LASER SCANNING OR IMAGE-BASED MODELING?
A COMPARATIVE THROUGH THE MODELIZATION OF SAN NICOLAS CHURCH

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ABSTRACT:

Nowadays, the demand for 3D models of historical monuments is continuously growing in the field of archaeological and architectural applications. Currently, the two main sources that can provide detailed and reliable 3D surface models are Photogrammetry through image-based modeling and Terrestrial Laser Scanner through laser scanning techniques. Among the plenty of works so far presented the use of laser scanner for Cultural Heritage survey seems to aim towards a monopoly in the 3D modeling pipeline. Nevertheless, up to now some geometric related issues have been not yet solved by laser scanner and thus, time and patience are required to get final results. Consequently, Photogrammetry through image-based modeling seems to be an economical and efficient alternative to accomplish these problems, especially when close range applications involving simple objects and some geometrical constraints can be assumed.

According to such remark, in this paper we deal with the comparison between image-based modeling and laser scanning techniques applied to the survey of the outside of the emblematic romanic church of San Nicolas, located in the city of Avila (Spain). Results and conclusions have been reported in the end to answer the question: laser scanning or image-based modeling?. To this aim, the work was carried out according to three different stages. Firstly, the church was fully surveyed with a terrestrial laser scanner and post-processed using laser scanning software. In a second stage, digital colour images were acquired with a high-resolution camera and post-processed using image-based modeling software. Finally, in a third stage a global comparison of both 3D models based on results, accuracy and time was assessed.

1. INTRODUCTION

In the Cultural Heritage avenue, the classical and mature Photogrammetry has experimented an important evolution: from 3D coordinate extraction of points through stereo-restitution to Digital Photogrammetry based on image-based modeling which exploits the bundle adjustment technique and the overlapping between images. Nevertheless, the number of produced points and the level of automation for close range applications involving complex objects are still relatively low and require time consuming procedures.

Although the development of specialized software for direct production of 3D models following simple photogrammetric techniques have broadened the field of applications, yet this does not change the basic characteristics of the method. The emergence of terrestrial laser scanning and state-of the art software developments for processing large amount of the produced data may lead to the impression that this technology is the main solution for 3D models generation. However, laser scanners still remain quite bulky instruments and difficult to use especially for data collection entailing high level positions with respect to the ground. Consequently, the existence of occlusions and the lack of data in some parts of the objects are frequent, resulting to incomplete models. Moreover, although there is certain autonomy of laser scanning with relation to topographic field work, still this is not always the case; i.e., when there is a need to incorporate a model into a particular reference system, or when the shape and characteristics of the monument do not allow a reliable cloud-to-cloud registration, there is need of surveying measurements.

As a result, the question, laser scanning or image-based modeling?, can not be answered across the board. As we have seen, each technique owns its advantages and disadvantages at different working fields and depending on the own object's features. Even in many cases a combination of both techniques might be a useful solution. Approaches such as (Finat et. al. 2005) and (El-Hakim et. al., 2005) have been addressing the use of range scans and images to develop the modeling of complex sites.

In this sense, our goals overlap with the work remarked of these researchers, but before that we want to perform a comparative focused on qualitative and quantitative analysis of these two methodologies.

Next sections deal with the approaches developed in San Nicolas Church for 3D modeling from laser scanning and image-based modeling. A final section is devoted to show a comparative between both approaches extracting conclusions and results.

2. HISTORICAL AND ARCHITECTURAL ASPECTS ABOUT SAN NICOLAS CHURCH

The origins of the church of San Nicolás (Figure 1) date back to the early days of the repopulation of Castille, a fact supported by an inscription which shows that its devotion to San Nicolás, the Bishop, took place in 1198. It is right in the middle of the Moorish quarter, 200 m outside the City Walls, and the poverty of its materials reflects in some way the poverty of its former parishioners.

Figure 1: San Nicolas' Church

From the outside it can be seen that the church has a single apse, a tower and two doors. The tower has three decreasing sections, and was built in two different periods, which explains why the access staircase is spiral in the first section, and made of wood supported by the walls in the upper half. Apparently, it never had bells.

The church is 30 m long (east-west direction), 22 m wide and 12 m tall in the central part with a maximum height at the tower with 24 m. This fact leads to an extra laser station, away enough of church in order to scan the upper part of the tower due to the limited scanning vertical range of Trimble GS200 (40º above the horizon).

It is formed by a three naves main body, articulated with the apse, the tower and a minor construction devoted to the sacristy. It shows the typical romanic style absence of ornamentation except for the two doorways. They are placed at the north and south facades with five and two archivolts respectively and the also usual decorative motives that demand a higher resolution scan. The main nave exhibits four buttresses in its occidental part.

The church is in the middle of a city garden and so, it makes easier to surround it and place the laser scanner or whatever sensor. The church is relatively well preserved, i.e. it shows a high regularity in its surfaces geometry and radiometry.

On the side of the drawbacks, we may talk of a dense "curtain" of trees which occlude part of the facades. Both on the east and north parts, buildings are too close to the church to allow a flexible design of the geodetic network. On the west there is a high traffic street while at the east there is a quiet street but full of middle size vehicles parked there.

3. 3D MODELING FROM LASER SCANNING

Surface reconstruction is a well studied problem in Computer Graphics with a wide range of applications. With the advent of laser scanner systems, which can provide dense data sets from a variety of objects, the issues of surface reconstruction and modelling of closed surfaces are receiving great attention as they are not completely solved. Moreover, the challenge for surface reconstruction algorithms lies in finding methods which can cover a wide variety of shapes.

The scanning process at each station consisted on the acquisition of a low resolution RGB image with the scanner camera in order to manage the areas to be scanned and also to project the image texture on the point cloud. A medium-range laser scanner was used. Trimble GS200 (Figure 2), which incorporates a rotating head and two inner high speed rotating mirrors that allow to acquire a scene with a large enough field of view, i.e. 360º H x 60º V, reducing the need of using lots of scan stations. The sensor accuracy is below 1.5mm at 50m of distance with a beam diameter of 3mm. In our case, a resolution of 30 mm was set up in both directions (horizontal and vertical) at 30 meters of distance.

Figure 2. Terrestrial laser scanner: Trimble GS200 (www.trimble.com).

After that, the data post-processing step included:

- Cloud point depuration applying spatial and topographic filters to eliminate overlapping areas and to erase noisy information. Manual segmentations were also applied to eliminate those features that were not eliminated by the filters.
- A semiautomatic register between point's clouds based on ICP (Iterative Closest Point) algorithm and supported by the search of point's correspondences.
- Mapping of high resolution textures. An external digital camera is registered (manually) to laser model in order to obtain high resolution RGB values projected onto the points cloud.
- Derivate products: mesh generation, sections, orthophotos, fly through and simplified models.

Nowadays, all above operations are performed in a number of modeling software packages (e.g. RapidForm, Cyclone, Polyworks, RealWorks, etc). In our case, RealWorks Survey 5.1 was used to accomplish these tasks. Nevertheless, the main problem associated to these tools is that none allow to obtain efficient simplified models which incorporate topological relations together with geometrical constraints, providing an interactive and virtual representation on Internet. Therefore, there exist a big gap between laser scanner software and powerful modelling rendering and visualization packages (known as 'computer animation software'), which use polygons to accurately represent the model, providing an optimal surface description.

4. 3D MODELING FROM IMAGES

In the last years, the development of systems and specific software tools in the field of Close Range Photogrammetry have experimented a huge proliferation. These software packages incorporate photogrammetric algorithms which allow to solve image-based modeling approaches without stereoscopic vision, using bundle adjustment together with geometrical constraints.

By pointing manually and monoscopically on homologue points on more than two overlapping images the optimum ray intersections are determined. For better accuracy and more reliable data determination, images should be taken rather with a convergence of 20º-90º (Figure 3), instead of the desired normal case of the convetional procedure of stereo-restitution. The creation of the model is achieved by selecting points that create planes or other mathematical surfaces (basic primitives) and by adding geometric constraints. A big advantage of these packages, e.g. PhotoModeler, 3D Builder, Canoma and others, is the simplified and user friendly interface that they offer, since they are made mainly for non-photogrammetrist. The basic problems are the lack of automated procedures, for example matching, which increases the required workload, and the insufficient ways for the assessment of the achieved accuracy. The procedures and technical information i.e. mathematical model used or radial lens distortion approach, remain hide like a 'black box'. However, it is a cost effective solution with interactive processing for the 3D geometric recording of monuents and without any need for special knowledge of Photogrammetry.

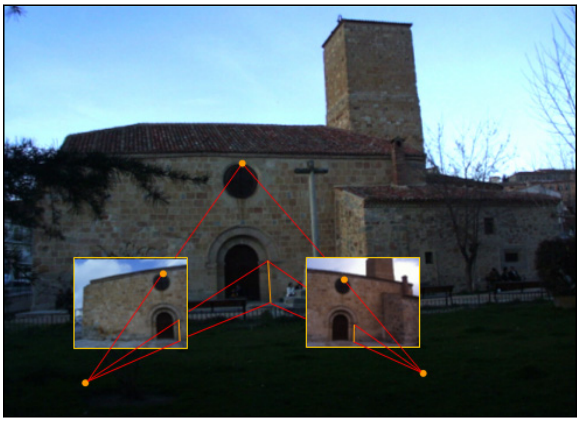

Figure 3. Overlapping images taken in the convergence case.

For the comparison described in this paper, a high-resolution camera, Nikon D70 (Figure 4), was used to capture digital images, while in the 3D modelling approach PhotoModeler software package (www.photomodeler.com) was used.

PhotoModeler is a powerful 3D software product that calculates measurements and constructs 3D models from images simply and easily. This software has the ability of:

- Self-calibration or introduction of interior orientation parameters, allowing the use of non-metric cameras.
- The use of lines between points for the determination of the delineation of the objects.
- Imposing constraints, such as collinearity or coplanarity of points, perpendicular or parallel lines.
- Determining epipolar lines improving the location of homologue points.
- Producing models without control points, while the scale is determined by measured distances.
- Adding to the model mathematical surfaces, such as basic primitives (cylinders, cones, etc.) or other second order surfaces (quadrics).
- Producing orthoimages at defined projection planes.
- Creating TIN and wireframe models.
- Appying texture to the model from images selected manually or automatically, and producing of photorealistic textured models.
- 3D viewer, with zoomimg, rotating and measuring capacity on the model.

Figure 4. Digital camera: Nikon D70 (www.nikon.com).

Through these capabilities, local or full 3D models using one or more digital cameras or even multiple frames of video recording of the monument can be generated. Speed, ease, low-cost, and the variety of alternatives in data acquisition make the use of such types of software very attractive. However, the production of detailed and accurate models of a complex building or monument can be a cumbersome and time consuming task. The topography of the surrounding area of the monument and the existence of possible obstacles may hinder the multiple image capturing and thus the effectiveness of the procedure. However, the automatic creation of 3D compact models with topology and geometrical constraints and without holes or gaps is an adventage.

5. CASE STUDY: SAN NICOLAS CHURCH

In this paragraph we report a qualitative and quantitative analysis between image-based modeling and laser scanning techniques applied to the survey of the outside of the emblematic romanic church of San Nicolas.

Following the 3D modeling from images approach several aspects related to accuracy and time are remarked:

In the camera self-calibration step, a rectangular and two-dimensional grid was used as a testing bench formed by four control points and 107 tie points (Figure 5).

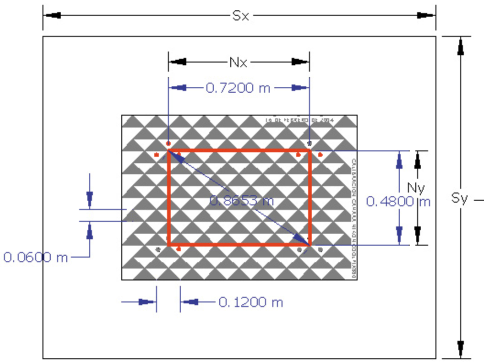

Figura 5. Calibration grid used in camera self-calibration.

This step carried out a workload of 4 hours to photographic taking and 2 hours to calibration processing. The internal parameters obtained were compared with other calibration packages (such as Pictran and Matlab), obtaining good results in focal length and principal point coordinates and small discrepancies in radial lens distortion coefficients.

After that, a photographic taking of San Nicolas church was performed consuming a total of 4 hours. A total of 106 images were acquired from different viewpoints around the church with the aim of guarantying a perfect coverage of the object, obtaining enough information in object modelling. A mathematical model composed by 157.636 equations and 78.636 unknowns was conformed (Table 1), guarantying enough number of redundancies, 79.000.

IMAGES	EQUATIONS	UNKNOWNS
	Control P. 50 Ptos.×2 Eqs.×8 Imag.=800 Eqs Control P. 30 Ptos.×2 Eqs.×5 Imag.=300 Eqs Control P. 17 Ptos.×2 Eqs.×4 Imag.=136 Eqs	Fixed: Internal camera parameters
106 IMAGES	Tie P. 400 Ptos. ×2 Eqs. ×10 Imag.=8000 Eqs. Tie P. 5000 Ptos. ×2 Eqs. ×5 Imag.=50000 Eqs. Tie P. 8000 Ptos. ×2 Eqs. ×3 Imag.=48000 Eqs. Tie P. 12600 Ptos. ×2 Eqs. ×2 Imag.=50400 Eqs	Variables: 6x106img=636 eqs. (camera viewpoints)
	Redundancies: r: 79.000	Tie Points 26.000ptos.x3eq= 78.000 unknowns
	Total: 157.636 equations	Total: 78.636 unknowns.

Table 1. Statistic data related with mathematical model in image-based modelling approach.

With relation to the most important step, the processing, an image-based modelling approach using PhotoModeler was performed. This step includes the 3D modelization with textures, as well as the restitution and vectorization of each architectural element (Figure 6). A workload of 150 hours was required to accomplish this task. An average accuracy of 3.4 cm was obtained through this methodology.

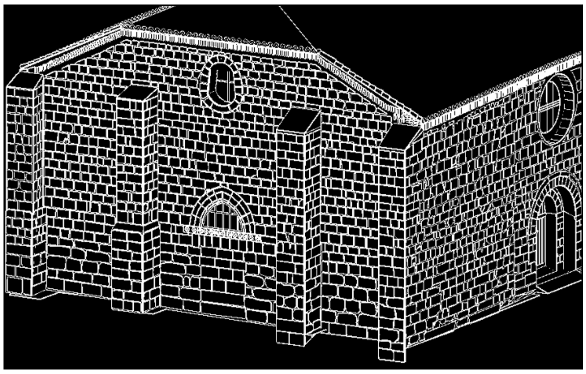

Figure 6. Wireframe model of San Nicolas church obtained through semi-automatic restitution and vectorization.

Finally, with the goal of promoting and publish our work a interactive environment based on VRML (Virtual Reality Modeling Language) was developed, in which the user can fell immersed and even touch the different elements of the church (Figure 7). Furthermore, alphanumeric information was attached to the model giving as a result a Geographical Information System applied to the Cultural Heritage. This task consumed a total of 150 hours.

Figure 7. Textured model of San Nicolas church, adding a virtual recreation of the surroundings.

On the other hand, following the 3D modeling from laser scanner approach the next requirements were taken into account:

In the acquisition process, a minimal number of 8 stations were used to guarantee a good coverage of the objects and reduce error propagation between scans. A resolution of 30 mm x 30 mm for a distance of 20 meters was set up.

The total time used in the scanning process was about 6 hours with an average time of 45 minutes per station, obtaining 5 millions of points scanned. A relative accuracy of 2 mm was obtained in each point scanned.

After that, a cloud point treatment was carried out using spatial and topographic filters to reduce information and to eliminate noisy and unnecessary data (Figure 8). Manual segmentations were also applied to eliminate those features that were not eliminated by filters. This task consumed 2 hours.

The register of multiple clouds based on the search of homologous points carried 2 hours. After alignment process a global accuracy of 1.3 cm was obtained.

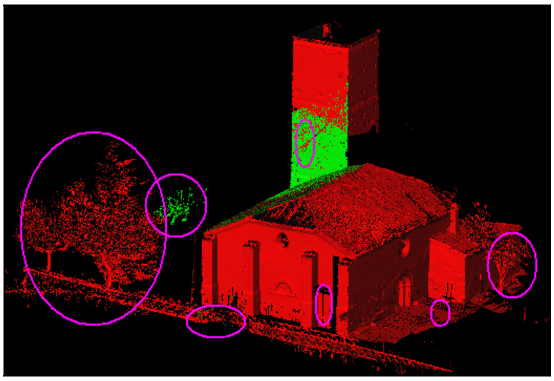

Figure 8. Alignment of different scans and depuration of unnecessary information.

Finally, a manual procedure based on mapping high resolution textures was performed. An external digital camera was registered to laser model identifying correspondences between 3D points cloud and 2D image points. As a result, a final laser model with high resolution RGB values projected onto the points cloud was obtained (Figure 9). This task was especially delicate due to the different illumination conditions present in digital images. A total of 8 hours were required to map high-resolution textures properly.

Figure 9. Final laser model obtained mapping high resolution textures.

Derivate products such as: mesh generation, orthophotos or metric measurements were immediate, requiring 4 hours to get them. However, maps generation i.e. wireframe models or isometric views required time and patience for obtaining a final result. A total of 150 hours were used to obtain complete isometric views.

Next table (Table 2) shows a comparison between both approaches based on five aspects: accuracy, time, cost, results and applicability.

	Accuracy	Time	Cost	Results	Applicability
Image-based modelling	3.4 cm	310h	300 €/day	Very good	Total
Laser Scanning	1.3 cm	172h	1.500 €/day	Good	Medium

Table 2. Quantitative and qualitative aspects about image-based modeling and laser scanning.

6. DISCUSION

In this paper we have dealt with the comparison between two different approaches in 3D modeling of Cultural Heritage: the traditional image-based modeling and the new technology of laser scanning. We have reached clear conclusions about the effectiveness of both techniques for Cultural Heritage modeling.

From a quantitative point of view, laser scanning approach provided more accurate results than image-based modelling. Furthermore, time required in laser scanning was only of 172 hours, while image-based modelling needed 310 hours. Nevertheless, several qualitative aspects have to take into account in both methodologies. With relation to results, image-based modelling offered great results with a wide range of applications: from an interactive environment to metric maps and wireframe models ready to be plotted. Efficient simplified models which incorporate topological relations together with geometrical constraints were created, providing virtual representations on Internet through VRML. Furthermore, image-based modeling constitutes a low-cost technique while laser scanning requires a large investment.

As a result, the question which technique is 'better' than the other can not be answered across the board. It will be a mix of factors and elements such as own characteristics of the object, applicability, economical support, client requirements, etc, which will provide the best strategy. As we can see (Table 3), each technique owns its advantages and disadvantages at different working fields. In many cases, a combination of both techniques might be a useful solution.

3D modeling from laser scanner	3D modeling from images
↓ No semantic information	↑ Semantic information
↓ Inaccurate lines and joints	↑ Accurate lines and joints
↓ Poor colour information	↑Good colour information
↑ Prompt and accurate metric information	↓ Hard-working and slow metric information
↑ Potency and automatization in	↓ Low potency and

data capture	automatization in data capture
↑ Excellent technique for the description of complex and irregular surfaces	↓ Time-consuming technique for the description of complex and irregular surfaces
↓ High-cost technique	↑ Low-cost technique
↓ The 3D model is an entity disorganized and without topology	↑The 3D model is an entity organized and with topology
↑ Light is not required to work	↓ Light is required to work

Table 3. Comparison of features: Laser scanning vs. Image-based modeling.

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