EXPERIENCES ABOUT FUSIONING 3D DIGITALIZATION TECHNIQUES FOR CULTURAL HERITAGE DOCUMENTATION

P. Ortiz [a, *], H. Sánchez [a], H. Pires [b], J. A. Pérez [a]

[a] University of Extremadura, Centro Universitario de Mérida, 06800 Mérida, Spain – pedrotop3d@yahoo.es, (sasah, japerez)@unex.es
[b] Superficie - Topografia, Lda, Águas Santas 4425-101 Maia, Portugal - hpires@superficie-geo.com

Commission V, WG 2

KEY WORDS: Cultural Heritage, CAD, Laser Scanner, Digital Photogrammetry, 3D Fusion, Architectural documentation, Virtual Reality

ABSTRACT:

In this paper we present three experiences about combining 3D digitalization techniques for cultural heritage documentation. Retable of Bouro (Portugal) is a big and complex wood structure from the XVIIth century part of the Monastery of Santa Maria do Bouro. An urgent conservation and restoration program was promoted in order to prevent further damage in the retable. A complete 3D graphical record was needed to support this intervention. The main objective was to keep control of the main structures and to detect wood deformations. This was the reason why laser scanner and direct measurement methods were used. The Gävle theatre is a XIXth century building which was recorded for virtual tourism. Thus, this 3D model was made with laser scanner and photo texturing. The third case consists of a highly accurate 3D-reconstruction of parts of Santo Domingo Church, an XVth century building, in order to get a detailed graphical record. Accurate laser scanning, photorealistic texture modelling and monoscopic photogrammetry methods were necessary for a complete and accurate 3D model of each part of the recording. The final outputs for each of these cases were adjusted to the needs of the conservation and restoration technicians. Bidimensional vector drawings, 3d models, orthophotographs and TIN surface orthoimages were produced in order to achieve this goal.

1. INTRODUCTION

The generation of 3D models of real world objects and buildings is a necessary requirement during the documentation of cultural heritage sites for reconstruction, restoration, analysis and visualization purposes. The generated model must guarantee several requirements such as high geometric accuracy, availability of all details, efficiency in the model size and photo realism depending on the cultural heritage application (El-Hakim and Beraldin, 2002).

There are many techniques that can be applied to digitalization and modelling in cultural heritage sites, per example image-based rendering, photogrammetry and laser scanning. The requirements of a particular documentation project demand using a combination of techniques to achieve an optimal result. For example, Sequeira et al combine panoramic images, photogrammetry and laser based models to model historical buildings (Sequeira et al, 2001). In (Bernardini et al 2002) the authors model the Michelangelo's Florentine Pietà combining range data from a structured-light projection system and stereo-photogrammetry. El-Hakim and Beraldin combine image-based modelling and rendering and range-based modelling to create 3D models of cultural heritage sites (El-Hakim et al, 2002). Beraldin et al generate a virtual model of a Byzantien Crypt by integrating high resolution textures from digital images with range data (Beraldin et al, 2002). The abbey of Pompey in Italy was modelled using aerial and terrestrial images and range data (El-Hakim et al, 2003). The digital reconstruction of large and complex heritage sites requires combining data from different digitalization techniques too. El- Hakim et al used laser scanning and digital images combined with floor plans and limited surveying to model the Chapel of Convent of Our Lady of the Sacred Heart (Otawa,Canada), the Temple "C" (Selinunte, Sicily) and the Stenico Castle (Trentino, Italy) (El-Hakim et al, 2005).

In this paper we present three practical experiences related to cultural heritage documentation that require combining 3D digitalization techniques to achieve high quality data. In the presented case studies there was also the need to combine different technologies and methodologies in order to achieve a final result that would meet the needs of those involved in the intervention projects.

In the case of the Bouro retable we focused in the achievement of a complex 3D model aiming to understand the structural relation between front side, the ornamented scenario, and back side, the structure that supports all the front side. The final 3D VR model allowed the conservation technicians a remarkable understandment of the relationship between front-face and supporting structure.

In the case of the Gävle Theater we developed an interactive walkthrough of its 3D model and its environment inside a virtual tourism application.

In the Santo Domingo church the objective of the documentation was to represent in bidimensional drawings at 1:20 scale the elevations of the main entrance, the baroque organ and the three retables (main chapel and two lateral

* Cabo Verde 15, 06800 Mérida - Spain, Phone.: +34-924317030 / +34-666278798

chapels). Although the need for bidimensional drawings did not request the use of 3D digitalization technologies, the need for a very detailed representation lead us to decide to use the laser scanning as the method to insure a correct geometric relation between all the parts of the objects and, at the same time, a fine detail on all the ornaments. Even with several scan positions we could not get a full coverage scanning due mainly to the organic shapes and volume of the objects. To solve this problem we used close-range photogrammetry to complement details on parts of the objects.

The remainder of the paper is organized as follows. In section 2, we present an overview of 3D digitalization techniques considered in our case-studies. Section 3 describes each case-study.

2. 3D DIGITALIZATION TECHNIQUES

The digital 3D reconstruction for cultural heritage documentation purposes can be done with multiples techniques. In our case, the election of the appropriate techniques depended on four main parameters:

1. Objective. The purpose of the digitalization establishes the required quality and format of the documentation. The documentation process can be done for structural documentation, deformation analysis, bidimensional drawing representation, virtual reality, heritage valorisation, etc.
2. Geometrical accuracy and visual quality. Each technique allows achieving different geometrical accuracy. Moreover, some applications require visual quality that is obtained using textures from digital images.
3. Physical characteristics of the object and its environment. Parameters like the size of the object and the space available around it (accessibility) determinate the appropriate options to its recording.
4. Available budget. A digitalization technique can be not feasible if the cost of the essential instruments is too high and if the time needed to accomplish the job is too long.

Figure 1 (Almagro 1999; H.Fotamitti 1964; N.Demir et al, 2004; R.Kadobayashi et al, 2004) illustrates a first approach to a graphic comparison between digitalization techniques based on the required amount of both field and office work and the achieved accuracy applied to cultural heritage documentation, including laser scanning and image-based modelling (IBMR) technologies.

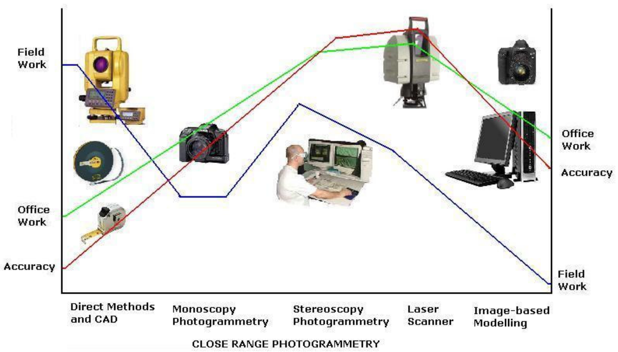

Figure 1. Digitalization techniques comparison

In the following lines, we describe the most usual techniques used for historical sites digitalization emphasizing the ones used in our experiences.

2.1 Direct measurements and CAD.

Traditionally, the surveying of heritage objects has been done by direct methods and complementary CAD drawing. Direct measurements are normally taken with tape measure, tachymeter, total station or/and other similar instruments. These instruments allow selecting the exact points for measure.

Moreover, direct methods can be used to complete other techniques and to georeference the whole model in a global coordinate system.

2.2 Photogrammetry

Both stereo and monoscopic photogrammetry are extensively used in cultural heritage documentation (Devebec et al, 1996) (Liebowith et al, 1999). In our case we used this technique because we had to capture data in areas with difficult access to a laser scanner. Monoscopic photogrammetry makes possible the 3D-reconstruction of difficult areas by taking some convergent photographs of the object.

Self-calibration was used in the case studies here presented. The interior camera parameters were obtained in the photogrammetry laboratory of University Centre of Merida (Spain) applying the method of self-calibration to known position points pattern materialized in the laboratory. The software was developed in this institution and it allows the calculation of Gaussian radial and tangential distortion, CCD scale factor, axis perpendicular deviation, etc.

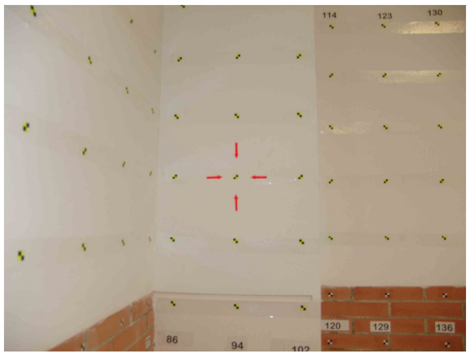

Figure 2. Calibration pattern.

2.3 Image based modelling and rendering (IBMR)

Image-Based Modelling and Rendering (IBMR) methods rely on a set of images of a scene to generate a 3D model and/or some novel views of this scene. IBMR would allow using one or several two-dimensional images in order to generate directly novel two-dimensional images, skipping the modellisation stage. The advantage of IBMR approach is that the use of a single camera allows us to keep our system inexpensive, as opposed to requiring expensive laser scanners, while being more easy to use as photographs with metric or self-metrics cameras. Pollefeys et al (Pollefeys et al 2003) present an approach for obtaining virtual models of archaeological sites with using a hand-held camera.

2.4 Laser Scanning

Terrestrial laser scanning is being extensively used to produce highly accurate 3D models of historical buildings and cultural sites (Ortiz and Sánchez 2003) (Santagati 2005) (Abmayr et al 2005). The 3D model is made by a large number of points which define precisely the geometry of the object. In addition, to acquire realistic appearance for the model, texture maps obtained form high resolution digital camera is required.

To cover every surface of the object and prevent discontinuities in the final model, it is usually necessary to use multiple scans from different positions of the laser scanner. The individual scans must be registered together based on matching geometric and image features according to a relative reference system. Two scans can be aligned when both scans have a common overlap or when there are at least three known points which situate the point cloud in a global coordinate system. The underlying mathematical calculations are based on the ICP algorithm (Besl and McKay, 1992). This alignment will affect the final accuracy of the global 3D model. Allen et al (Allen et al. 2003) developed a three-step automatic registration procedure which makes possible to reduce the registration time.

The resulting point cloud is filtered and meshed to obtain a noise-free and seamless geometric model. For interactive visualization purposes, it is advisable to apply a mesh simplification algorithm to reduce the number of polygons but preserving the visual appearance (Cohen 1998).

2.4.1 Fusion of laser scanner and image-based modelling: Combining range data and photogrammetric data we can create 3D photorealistic models. The pictures can be related with range data or between them for photomodelling tasks.

For this purpose, some terrestrial laser scanners integrate a camera. However, the quality of the photographs taken by them is not usually high enough for optimal results. In the presented case studies we used another external camera to improve image capture, resolution, distance to object and illumination conditions. In these cases, external parameters have to be known to integrate range data together with texture mapping. Matching between reflectance and intensity images has to be done. Calibration (Tsai, 1986; Tsai, 1987) is applied making correspondence between each image pixel with 3D coordinate. The RANdom SAmple Consensus algorithm is also applied here to ensure the calibration results (RANSAC) (Fischler 1981).

3. CASE STUDIES

In the table 1 we show the 3D digitalization techniques used for each case study. In the following subsections, we describe each one in more detail.

Case study	Digitalization Techniques
Retable of Santa Maria do Bouro Monastery	Laser scanning and direct methods
Gävle Theater	Laser scanning and image-based modelling integration
Santo Domingo Church	Laser scanning and image-based modelling integration, monoscopic photogrammetry, direct methods.

Table 1. Summary of digitalization techniques used for each case study

3.1 Using laser scanner in almost inaccessible complex historic sites: Retable of Santa Maria do Bouro (Portugal).

The monastery of Santa Maria de Bouro is located in the north of Portugal, closed to the Natural Park of Geres. The church and the monastery were built in XIIth century and its wooden retable (Figure 3) in XVIIth century. The retable has an exterior and an interior part which is divided in three floors. These floors communicate by staircases and are supported by a lot of props and scaffolds.

The wood of the retable is damaged by termites and humidity. The technicians in charged of the conservation plan decided that the retable must be dismantled piece by piece for its restoration. In this way, a complete study was necessary to record all pieces position, to recognise possible deviations and to reconstruct in 3D the global structure and the details of each wooden piece.

3.1.1 Data Capture: The use of digital photogrammetry or direct measurement and CAD techniques hinders us from capturing a high number of details of the monument and takes too much time. Besides, it is really difficult to create a detailed 3D model from photogrammetric methods because of the complex accessibility conditions of the interior part (Figure 4). Under these conditions, we developed this project with laser scanner technology. We chose Leyca™ Cyrax 3000 laser scanner because of its precision and angular field view, 360º in horizontal plane and 270º in vertical. Thus, only one scan was necessary for digitalizing each interior compartment.

Figure 3. Appearance of Bouro retable.

Figure 4. Interior part of the retable. Laser scanner Cyrax 3000 in a complex area.

The retable has interior zones which make impossible to obtain any overlapping area among scans. This is the reason why we used targets to join all the scans in a global coordinate system. The targets were located in different planes of the global system in order to reduce the global alignment error. For the data capture phase, we needed 13 scans, 22 targets and 4 days of field work. Two persons were enough to carry the instruments, position the targets and operate the laser scanner. The single-point accuracy of this laser scanner is 6 millimetre and the resolution used for the model survey was 1.5 cm.

3.1.2 Postprocessing: After the scanning process, 3D coordinates were assigned to each target using a laser total station to get a global alignment. The standard deviation of the global model was 3.5 cm. This value was accepted taking into account the difficult stability conditions of the floor.

To undertake this stage and to know the main structural deformations we decided to mesh and texture the global point cloud. The polygonal 3D model shown in Figure 5 contains all the necessary details for carrying out a structural analysis and valid measurements. Horizontal and vertical sections made to this model were a useful tool to analyse the different structures of the retable and its possible deformations and deviations.

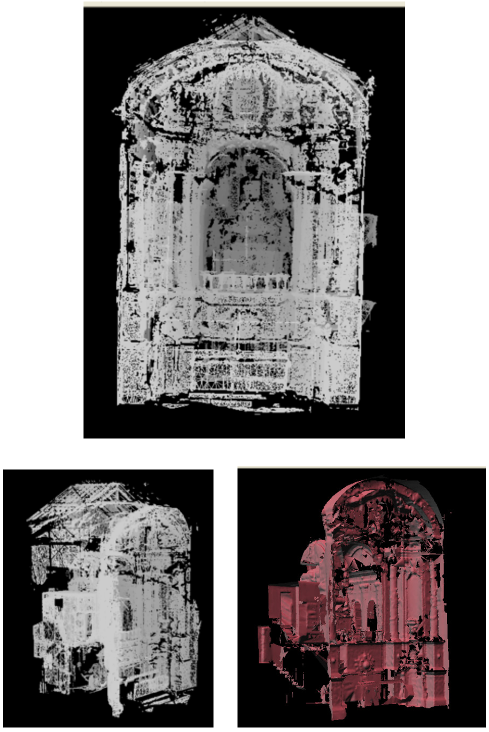

Figure 5. Triangulation and mesh of retable of Bouro. triangulation and modelling with and without exterior walls.

3.2 Combining range data with high quality textures for virtual tourism: Gävle Theater (Sweden)

The Gävle Theatre (Figure 6) was built in the 19th century by Axis Peace Nyströms and restored in the 80s of the next century. The measurements of the main facade of this beautiful building are 11.9m wide × 10.6m high and the theatre has 23.8m wide × 76.16m deep. The theatre is located in the centre of Gävle between two roads with intense traffic and surrounded by high trees. Those conditions made more difficult the building digitalization.

The virtual model of the theatre is part of a virtual tourism application. In these applications, both visual quality and interactive frame rate are required. Visual quality can be achieved by adding phototextures to the mesh generated from the registered point cloud (Figure 7). To achieve the second feature, this mesh must be reduced by polygon simplification algorithms.

Figure 6. Gävle Theater

A more detailed description of the modelling pipeline can be found in (Ortiz and Sánchez 2003).

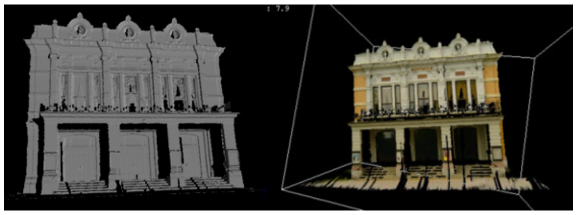

Figura 7. Phototextured model of the Gävle Theater

3.3 Highly detailed 3D reconstruction with laser scanner and image based-modelling integration together with photogrammetry: Santo Domingo Church (Portugal).

Santo Domingo church is situated in Guimarães city, in the north of Portugal. This church has a gothic structure and three baroque retables built in the XVIIIth century.

Santo Domingo Church was digitalized in five different parts: Main exterior facade of the church, two retables situated on both sides of the church, the church organ and the main chapel retable.

Figure 8. Baroque retable and organ of Santo Domingo Church.

The initial conditions required a highly detailed 3D reconstruction. The great number of small details and its organic relief lead us to use laser scanning together with photogrammetry for details which the laser could not capture because of its viewpoint. For phototexturing laser scanning and image-based integration were used.

3.3.1 Data capture: Laser scanner Cyrax 3000 was used together with a Canon EOS 350D camera. The lens used had fixed focal distance to guarantee the concordance with the calibration parameters previously calculated.

The field work consisted in scanning each object and taking complete photographic coverage for photogrammetry and phototexturing tasks. We spent 4 days in field work, doing 10 detailed scans and 45 pictures of all the objects. Three persons were necessary to accomplish this work.

The maximum laser accuracy, 6 mm, was used for this work. Camera calibration was necessary for texture mapping.

3.3.2 Digital Photogrammetry: Digital photogrammetry was used for 3D reconstruction of different parts which were occult or half occult for the laser scanner. The 3D models of some of the objects created by digital photogrammetry were integrated with the global range data model identifying several common points. Phototexturing was also done through photogrammetric data.

Figure 9. 3D phototextured model of the main facade of Santo Domingo Church.

3.3.3 Georeferenciation: A global coordinates system was situated around the Santo Domingo church using a Leica 500 GPS. 3D coordinates were assigned to topographic stations in interior of the church and, after that, to several points on the different pieces. Finally, at least three points assigned by total station were identified in range data. In this way a georeferenciation was possible using a 3D transformation system.

3.3.4 TIN surface orthoimage: The final output of the work consisted of a 2D elevation and a 3D model for each piece.

For the 2D elevations there was the need to develop an optimal system which could allow detailed CAD restitution in a orthographic projection. For this task we created an orthoimage of the TIN (Triangular Irregular Network) surface, which results of an orthoprojection of the 3D range data, previously georeferenced and triangulated, into a 2D vertical plane parallel to the facade of the objects. The TIN surface orthoimage improved the orthophoto process in the particular case of Capela do Santíssimo (Figure 10) due to the covering dust spread all over the retable, indicating a long period of cleaning negligence. The texture obtained from photographs was very faint leaving small details like ornaments very difficult to see in restitution process. Because the TIN orthoimage just reflects the model shape discontinuities, all the pale details in the photographs were clearly viewed. Apart from this it shortens the processing time, and does not depend on light conditions for its creation, obtaining, at least, easy and accurate results.

Figure 10. Comparison of an orthophoto and TIN orthoimage of Capela do Santíssimo retable.

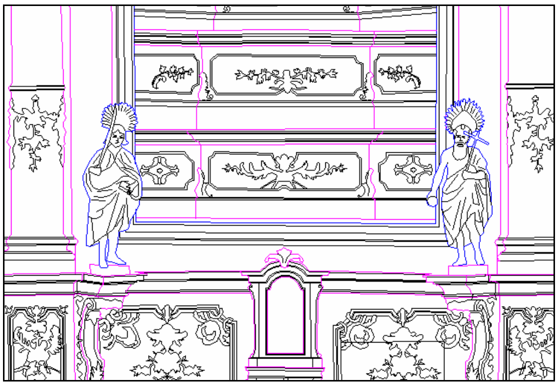

Figure 11. 2D vector drawing of one of Santo Domingo Church retables.

4. CONCLUSIONS

There is not a single method that can be applied to all cases of heritage documentation. An optimal technique combination will depend on different parameters defined in this article. In this paper we have presented three experiences about combining 3D digitalization techniques for cultural heritage documentation.

Laser scanner is an important but not definitely method. High information amount creates some processing difficulties. Although, like in the example of TIN orthoimage, many advances and new complementary outputs are expected as more and more researchers use this new technology.

4.1 Acknowledgements

The authors would like to thank Daniel Rubio Caballero and Víctor González Sánchez for helping us in the creation of this paper. At the same time we would like to thanks the kind support and cooperation from IPPAR (Portuguese Architectural Heritage Institute) in Santa Maria do Bouro Church and FAUP (Faculty of Architecture - University of Oporto) in Santo Domingo Church.

References

Abmayr, T., Härtl, F., Reinkönster, M., Frölich, C., 2005. Terrestrial laser scanning-applications in cultural heritage conservation and civil engineering. 3D-Arch "Virtual Reconstruction and Visualization of complex Architectures"

Allen, P.K., Troccoli, A., Smith, B., Murray, S., Stamos, I., Leordeanu, M., 2003. New Methods for Digital Modeling of Historic Sites. IEEE Computer Graphics and Applications, vol. 23, no. 6, pp. 32-41, Nov/Dec.
Almagro, A., 1999. Photogrammetry for everybody. CIPA International Symposium, Olinda, Brasil.

Beraldin, J.-A., Picard, M., El-Hakim, S., Godin, G., Latouche, C., Valzano, V., Bandiera, A., 2002. Exploring a Byzantine crypt through a high resolution texture mapped 3D model: combining range data and photogrammetry. ISPRS/CIPA Int. Workshop Scanning for Cultural Heritage Recording – Complementing or Replacing Photogrammetry. Corfu, Greece.

Bernardini, F., Rushmeier, H., Martin, I.M., Mittleman, J., Taubin, G., 2002. Building a digital model of Michelangelo's Florentine Pieta. IEEE Computer Graphics and Applications, 22(1), pp.59-67.

Besl, P.J., McKay, N.D., 1992. A method for registration of 3-d shapes. IEEE Transaction PAMI, 14(2), pp. 239-256.

Cohen, J., 1998. Appearance-Preserving Simplification of Polygonal Models. Ph.D. Dissertation. University of North Carolina at Chapel Hill.

Debevec, P., C.J. Taylor, J. Malik, 1996. Modeling and rendering architecture from photographs: A hybrid geometry and image-based approach. SIGGRAPH'96, pp. 11–20.

El-Hakim, S. F., Beraldin, J.-A., 2002. Detailed 3D Reconstruction of Monuments Using Multiple Techniques. Proceedings of the International Workshop on Scanning for Cultural Heritage Recording - Complementing or Replacing Photogrammetry, Corfu, Greece. September 1-2, 2002. pp. 13-18.

El-Hakim, S.F., Beraldin, J.-A., Picard, M., Vettore, A., 2003. – Effective 3D modeling of heritage sites, 4th Int. Conf. 3D Imaging and Modeling (3DIM'3), Banff, Canada, pp. 302-309.

El-Hakim, S.F., Beraldin, J.-A., Gonzo, L., Whiting, E., 2005. A Hierarchical 3D Reconstruction Approach for Documenting Complex Heritage Sites. In XX CIPA Int. Symposium. Torino, Italy.

Fischler, M.A., Bolles, R.C., 1981. Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography. Communications of the ACM, Vol. 24, No. 6, pp. 381-395.

Liebowitz, D., A. Criminisi, A. Zisserman, A., 1999. Creating Architectural Models from Images. EUROGRAPHICS '99, 18(3).

Demir, N., Bayram, B., Alkis, Z., Helvaci, C., Çetin, I., Vogtle, T., Ringle, K., Steinle, E., 2004. Laser scanning for terrestrial photogrammetry, alternative system or combined with traditional system?. XX ISPRS Congress. Istambul, Turkey.

Ortiz, P., Sánchez, H., 2004. Analisys of Gävle theater throught a hight resolution texture mapped and range data. International Workshop applied to the rehabilitation of city centres. Lisbon, Portugal.

Tsai, R.Y., 1986. An Efficient and Accurate Camera Calibration Technique for 3D Machine Vision. Proceedings of IEEE Conference on Computer Vision and Pattern Recognition, Miami Beach, FL, pp. 364-374.

Tsai, R.Y., 1987. *Metrology Using Off-the-Shelf TV Cameras and Lenses* IEEE Journal of Robotics and Automation, Vol. 3, No. 4, pp. 323-344, August 1987.

Pollefeys, M., Van Gool, L., Vergauwen, M., Cornelis, K., Verbiest, F., Tops, J., 2003. 3D Capture of Archaeology and Architecture with a Hand-Held Camera. The International Archive of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 5/W12, pp. 262-267.

Santagati, C., 2005. 3d laser scanner aimed to architectural heritage survey: from the point cloud to the geometrical genesis determination. 3D-Arch "Virtual Reconstruction and Visualization of complex Architectures".

Sequeira, V., Wolfart, E., Bovisio, E., Biotti, E., Goncalves, J.G., 2001. Hybrid 3D reconstruction and image-based rendering techniques for reality modeling. SPIE Vol. 4309, Videometrics and Optical Methods for 3D Shape Measurement, pp. 126-136.