to the stereoscopic images	It is done in three phases: a) panoramic scanning to verify the position and the exact coverage of the object, b) full-blown scanning (detail scan), c) scanning to very high definition of the individual markers (reflector scans).
Digital views with Nikon D100 calibrated and mounted on the Laser scanner		The camera is mounted onto the laser scanner and follows its movements. The internal and external orientation in the laser scanner system are known. The images are automatically taken at regular intervals registering the angular parameters of the laser scanner. As a result, the parameters of external orientation of the photograms are known.

Managing the data acquired	Management software of topographic files: Starnet	Management software of topographic files and laser scanner data: Starnet RiscanPro Ricube
Orientation Alignment	Apex software for digital photogrammetry allows orientation of the images in individual models or in galley strips.	RiscanPro software of acquisition and management of data from the laser scanner, allows us to align two or more point clouds of different scan positions. The operator can align one cloud onto another and orient point clouds automatically on control points (defined in the general reference system given by the topography).
Rectification and editing	Apex, Autocad2002.	RiscanPro, Scandig3D (rectification from orthophoto) and Pointcloud (rectification from point cloud), Autocad2002.

Costs and times analysis

The costs and times are known for analytical and digital photogrammetry.
The costs and times of laser scanner surveys are being studied.
The basic costs are known and include hardware and software, personnel, travel costs, costs of assistance (elevation equipment, etc) and we are studying the times and costs of managing and processing the data.

The costs for the survey campaign, which is related to the times of acquisition of the laser scanner, are low because the marking is limited to the ground level and the scannings and terrestrial photos enable the surveyor to work without using platforms and in faster scanning times.

Comparative table of the times

PHOTOGRAMMETRY			LASER SCANNING	
Marking	1 h		Marking	30 min
Topographic support	20 min		Topographic support	10 min
Stereo images for 6 models	1 h		Laser scanner (3 stations)	45 min
			Acquisition of images	15 min
Calculating the coordinates of the support points and preparing the files	1 h		Calculating the coordinates of the support points and preparing the files	1 h
			Selection, filtering and decimation	15 min
Orientation of 6 models	3 h		Orientation of the 3 clouds in the absolute system	10 min
Rectification of 6 models	30 h		Rectification from 3D orthophotos	20 h
Extraction of 6 profiles (manual)	1 h		Extraction of 6 profiles semi-automatically	10 min
Production of automatic DEM with 1 cm pitch	2 h		The DEM is the point clouds	
Orthophoto from individual model	1 h		Orthophoto from individual scanner	1 h

Conclusions and outlooks

From the analyses made, we can affirm that in the laser scanner sector, the products available on the market today are able to fully meet the needs of metric survey in an architectonic and urban scope: depending on the models, every instrument can meet a more or less ample range of applications.
In essence, the biggest problems are related to the lack of operational completeness of the various software that requires the user to use several software programmes.
To date, processing the data acquired is not a mundane procedure: it must be conducted very carefully and every individual phase (from pre-processing to modelling to mapping) must be done with care, analysing and validating the results acquired, and while selecting the software to use very carefully.
It is important to consider that the treatment phase of the data holds a predominant place in the economy of the work and it is important to choose not only the laser scanner model but also the software that can obtain results that meet the needs of precision normally associated with survey work.
The Riegl laser scanner and the software used have made great steps forward in terms of obtaining these results: strict handling of the data, accuracy in the individual procedures, by obtaining graphics (vector and raster rectifications, 3D surfaces) finally comparable with the ones that can be obtained by following the more traditional survey methods, photogrammetry and topography (*fig. 7 and fig. 8*).

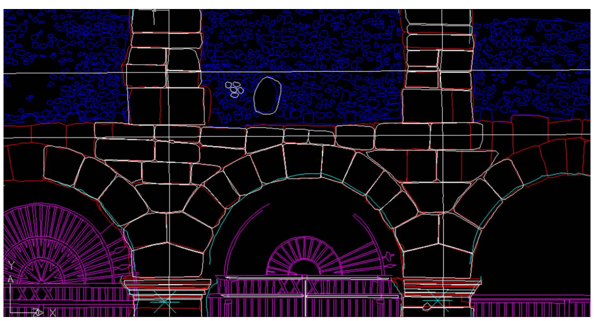

fig 7 Comparison between restitution tiny and restitution from ortofoto with Scandig 3D

fig. 8 Comparison between the two ortofoto: on the left ortofoto from photogrammetry and to right ortofoto from laser scanner

One problem encountered is linked to the quality of the digital images. Even when carried out with a Nikon D100 with 6.1 million pixel sensor and while using the 20 mm focal, the resolution of the image is insufficient (= few pixels) and a resample has to be done from the ground up to generate the orthophoto at a scale of 1:50 (*fig. 8*). The solution lies naturally in the choice of lens to use.

Digitalisation of the 3D orthophoto, made with Scandig3D, can be considered at the nominal scale of 1:50 and an average deviation of 2.5 cm was found during comparison with the photogrammetric rectification. This deviation is mainly caused by the difficulty in recognizing the architectonic elements in photogrammetry and with laser scanners. The current state of conservation of the material of the Arena has made the object devoid of corners: from this, we find that the identification of the contours on the curved surface is influenced by the interpretation of the person doing the rectification. In conclusion, the differences encountered were due to the different interpretations by the various professionals involved.
Therefore, integration of the laser scanner, as an instrument for terrestrial survey, with the digital calibrated camera obtains not only vectorial and raster rectifications more conveniently, it also produces more sophisticated representations such as the 3D orthophoto or solid image. These latter represent the new products that can be used directly by the final user, as extremely useful instruments i the sector of architectonic property, in particular in projects aiming to understand, document, and conserve architectures.
The system proposed has also shown to considerably reduce the times of acquisition during the campaign in addition to having simplified some phases of data rectification (digitalisation from a single image) minimizing the costs of the "specialised portion" of the survey (hiring a specialised technician).
Introduction of the laser scanner and development of these new and absolutely innovative products lead us to imagine a new role for operators in the survey field.
For instance, a specialized scanning service - elaboration of laser scanner data in order to achieve only solid images or 3D orthophotos while leaving the rectification not to the specialist rectification expert but to the specialist in restoration or structures or history etc.
Organization of this service, which will be experimented on at the photogrammetry laboratory at CIRCE, whose final users are graduate students, must be studied while considering a division into phases carried out by operators with diverse, specific areas of expertise. A preliminary organizational proposition might be as follows:

- campaign phases:
  (by specialists in topographical survey, photogrammetry, and laser scanner)
  - topographical survey (framing or support grids);
  - laser scanning (from several stations);
  - photo acquisition;
- processing phases:
  (by specialists in laser scanner survey)
  - filtering laser data;
  - decimation of data (according to the nominal scale of the survey);
  - Reporting, aligning, georeferencing, scannings;
- production of the printouts:
  (by specialists in topographical survey, photogrammetry, and laser scanner)
  - solid images;
  - 3D orthophotos;
- rectification phase:
  (by specialists in restoration, structures, etc)
  - use of software for extraction of horizontal or vertical profiles;
  - interrogation of solid images or 3D orthophotos (coordinates, distances) to rectify the plans and prospects.

References:

Kraus K., 1997: *Photogrammetry*, Volume 2, Dümmlers Verlag

Migliari R., *Frontiere del Rilievo, dalla matita alle scansioni* 3D, Gaugemi Editore, Roma 2001

Dequal S., Lingua A., Rinaudo F., "Ortofoto digitale di precisione", Supplemento Speciale Bollettino SIFET, n° 2 2001,
pp. 119-131, Parma 2001

Bornaz L., Lingua A., Rinaudo F., "A New Software for the Automatic Registration of 3D Digital Models Acquired Using Laser Scanner Devices", In Atti del CIPA WG 6 International Warkshop on Scanning For Cultural Heritage Recording, Greece, Corfu, 1-2 september 2002

Rinaudo F., "Calibrazione di immagini non metriche mediante l'uso dei dati laser scanner terrestri" ,in Atti della 6° Confereza Nazionale ASITA Geomatica, Perugia, 5 – 8 novembre 2002

Bitelli G., "Rilievo di beni architettonici", in Atti della 6° Confereza Nazionale ASITA Geomatica per lìambiente, il territorio e il patrimonio culturale, Perugia, 5 – 8 novembre 2002

Balletti C., Guerra F., "Laser applications for 3D survey of cultural heritage", in The International Archives of Photogrammetry and Remote Sensing, Volume XXXIV, Part 5, "Close range imaging, long range vision", in Proceeding of the ISPRS Commission V Symposium, Corfu, 2-6 settembre 2002. ISSN1682-1777.

Balletti C., Guerra F., Lingua A., Rinaudo F., "True orthophoto of the San Marco Basilica in Venice", in atti del workshop dell'ISPRS Commission V WG4 "Vision techniques for digital architectural and archeological archives", Ancona, 1-3 luglio. ISSN 1682-1750

Balletti C., Guerra F., Rinaudo F., Lingua A., Auditore G., Pilot L., "Comparison of surveys of St. Mark's Square, in Venice" in Proceeding of Internationa al Symposium CIPA 2001 "New perspective to save the cultural heritage", Antalya, 30 settembre- 04 ottobre 2003, pp. 251-257