Terrestrial laser scanning for the digital preservation of a Croatian historical village "Dobranje"

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Key words: terrestrial laser scanner, cultural heritage, 3D model

SUMMARY

Croatia is a country rich with cultural monuments, buildings, sculptures and cultural heritage in general. New surveying techniques, such as terrestrial laser scanning, allow the collection of specific spatial and structural data of cultural heritage monuments. Those techniques make a creation of accurate and reliable models possible. Terrestrial laser scanners have various uses in cultural heritage conservation tasks.

This paper describes the research agenda at the Faculty of Geodesy, University of Zagreb, related to the inclusion of three-dimensional terrestrial laser scanning into all-important heritage of Croatian village Dobranje. The Dobranje village is under patronage of Ministry of Culture of the Republic Croatia.

Dobranje is situated in the central part of Croatia near the town of Imotski, next to the border with Bosnia and Hercegovina. This area has been habituated for ages. Proof of that can be found in Iliric burial stone knolls, tombs dating from Middle Ages and so on. Cultural heritage of Dobranje village, and particularly the historical-architectural aspect of it, is very important. Evidences of historic evolutions can be found on all such objects.

The paper presents the use of new technology, terrestrial laser scanning (TLS) that provide a good contribution to that task. Innovative terrestrial 3D laser scanning technology is used for creating accurate 3D documentation. Data obtained that way can and will be used for the purpose of protection, conservation and valorization of architectural, archeological and all important heritage. Such data and models can be used for the analysis of the structures and for reconstruction in case of any devastation.

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1. INTRODUCTION

Croatia is a country rich with cultural monuments, buildings, sculptures and cultural heritage in general. New surveying techniques, such as terrestrial laser scanning, allow the collection of specific spatial and structural data of cultural heritage monuments. Those techniques make a creation of accurate and reliable models possible. Terrestrial laser scanners have various uses in cultural heritage conservation tasks (Remondino, Rizzi, 2009).

Dobranje is situated in the central part of Croatia near the town of Imotski, next to the border with Bosnia and Hercegovina. This area has been habituated for ages. The first habitants were nomadic tribes that didn’t have a permanent residence in those parts but found them suitable for herd grazing. The first official mention of Dobranje can be found in the records dating from 1585 AD. Despite the official records there is a belief that Dobranje was habituated even before. Proof of that can be found in Iliric burial stone knolls, tombs dating from Middle Ages and so on (Čubelić 1984, Alaupović-Gjeldum, 1993, URL1).

The ministry of Culture of Republic of Croatia took these under its patronage for the purpose of protection and preservation of such an important cultural heritage. For the purposes of protection recording of the objects is necessary. That is why the Faculty of Geodesy was engaged to register the objects spatial position and form. Figure 1.1 shows an aerial view of the object.

Figure 1.1 Aerial view of the object

The question was raised how to monitor cultural heritage. How to monitor damage caused by aging, natural phenomena's and human influence?

Development of laser technology, digital photogrammetry and GPS technology in combination with conventional survey made it possible to collect a large amount of spatial data, with high precision and in a very short period of time. In this way complete and realistic information about the cultural heritage can be obtained. Such form of information was impossible to obtain in the past. Consequently, spatial data documentation about cultural heritage has higher quality (Remondio, Campana, 2007).

Therefore one possible answer to the previous questions is to engage a three-dimensional laser scanner: a very efficient, sophisticated instrument which measures tens of thousands of points per seconds that uses LIDAR technology, (Luhmann et al. 2006), (Jacobs 2005). Proper combination with Photogrammetry will give better textured 3D models (Boehler and Marbs 2004)

Light detection and ranging (LIDAR) technology is an active remote sensing technology which allows accurate measurements of cultural heritage over small and large areas. The main advantage of the technology is that it provides a direct method for 3D data collection. The laser scanners detect the range from objects by recording the time difference between laser pulses sent out and reflected back or by measuring a faze shift between the emitted and reflected signal. The main difference between these two methods is in range and speed. Pulse scanners are slower but have grater ranging capabilities. Furthermore, they are highly accurate because of the millimeter- and centimeter-level laser ranging accuracy and precise sensor platform orientation supported by an integrated position and orientation system (POS) (Campbell, 2002.).

Unlike the traditional photogrammetric methods, LiDAR technology directly gathers an accurately georeferenced set of dense point clouds. Some scanners are capturing colored point clouds, what is more representative scanned object. Other scanners have a digital camera mounted in/on scanner to obtain color on point cloud. (Lerma, 2009). Point clouds can be used in basic applications almost immediately. That capability provides the user with on the spot possibility of inspection and quality evaluation.

Faculty of Geodesy owns a Trimble GX 200 terrestrial scanner that was used in this project. He has measuring rate of 5000 points per second and angular coverage of 360° x 60° with absolute accuracy of +/- 3 to 8 mm (Shan, Toth, 2009). Figure 1.2 shows that scanner in the process of measuring on the site in Dobranje and a small segment of the point cloud obtained by the measurement.

Figure 1.2 Trimble GX 200 during measuring in Dobranje (left) and a part of the measured point cloud (right)

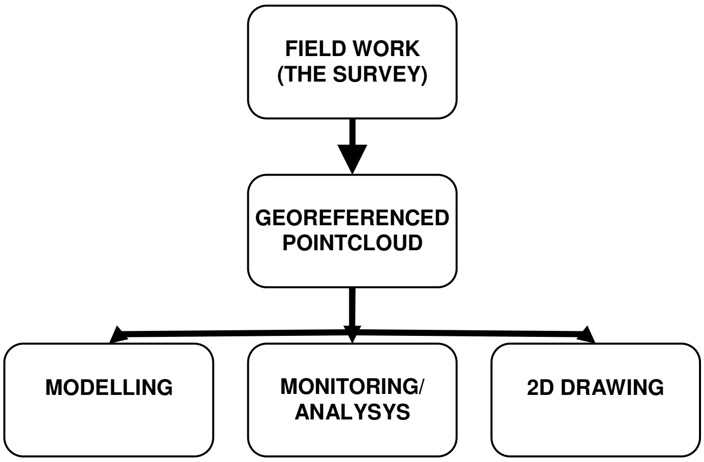
In case of partial or total destruction of the object it is now possible to restore it in a way that looks closest to the present appearance and condition. High-quality analysis, using laser scanning methods, can be created for determining the difference before and after the reconstruction or restoration of cultural heritage. In this way, the difference between the original and the renewed state caused by human factor can be reduced to minimum.

Figure 1.4 shows a chapel in a relatively preserved condition and figure 1.5 one of the outer walls which deteriorated over time. Unlike the chapel there was obviously no interest of the local population for the maintenance of those walls. Patronage of the Ministry of Culture will ensure further deterioration and possible total devastation of the object.

Figure 1.4 Outer wall of the chapel

Figure 1.5 The main entrance on the west part of the object

Phases of a 3D scanning process are shown in a schematic view 1.1. This is only a general overview. The process is actually much more complex which is why each phase has to be carefully planed and executed. The entire process will be described further down.



Schematic view 1.1 3D scanning processing steps

2. THE SURVEY

Preparation is the first step of survey, which, if done correctly, ensures optimal results. In case of Dobranje that meant inspecting the object and finding station positions that will allow the scan of all details of interest to the best of possibilities. The main problem, were the surrounding objects that obscured the line of sight and made it impossible to scan the entire object. Also the scanning range of the instrument had to be taken into account. Trimble GX scanner has a scanning range of a minimum 2 m up to 350 meters (URL2). The chosen stations are shown in the figure 2.1 relative to the floor model of the object.

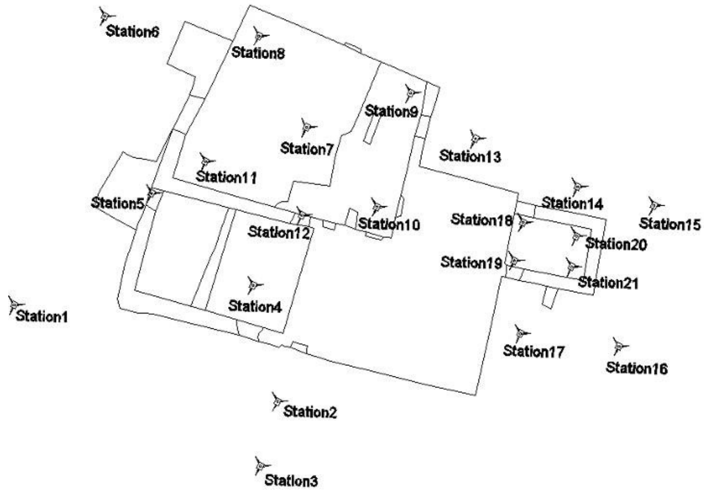


Figure 2.1 Station positions

Trimble GX scanner has the possibility of defining station position and determining the real world orientation of the scanner in a similar way it is done in classical survey using total stations (Trimble 2007, URL3). That method was used in the measurement. Station and target positions were determined with the use of GPS and terrestrial measurements.

GPS measurements provided a basis for all subsequent measurements. Classic terrestrial measurements used that basis for determining the positions of the remaining station and target positions.

Eccentricity of the scanner camera had to be considered so that the visibility between scanner and target had to be ensured even better than with a total station. This was problematic because of narrow passages between the object that was being scanned and the neighboring objects.

Once the stations were set up and their respective positions determined the scanning process could begin. That meant setting up the scanner, inputting its position, and determining its orientation with the help of targets.

The scanning process, after setting up, consists of either ordering a 360° scan or determining objects of interest for scanning. The objects were determined with the use of an internal scanner camera and a photo shot tool of Pointscape software used for controlling the scanner. Specifying objects has an advantage of shorter scan intervals and an option of defining higher resolution scans for smaller objects of grater importance.

In this project object selection was used. In that way major surfaces of the walls were scanned with a resolution of 1.5 cm while details like small openings, windows and doors that contain smaller details were scanned with a resolution of 0.2 cm. That possibility was especially important in the chapel where the walls are smooth but the altar has many small details like the figure 2.2 shows.

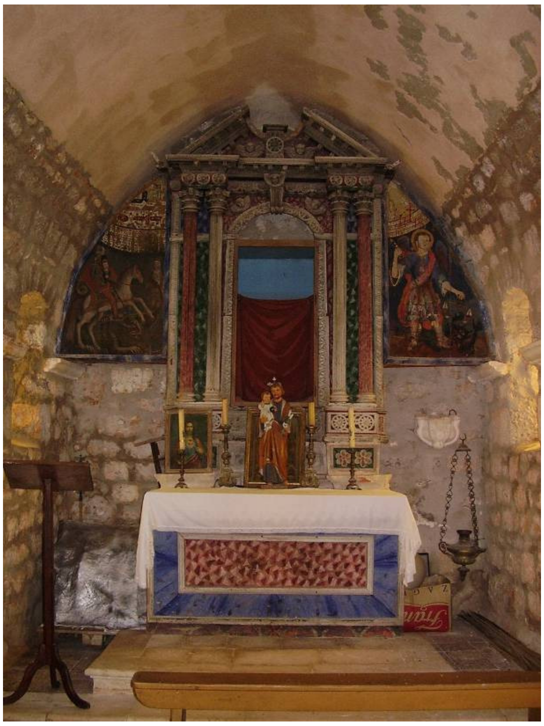


Figure 2.2 The altar of St. John (Ivan) chapel

The final result was a collection of 16,257,288 points scanned from 21 station positions. This raw data needs to be processed and prepared for modeling and creation of wire frames.

3. PROCESSING THE MEASUREMENTS

3.1 Editing raw data

After collecting data on the field that data needed to be processed in the office. First, the point clouds had to be cleared of all the unwanted data. That meant deleting all the excessive points created by obstacles, like bushes, shrubs and other inanimate objects obscuring the object of interest. The raw unclean object is shown in the figure 3.1.

Colors are assigned to points during the scanning. Trimble GX 3D scanner used for this project has an internal camera which allows point coloring simultaneous to laser scanning.

Figure3.1 Raw point cloud

Figure 3.2 Cleaned point cloud

A lot of interferences can be seen in the line of sight and some of the plants were even growing from the object. That was very inconvenient because it was hard to select only the unwanted points and leave a “clean” object. Obstacles were one of the reasons why there was a need to scan the same surfaces from different positions. The other is the fact that the surface of the object is irregular so it had to be scanned from different angles for every detail to be scanned.

Scanning of the object required a total of 21 station positions. Although, that number is high, because the surrounding empty space was very narrow. Additional station positions were needed for full coverage of the object.

Four station positions covered the outer walls facing south and west. Five of them covered the larger open space inside, and three for the smaller one. Four stations were set inside of the chapel and five for the east facing outer walls of the object (Figure 2.1).

After the process of cleaning the point clouds to the best of possibilities, the alignment process began. Alignment process was necessary even in this case, where the station positions and instrument orientation were determined. Normally, one would presume that when using this method of scanning, alignment would not be needed. Unfortunately it was noticed that point clouds measured from different stations were not perfectly aligned. The reason for that can probably be found in previously stated fact of instrument eccentricity as well as short distances between the station and orientation positions.

Cloud based registration was used in this project. Cloud based registration consists of manual and automatic alignment process. In the manual part, common points are identified on two neighboring point clouds. Manual alignment provides the basis for automatic alignment. Automatic alignment is done by software. The software identifies overlapping areas on the clouds and aligns them accordingly.

The automatic part of the process proved difficult because the software consistently tried to overlap the inside faces of the walls with the outside faces. That software error created walls with zero thickness. The problem was solved by segmenting the clouds into parts that really do overlap. Aligning those segments ensured that the corresponding clouds were also aligned appropriately.

Accuracy of the alignment depends on the quality of gathered data as well as software recognition capabilities. Software recognition capabilities are represented by the software capability of correctly identifying overlapping areas. Cloud alignment was mostly achieved with a mean square error better than 1 cm. The overall alignment process proved to be very successful, considering the number of stations and their resulting point clouds. The last enclosing group of clouds was aligned with an accuracy of 1.3 cm.

Good results were achieved because of quality field work and alignment process organization. Sets of clouds were aligned and grouped, and then those groups were aligned with each other. Alignment is done for two clouds at a time after which, if satisfactory results were achieved, the clouds are grouped into one.

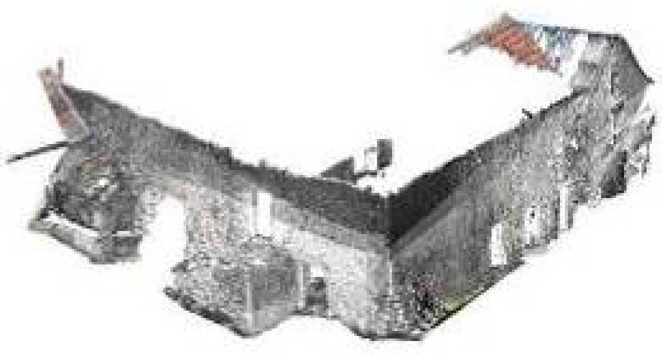


Figure 3.3 Aligned and merged point clouds

Aligned and grouped point clouds are then processed for noise reduction and point reduction. Noise reduction is also a way of cleaning the cloud of unwanted data caused by imperfections of laser measurements. Those imperfections are mostly the result of reflecting properties of the object.

Point reduction is a method of decreasing the number of points in the point cloud while retaining adequate data consistency. In the case of Dobranje, point spacing of 1 cm was used. It was estimated that a 1 cm resolution will leave enough detail for project quality while reducing the work load significantly. After all the cleaning, noise reduction and point reduction, the starting 16 million points were reduced to a number of approximately 11.5 million points.

Figure 3.4 Final point cloud of the entire object

Considering the size and complexity of the object it was then decided that smaller sections of point cloud will be made for mesh creation. Smaller sections ensure smaller point numbers in mesh creation that allow stability of the computer system and faster mesh creation for each segment. More importantly, smaller sections allow easier manipulation of the meshes and an unobscured view of each segment. Mesh segments were created with overlapping areas to ensure easier transition on bordering areas while drawing.

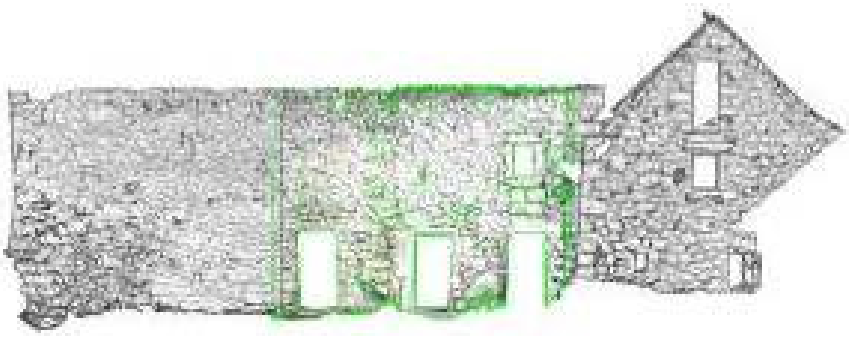


Figure 3.5 Mesh sections

When created, meshes look ruff. For a finer mesh product, noise reduction and smoothing needs to be preformed. These operations produce a mesh with clearly recognizable edges and surface contours. A smooth mesh is required for visualization purposes and improved feature recognition needed for drawing on the mesh (Figure 3.6).

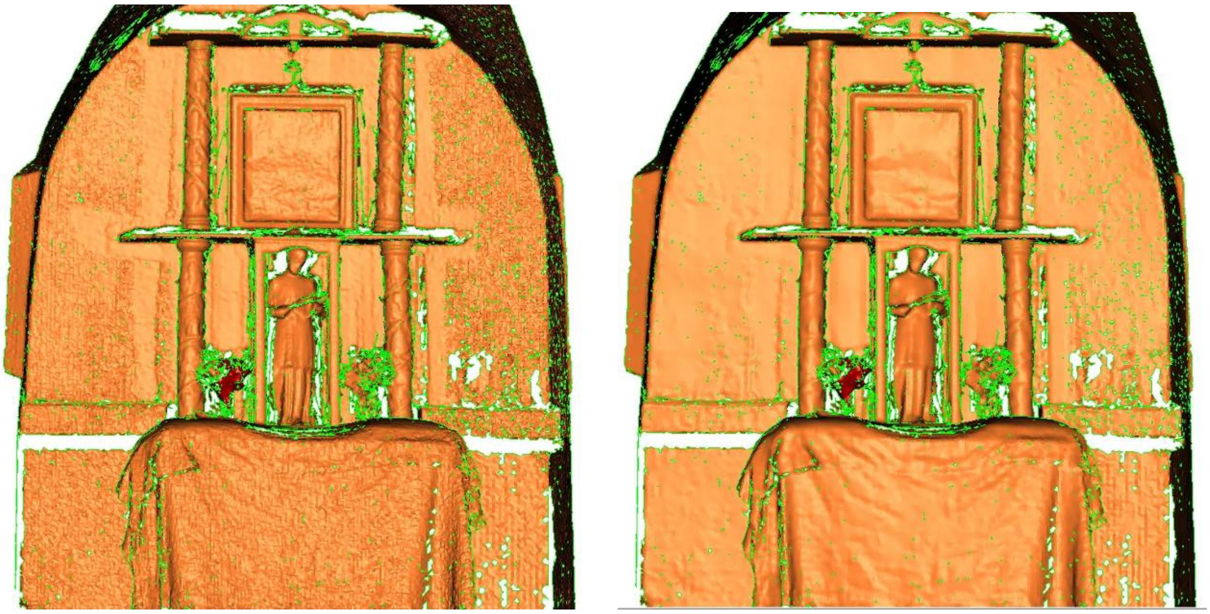


Figure 3.6 Mesh after creation (left); Mesh after smoothing and noise reduction (right)

In most cases the final user needs some kind of CAD product that can be worked on, since meshes consume a lot of memory space and require strong computers for manipulation. That is why the following step in the process is creating a CAD model from the created mesh.

3.2 Wire frame creation

Ministry of Culture demands for this project, included a creation of a CAD model. CAD models can be used without any kind of cloud or mesh manipulation software. They are also easily printed for field work. It was necessary to create a wire frame model for those purposes.

A wire frame can be created by drawing lines directly on the mesh in 3D or by creating an orthographic plane and using the mesh like an orthophoto image. It was previously stated that this objects faces are irregular so the choice was made to draw directly in 3D. That choice slowed the workflow dramatically but ensured that the perspective view provides the final user with a realistic perception of the object.

Figure 3.7 3D wire frame model

Wire frame has been created by drawing the outlines of all the stones, openings and details found on the object. The outlines were drawn from specific orthographic views of the wall segments. The shapes, sizes and positions of the stones allow architects to determine the time period the object was built in. The shapes of the openings allow them to determine the use of those openings. For example if there were beams supporting the roof or if there were openings for armored sentries and so on. Positions of the stones can also be used to determine were there any modifications to the original object. In the case of Dobranje, it turned out that the original object was smaller than it is today but was expanded in a later period of time. It allows changes of the original to be tracked and various assumptions to be confirmed or rejected. For example figure 3.9 shows traces of a former roof.

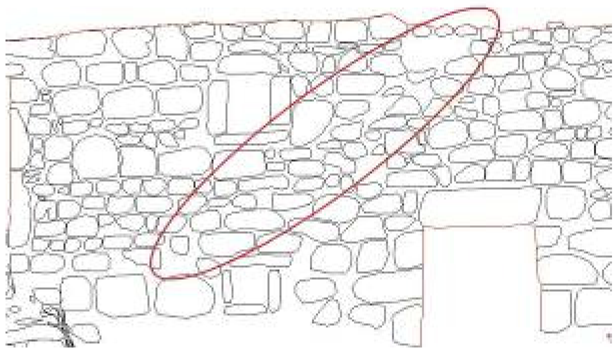


Figure 3.8 Traces of a former roof

Once the wire frame was created it was than exported for CAD software use. 3D wire frame model was presented. Specific segments were prepared in separate files for inspection, manipulation and printing. The segments prepared were orthographic views of each individual wall. Each wall needed to be shown separately because unlike the figure bellow most of them were partly obscured by other parts of the object. In the end, 18 files separated into groups were created. Each group was given a name according to the part of the object it represents. There were two open spaces inside the outer walls and the inside of the chapel. That made three groups. Outer walls were named based on the direction they were facing. Figure 3.9 represents the outer wall facing south. Although it was stated that it isn't obscured, the figure shows that a part is missing. Unfortunately, the reason for the incomplete model is that the neighboring house is leaning on the object. That fact made it impossible to scan the entire wall. Some specific significant details were marked with a height dimension. Other dimensions, like wall thickness, wall area, dimensions of the stones and openings were presented to the investor.

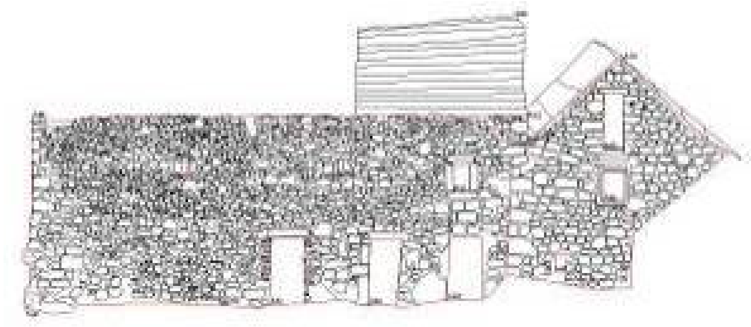


Figure 3.9 Outer wall facing south

4. CONCLUSION

Unlike classical terrestrial survey, which provides a relatively small number of discrete points, when compared to laser scanning, or photogrammetry which provides plane projections, laser scanning produces direct 3D data taken from objects of interest. Such data in a shape of point clouds by them selves already provide the user with “tangible” objects for inspection and after further processing for any kind of data manipulation. Point cloud should be documented in database in a form of unique extension. The process of collecting data should be accessed with a special attention for laser scanning is very complexed tehnology.

Laser scanning proved to be a valuable asset in cultural heritage preservation. Conventional surveying methods can produce quality results in some aspects of preservation but when objects of interest contain a great number of detail laser scanning raises the bar of efficiency, accomplishment of survey and realistic presentation of such objects. Cultural heritage professionals such as architects, archaeologists, conservators and other can make the best possible use of laser scanning technique (Barber 2007).

Accurate 3D documentation obtained that way can and will be used for the purpose of protection, conservation and valorization of architectural, archeological and all important heritage. Such data and models can be used for the analysis of the structures and for reconstruction in case of any devastation and village Dobranje represents a perfect example.

Considering the fact that laser scanning is a relatively new method of survey it can only be guessed the proportions it will take after further development. But even in a present phase of development it provides a huge asset to all kinds of cultural heritage preservation projects. Proof of which can be found in this project.

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BIOGRAPHICAL NOTES

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