THE USE OF TERRESTRIAL LASER SCANNING IN THE RENOVATION OF HISTORIC BUILDINGS

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ABSTRACT

The aim of this paper is to demonstrate main aspects concerning contemporary methods of documentation and recording of a historical building for restoration purposes. The paper considers how terrestrial laser scanning data can assist the architect not only in the classic survey drawings, but also in the exploration of potential design alternatives concerning renovation of cultural heritage buildings. Accurate 3D models can be built from laser scanning data from the preliminary stages of survey study which can improve the understanding of the building and its behavior, in order to form restoration proposals. The building of Villa Rossa in Corfu provides the case study described in this paper, illustrating how data derived from laser scanning can form the basis for an architectural survey. Also, in this paper, different problems are mentioned and thoughts concerning the amelioration of methodology and collaboration between architects and TLS experts.

INTRODUCTION

Architectural surveys are composite studies that involve, among others, geometrical, morphological, historical, constructional data recording, design and analysis in order to serve as basis for viable protection and renovation proposals. Each monument has special characteristics, deriving from its singular identity and its evolution in time. In order to produce accurate architectural surveys a series of investigations, operations, “anatomies”, monitoring actions, etc are needed. All this information is recorded into architectural drawings, details, technical reports etc and mainly in a 3D model, where the historical building can be conceived as a whole, as one unit. A 3D model plays a crucial role in the study of the monument by architects, civil engineers and other scientists, in order for them to proceed to sound repair and renovation proposals for the final rehabilitation project.

During the last decades, all this multidisciplinary approach to historic buildings is supported by the use of simple or high-tech survey methodologies, mainly topographic or photogrammetric, or a combination of both.

An alternative approach involves the use of 3D laser scanning technology as a new tool for capturing data. The scanner records thousands of points per second and each point has location coordinates in space and color information. All of these points are placed into the same local coordinate system to make up a point cloud which represents the area, building, or object being

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scanned in a 3D space. Whilst conventional surveying techniques can be a slow process since individual points have to be collected one at a time, 3D laser scanning offers the ability to scan objects and sites from a distance and collect information of more than 10,000 points per second. Most importantly, traditional surveying captures the minimum number of points that will successfully and accurately accomplish the task at hand. 3D laser scanning can collect a very high density of points which aides in creating highly detailed plans and designs.

The use of terrestrial laser scanning has been very early shown that it can be successfully used for the recording of culturally significant objects such as statues, monuments and sites (e.g. [1], [2], [3]). However, acceptance among the larger profession of architects, curators and preservationists involved in the preservation, restoration and re-use of historic buildings requires a greater understanding of the practicality of laser scanning before it can be used as a common tool in architectural design. In order to achieve this it would require education that expands awareness of the value of laser scanning in practice and develops the ability to incorporate the advantages of laser scanning data into the design process from initial concept to work drawings by architects, designers and CAD operators.

The aim of this paper is to present a practical example of implementing terrestrial laser scanning as part of the architectural survey for the renovation of a monumental building. The result of the scanning process is a dense point cloud laying on the surface of the scanning object. Furthermore, a renovation project of a monumental building requires also the interior and exterior scans of the structure in order to extract the necessary information and produce accurate floor plans, sections and façades. To accomplish this, a 3D model consisting of lines, meshes, and planar surfaces that represent the building must be constructed. This model will be used to take the measurements that they need to make plans and designs for the renovation. To further improve the optical representation, digital photographs are also acquired from each scanning location. These photographs are used to create high resolution textures for the 3D models, as well as for the creation of orthophoto mosaics along façades and sections.

In this context, the geometric recording of a building with historical significance and special importance is discussed in this paper. Specifically, for the people of Corfu Villa Rossa is a landmark, a symbol of the 19th century era, but the abandonment for several years has caused a substantial amount of damage to the building. In Section 2 of the paper the basic principles of recording techniques are presented and in Section 3 the workflow of the laser scanning implementation from the recording of the building to the creation of different 3D models to accommodate the various stages of the renovation are discussed. The conclusions of this work are presented in Section 4.

SURVEY METHODOLOGIES

The accurate geometric description of a building can be performed by a number of different recording techniques. Traditionally, total stations are used to record single points by measuring the time for a laser pulse to travel the distance to the object and back. These instruments are useful to record the most prominent features of the building like edges or single points of interest, but there is a difficulty in acquiring complex surface structures because in practise only a small number of points from an object’s surface are measured (meaning that the missing and interpreted areas are greater than the data objectively surveyed).
Photogrammetric recordings are made by reconstructing 3D-information from multiple photographs. Using a pre-calibrated camera, the position from where the images were taken can be computed by taking a number of control point measurements. Once the images are oriented, 3D-information can be reconstructed by matching corresponding points in the images. The advances in computer power and the use of highly complex matching algorithms have enabled the automatic detection of matches and creation of a 3D-model of the object of interest. The problem with this technique is that it requires good lighting and sufficient texture. If these requirements are not fulfilled, the automatic matching algorithms fail to compute proper corresponding points. Therefore, this technique is not useful when working in an interior with low-light conditions. The final products are the orthophotographs (also known as scalable- or rectified photographs) which are images that have been distorted in a controlled way so that the pictures match real world conditions such as size and shape. As such, they can be used as digital maps that accurately describe the existing conditions of a surface.

Recently, terrestrial laser scanning (TLS) is gaining great interest for its relevant simplicity and speed. Laser scanning analyzes a real-world or object environment by measuring thousands of points with high accuracy in a relatively short period of time. Some scanners even have a built-in camera to acquire colour information that can be superimposed onto the geometric data. After an extensive processing phase, the collected data can be used to construct digital, two-dimensional drawings or 3D-models useful for a wide variety of applications. Different laser scanner principles exist, i.e. triangulation based, time-of-flight based and phase-difference based. In brief, time-of-flight scanners compute distances by measuring the timeframe between sending a short laser pulse and receiving its reflection from an object. Since the laser pulse travels with a constant speed, the speed of light, the distance between the scanner and the object can be determined. These types of scanners are relatively slow (10,000 points/s), but can measure points up to 1 km from the scanner without loss of accuracy. Phase-based scanners use a modulated continuous laser wave instead of laser pulses allowing for faster measuring (5,000,000 points/s). Because of the laser power required to modulate the beam to certain frequencies, the range of these scanners is limited to approximately 50–80 m. Triangulation scanners are the devices that project a laser line or pattern onto an object and measure the deformation of that pattern using a visible sensor to determine the objects’ geometry. The sensor, the pattern projector and the object being measured are configured in a triangle, hence the name triangulation scanner. Since the length of the baseline between the sensor and the projection device is limited by the field-of-view of the sensor, this type of scanners can only be used to measure objects up to a range of maximum 5 m.

In most practical cases, all the aforementioned survey methodologies are used. The final product from the combined use of these methodologies is usually the orthophotographs which when placed into a CAD environment can create a hybrid drawing from both raster- and vector- data that capture and represent existing architectural conditions. The methodology used in this project involved the following steps:

• Acquisition of scans and photographs from the interior and exterior of the building
• Registration of the acquired point clouds into a common coordinate system
• Orientation of the photographs
• Creation of a 3D model of the building
• Creation of floor plans from horizontal sections in several heights
• Orthophoto generation along façades and cross sections
• Creation of façade and section plans from orthophoto mosaics.

The above methodology has been implemented within the framework of the research project “Pilot
Survey of construction, documentation and investigation of pathology of the building of Villa Rossa undertaken by the School of Architecture of National Technical University of Athens and Corfu’s Prefecture (2009-2010). The building has historical significance and special importance for the island of Corfu in Greece (Fig.1). It comprises basement, ground floor, first and second floors with an area of approximately 270 m² in ground floor level. However, the construction (which has many additions, built in different historic phases) has not been maintained for several years resulting to a substantial amount of damage internally and externally. Specifically, cracks are deep and serious throughout the building and there are many areas on the ceilings and the walls where the plaster and other materials have worn or broken away. Also, areas of plaster of the ceiling have fallen away and have exposed the rusted steel I beams.

Figure 1: The building of Villa Rossa in Corfu

DATA CAPTURE AND PROCESSING

All data for this project were newly generated. Specifically, no drawings as-built (original construction) existed for this building, and no data sets (digital or hard copy) were used as references or as enhancements to the data produced.

The field work was divided into the following stages:

a) Planning: there was an assessment of the different conditions that were found regarding the building, such as recording of internal and external surfaces of the building, physical features, difficult access, and reduced illumination that determined the measuring methodology and the specific instruments being employed.

b) Surveying measurements: high precision topographic techniques were used to establish the reference coordinate system of all the data, to benchmark the TLS measurements and to establish an accuracy control of the TLS georeferencing. For this purpose, a control traverse network was established around the building which extended inside the building at each floor and the basement.
In addition, a total of 120 control points which were necessary for the registration of all data into a common coordinate system were also measured with accuracy of about 0.8cm.

c) Range data acquisition: The scanning of the building included internal and external acquisitions in order to create façades and ground plans and sections. A total number of 54 scans were acquired, of which 22 were from outdoors and 32 were internal. The scans were performed using the scanner Riegl Z420. The specific scanner has a measurement range of 2-1000m and a quoted accuracy of 10mm. In addition, it has the ability to accommodate an external CCD camera mounted on top of the scanner. The TLS was not set up over a known point but the position and orientation of the TLS was determined by resection from the reference coordinate system defined by the high precision surveying. Additionally, taking into account that the TLS incorporates an automatic dual axis compensator, the instrument was carefully levelled each time in order to define the vertical direction, providing a geometric constraint to check the vertical direction of the reference coordinate system. The scanning resolution was set up to 1cm.

d) Image data acquisition: an external CCD camera Nikon D100 was mounted on the TLS. The images were taken according to the basic principles of photogrammetry. The camera is controlled by the TLS software and allows the automatic download of the images. In each scan one to eight images were acquired depending on the extent of the scan. The analysis of each image was 2000x3008 pixels.

Data Processing

The processing of data acquired by different sensors is increasingly being used for complex sites modelling. In fact, there is a growing interest on the integration of laser scanners and digital cameras. In these integrated systems, the use of images is seen for the automatic registration of laser scanner datasets. The approach includes the conversion of the point cloud to a 3D mesh which represents the real object and the acquisition of texture detail via a photogrammetric process.

The processing of the various types of data requires the use of a common reference coordinate system. Thus, the most critical step preceding the data fusion is the geometric alignment or georeferencing of the separate datasets into the coordinate system which in this project it was defined by the total station measurements whereby geodetic control information was transferred onto the special targets. The georeferencing of the laser scanner data was achieved at an accuracy of 0.01m. With TLS data, registration and georeferencing are usually carried out in a combined procedure.

The next step is to also align the individual digital images that were recorded contextually with the scan in the field. At this stage it is necessary to ensure that the model’s surface points are identified and made to correspond with the same ones on the images. In this way a point cloud is created, where every pixel of the image is associated with a numeric value and colour. However, because of the high number of scans and the resulting large amount of image data it was decided to perform the processing in part. This means that after the full point cloud registration was performed the cloud was segmented into the areas shown in each image in order to complete the point cloud–image alignment.

The following step was the creation of the orthoimagery. This is performed by selecting the point cloud that represents the image and converting it into a mesh (grid of triangles) which corresponds
to the surface of the object. The projection of the image onto the surface of the façade using appropriate photogrammetric software produces the orthoimage. In Figure 2 it is shown an example of the point cloud showing part of the building. In Figure 3 the mesh of the same point cloud is given and the produced orthoimage is depicted in Figure 4. Regarding the final orthoimage and in order to guarantee realistic perception of the model, particular care was taken to reprocess all the digital images, correcting their luminosity, contrast and colour uniformity.

Figure 2: Point cloud of one facade
Figure 3: Mesh of the point cloud

Figure 3: Orthoimage of the facade
The same procedure was performed for all the acquired images separately. Then, the neighbouring orthoimages were connected with each other since all had been georeferenced as discussed above, in order to produce the photomosaic. The photomosaic for one part of the building is shown in Figure 4.

Digital images contain more texture information about objects and vector drawings make users easier to comprehend the object’s geometry. The advantage of the photomosaic is that contains both the above merits. Thus, the produced photomosaic was used in a CAD environment to produce scaled vector drawings for plans and sections of the building. Figure 5 shows the produced vector drawing which besides the geometric information depicts the damages and cracks on the surface of the building which aids the engineers and conservators to make decisions on the necessary remedial work. The same workflow was followed for the processing of the different types of data acquired from the internal of the building. Figure 6 shows an example of the created orthoimage from the main room with the fireplace. However, when developing models for use by architects, an issue that rises is the integration of the laser-scanning model into the architect’s existing approach to design, considering also the special characteristics of these models. Architects are used to work in plan, section and elevation. In general, working in a 3D CAD environment from design concept through working drawings is only becoming a recently accepted approach in practice.

Figure 4: Photomosaic from part of the building
With the 3D laser scanner the object’s surfaces enormous numbers of points are measured and represented by a mesh obtained from their interpolation. This theoretically allows an infinite number of two-dimensional projective models (plans, sections and elevations) and three-dimensional models to be created, which are not dependent on the viewpoints established a priori. The possibility of having available the total coverage of a building, in terms of data
acquisition, changes the very idea of a survey and its scale of reference. Unlike a traditional plan where the choice of section cannot be changed, 3D laser scanner technology allows sections to be created through the digital model at any point according to what is required. This is as true for the horizontal planes (plans) as for the vertical ones (sections and elevations).

Figure 7 illustrates the derived section from the georeferenced point clouds. The point clouds can be used at different heights to create plans on each floor of the building. Every section is a point cloud which describes the external and internal surface of the building at a specific height. In Figure 7 it is seen a detail of a horizontal section in the outer wall depicted in red colour and the internal wall depicted in green colour. The sections in the figure are given by a sequence of points rather than lines. In order these graphs to be employed by the architects, feature lines should be determined based on the extracted points.

Figure 7: Example of section derived from point clouds

With the advent of TLS there is a growing need for the development of automated algorithms that allow feature and line extraction from the point clouds. The existing algorithms come from the research field of computer vision and computer graphics and are typically based on previously generated triangular irregular networks (TIN) (e.g. [4], [5], [6]). They tend to use the TIN model in order to exclude the influence of measurement noise or other errors present in the point cloud. But
one of the main disadvantages of these approaches is that they typically do not consider sensor specific measurement characteristics (e.g. the rounding off of edges due to the spatially extended footprint of TLS systems). Furthermore, no stochastic information is usually provided and the previous smoothing of the TIN may introduce a too high rounding off of the determined feature lines.

In this project, interpolation lines were extracted from the laser points using the method of least squares (Fig. 8). The vector drawings arising from this process are used as the basis on which the final plans at a scale of 1:50 are made by the architects. Also, it should be mentioned that often there is a requirement of complementary in situ measurements with handheld rangefinder for the completion of the vector products in areas where there is a lack of TLS data (e.g. shadows, occlusions), and areas that need a higher resolution and accuracy than that provided by the TLS.

Finally, it must be emphasised that the use of the collected data and the obtained products is not restricted to one single application (i.e. geometric recording), but it can also be used for 3D-virtual model creation for tourism purposes, heritage archiving, as-built plans, deformation monitoring over time, etc.

Figure 8: Example of vector product derived from point cloud
THOUGHTS and REMARKS CONCERNING TLS APPLICATIONS and FUTURE ASPECTS

The use of TLS can lead to survey documentation in a very time efficient and accurate way. Prerequisite for this is that TLS is used by engineers, that are not only well trained operators, but also have a good knowledge of historical buildings or a very close collaboration with the architects in charge. Although the post processing of laser scan data still requires a lot of (semi) manual work and its accuracy is slightly lower than other techniques, it benefits from the fact that it provides a full surface description, instead of measuring only specific points as with total station survey.

In this phase, depending on the prescribed survey accuracy, good knowledge of the building and its details is needed in order to avoid mistakes in the translation of scanned data to cad drawing. Once a full surface description is available, sections can be easily extracted in any direction, with the collaboration of architects, who enrich drawings with construction data and details hidden between the external and internal skins of the monument.

To this aim, this paper has considered how terrestrial laser scanning data can assist the architect exploring potential design alternatives in a renovation project. A multi-sensor approach for the 3D data acquisition and development of vector products of a building, such as Villa Rossa, has been presented. Especially, the use of TLS opens a new way in architectural survey not only in the efficient way of data acquisition but also in the final products which obtain metric and texture information.

If scanning is to be accepted by preservation architects, a new approach can be adopted not only to fruitful multidisciplinary collaboration in data recording, but also to design methodology, as a 3D model can serve as basis throughout the design process from the early phases of preliminary study. Of course, for the moment, 3D models produced by TLS cannot replace construction analysis or dynamic 3D models that are formed and designed in another “philosophy”, with more information concerning the load bearing structure, and are produced in later stages of survey study.

As technology advances and the economic approach to TLS becomes more friendly to the user, a greater understanding among architects of the practicality of laser scanning is an essential factor, in order for the method to be accepted as a common tool in design, whenever needed. Besides, it is important to develop workflows that benefit from the collection of laser scanning data in situ as well as processing tools such as dedicated software for laser-scanning data translation, editing, and conversion in support of architectural practice. Before overcoming barriers within architectural offices to make the needed investment in software and hardware capable of processing and converting points’ clouds into data needed in the development of design, it is crucial to increase the scientific awareness in understanding the advantage of acquiring accurate 3D data sets by using laser scanning in design practice.

REFERENCES


