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GEOMETRIC SURVEY THROUGH LASER SCANNING OF A HISTORICAL BUILDING IN ALBERTA

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Abstract: Advances in technology have provided engineers with the tools to conduct geometric surveys faster and more precisely. Laser scanning has bridged the gap between classical geometric data collection and modern technology. However, limitations exist within laser scanning. Users need to be aware of these limitations, like obstructions, cost, scanning distances and their effect on accuracy, before applying the methodology, especially when evaluating existing buildings. A case study was conducted on a historical site in Alberta to investigate the feasibility of using such technology to assess the safety of an existing structure. The assessed building is the absorption building, built in 1930 at the Turner Valley Gas Plant, a National Historic Site. This building is constructed from different steel sections connected via steel nails randomly chosen in size, number, and location by the contractor. High vaulted ceilings, obstructions, and missing members are common within the building which increase the complexity of surveying it. Two cloud models created from different data sets and products were compared. The same post processing register was used for comparison. Conclusions derived from the results are that the methodology is only useful when used appropriately, that scan quantities and overlap are required to obtain adequate data and that post-processing factors like decimation can result in a loss of required topographical data.

Keywords: Laser Scanning; Historical Structures; Geometric Survey; Decimation

1 INTRODUCTION

Technology plays a key role in the development of structural models that are used later to assess the structural capacity of a building. Various methods exist to achieve a certain goal, but not all methods are feasible to use or yield the same accuracy. One must determine the best “fit” to achieve the most accurate results. The adequacy of using laser scanning for geometric surveying of historical buildings is discussed as well as advantages and drawbacks with the method. Scanning was conducted on the absorption building at the Turner Valley Gas Plant located in Turner Valley, Alberta. The Turner Valley Gas Plant (TVGP) is a Provincial Historic Resource and a National Historic Site; it is significant as the location where Canadian natural gas was first discovered and processed in 1914, and thus as the birthplace of Western Canada’s energy sector (Turner Valley Gas Plant - Alberta’s Energy Heritage.2020). The absorption building constructed in 1914 housed the first ever absorption plant in Canada. The building was reconstructed in 1930 after a fire and the latter building has undergone adaptations as the petrochemical processing technologies changed (Turner Valley Gas Plant National Historic Site of Canada.2020). At the time, the buildings and their structural form were not of major importance - processing the oil and gas was the primary concern. The adaptations have resulted in structural components that are deficient and thus, the building was closed to the public due to safety concerns. The objective is to conduct a structural analysis using finite element analysis and BIM to determine the current level of safety and whether any strengthening is needed to be able to open the building to the public. Achieving this objective requires a non-invasive technique to obtain measurements which are difficult to obtain manually. Laser scanning aids in bridging this gap. Laser scanning provides the perfect methodology to assess the geometry of the TVGP absorption building.

2 METHODOLOGY

Laser scanning uses the time-of-flight method and collects positional data based on the angular horizontal and vertical reflection of a line laser on a mirror surface to the surrounding materials (Lubowiecka et al. 2009, Shanbari et al. 2016, Yastikli. 2007). The scanner tracks the laser's angular position as well as the time at which the laser contacted the mirror. The rate at which the wave travels through space is known and the distance is therefore determined (Yastikli. 2007). Laser scanning provides an alternative method to the typical tape measure and other conventional surveying tools with similar accuracy. The typical procedure for the laser scanning method is to conduct a scan, collect the data and map them on site if the product permits, register the scans through a post processing software, and upload them into a cloud model space to assess the point cloud. Geometric values can be obtained from the register software and do not need to run through a cloud model. Sources of error can be due to the post processing software, additional post processing, the scanning device, or human error. The quality of the scanning operation depends on two key parameters:

1) The number of scans
2) The amount of overlap between scans

The number of scans directly affects the precision and quality of the model (Charlton et al. 2009, Yastikli. 2007). The number of scans is based on the user's preferences. To obtain the most accurate results, working with a device intended for field use is recommended. The individual laser scans are presented in a model space and gaps between the scans can be assessed for accuracy. The need for a high frequency of scans is a result of the limitations of the laser scanners vertical and horizontal angular range, in addition to obstructions within the scanning location.

Overlap between scans is equally as important. Individual scans create a cloud of data points. As the distance from the laser scanner increases the quantity of points decreases (Baltsavias. 1999). This is an effect of the laser scanner collecting data in a radial fashion. Therefore, overlap between scans is required to achieve a holistic data set and minimize the dispersion effects. Although independent scans could be sufficient, a system of scans with overlap leads to higher accuracy levels (Charlton et al. 2009).

Laser scanning like any technology has its disadvantages. Large sources of error are present if scans are far apart or infrequent (Baltsavias. 1999, Charlton et al. 2009). Post processing allows users to select points from which to measure. As scan quantities decrease the point cloud decreases in size and as a result measurements are less accurate than anticipated. In addition to the above, laser scanning is limited to collecting data within the line of view of the laser scanner (Baltsavias. 1999). Most laser scanners have a large range of motion and can rotate on point to obtain more angles and data. However, the range of data is still limited. This effect can be seen specifically in areas of high vaulted ceilings and surrounding obstructions (Baltsavias. 1999, Lubowiecka et al. 2009). Due to dispersion the point cloud reduces in size when approaching the ceiling and is non-existent behind obstructions. If a component of the building is of interest but is hidden by surrounding members, the laser scan will not be able to recognize the desired component. To counteract this effect, one can take more scans or increase the elevation of the laser scanner to obtain a different line of view. In sites featuring high vaulted ceilings, scaffolding may be required. The quantity of scans and the various equipment required is very costly when compared to hand measurements and the device itself may not be feasible due to high product costs (Baltsavias. 1999, Charlton et al. 2009). Post-processing procedures can be used to alter the point cloud data. Decimation is the process of refining the point cloud to obtain data points that are equally spaced apart (Smith.2022). The user defines the spacing, and the larger the spacing is the more data that needs to be removed. However, decimation can negatively alter the data prior to inputting into a cloud model (Veneziano et al. 2018). So, this begs the question what is the benefit? The largest benefit to the methodology is laser scanning requires a fraction of the time to complete when compared to the collection of geometries the old-fashioned way (Lubowiecka et al. 2009). When carefully conducted and post processed laser scans provide very accurate results. Numerous devices are available using this technology. The best device to be used depends on the strength and accuracy required in the model space.

Laser scanners that are equipped with panoramic photo abilities provide context to the post-processed cloud model (Baltsavias. 1999). This feature allows users to view the data in colour and as if they were virtually present on site. The data of laser scanning provide the accuracy for the measurements while the panoramic photo is a tool for ease of assessment. The accuracy of laser scanning required is important to note prior to selecting the equipment, since laser scanning equipment varies based on its quoted precision (Shanbari et al. 2016). In the case of the TVGP absorption building the photos are required to make sense of the point cloud. There are obstructions and components of the building that are structural but data from both are still collected. The imagery allows one to understand what it is that is being measured and ensure they are working in the correct area of the point cloud. In addition, the absorption building has many missing members that need to be documented to conduct a structural assessment of the building's capacity. Laser scans and photos are immediately overlapped in a cloud model or register post-processor. One downfall is that if the overlap of two data sets is not accurate users can select the wrong data points (Smith. 2022). For example, an individual is measuring the length of a building and the walls of the building have a layer of sheathing surrounding the outermost column. The desired measurement would be from edge to edge of the sheathing. If an overlap between the photos and laser scan data exists, the user may appear to be selecting a data point on the sheathing but is instead selecting a data point on the outermost column.

3 TVGP Absorption Building Case Study

Figure 1: Exterior view of the absorption building located at the Turner Valley Gas Plant. The image shows the five absorption towers, and the corrugated iron sheathing. (Parks Canada Agency.1995)

The absorption building consists of a steel frame with corrugated iron sheathing built on a concrete foundation, as shown in Figure 1 (Turner Valley Gas Plant National Historic Site of Canada.2020). The columns and girders of the frame are historical pipe, while the beams are historical angles (Turner Valley Gas Plant National Historic Site of Canada.2020), as shown in Figure 2. The connections between members vary from welds to ties and pin connections. Through the middle of the building stand 5 absorption tanks, which have a diameter of 1 meter; these tanks obscure the view of the roof members and trusses. In addition to the obscured view, the absorption building has vaulted ceilings and many missing or deformed components which can be hard to keep track of, as shown in Figure 3. The building is 6.1 meters wide and 13 meters long. Within this condensed space the use of a ladder was limited to reach members; a more convenient, non-invasive alternative was needed.

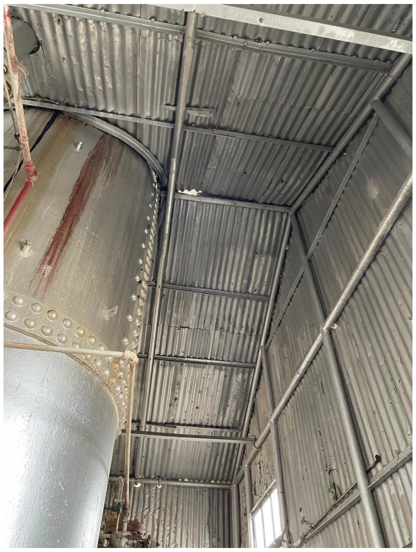

Figure 2: Interior view of the absorption building, depicting the various connections and types of members, alongside the vaulted ceiling and absorption tower.

Figure 3: Photo and MiraCAD model comparison of the interior view of the absorption building, depicting a member that was manipulated to meet the demands of the oil and gas piping.

Two different geometric surveys were used for the absorption building. Both were conducted using Leica Laser Scanners and Reality Capture technology. The first was conducted by the Government of Alberta with MiraCAD using Leica Scanstations P40 (Smith, 2022), while the second was conducted as University of Calgary research using Leica BLK 360. Cyclone Register 360 was used for post-processing in both models. Variations were discovered between the two models. The results and setbacks of each model will be discussed with respect to the assessment of a historical structure. The quoted precision of the two scanners is tabulated in Table 1 (Leica BLK360 Data Sheet.2022, Leica Scanstation P40 Data Sheet.2022). Both scans were completed within the operational temperature range proposed by the manufacturer (Leica

BLK360 Data Sheet.2022, Leica Scanstation P40 Data Sheet.2022). The objective of the scans was to obtain geometrical lengths and diameters of building elements within 5 millimeters of accuracy. This data would then be used to create a BIM model and further assess the structure.

Table 1: Quoted 3D Precision Accuracy of Product

Product	Precision
Tape Measure	+/- 1 mm
Leica ScanStations P40	+/- 3 mm @ 50 m
Leica BLK 360	+/- 4 mm @ 10 m

The Leica Scanstation P40 has a horizontal and vertical range of 360 and 290 degrees, respectively (Leica Scanstation P40 Data Sheet.2022). It is equipped with a camera, however MiraCAD used an external camera for the photometry. Photos and scans are taken at the same location. The photos are used a source of colour to the scans. Through MiraCAD Cloud 360 users can transverse from photo to photo. Between photos users enter the point cloud where objects look like a composition of atoms instead of a solid object. It is between the photos that errors are created. Since the objects have no defined boundary the selection of data points becomes difficult to accurately conduct, especially in areas of scarce data points. Prior to uploading the data into the cloud model, the registered data were decimated to reduce the file size (Veneziano et al. 2018). The scan locations were decided based on the location of obstructions. As seen in both figures below scan locations were primarily selected between the absorption towers to ensure that the roof trusses in these locations were captured.

The 12 setup locations using the Scanstation P40 for the MiraCAD model (Cloud 360 MiraCAD.2020) are depicted in the plan view of the building shown in Figure 4. The scan locations are depicted as blue circles and the focus is within the building parameter.

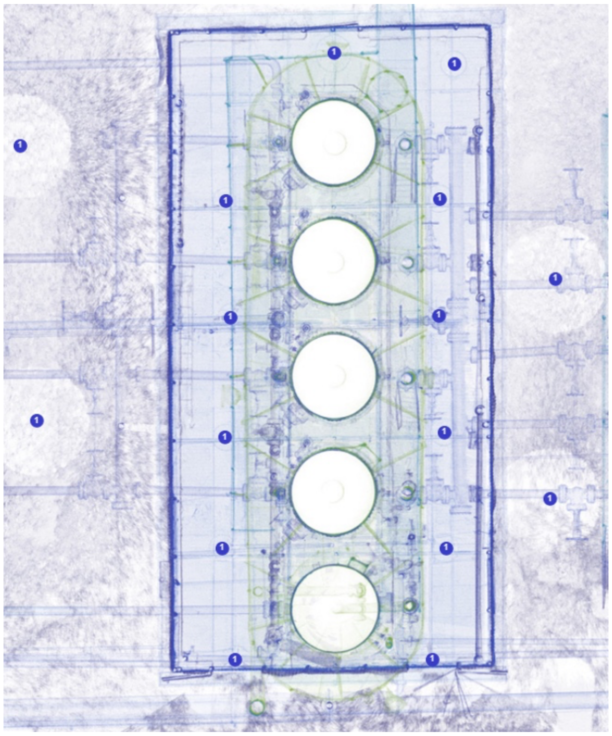

Figure 4: Scanstantion P40 scan setup (Cloud 360 MiraCAD 2020)

The Leica BLK 360 is equipped with an internal camera and has a horizontal and vertical range of 360 and 290 degrees, respectively (Leica BLK360 Data Sheet.2022). The University of Calgary model used the internal camera of the BLK 360. When the internal camera is used the images and scans are registered together and provide a smooth model, by which users are unable to differentiate the point cloud from the model space as it all appears in similar resolution to a photo. Decimation was not conducted on the University of Calgary model and measurements were recorded within the register space as a cloud model was not required.

The setup for 8 scan locations using the BLK360 scanner for the University of Calgary model is shown in Figure 5 The scan locations are depicted as red circles.

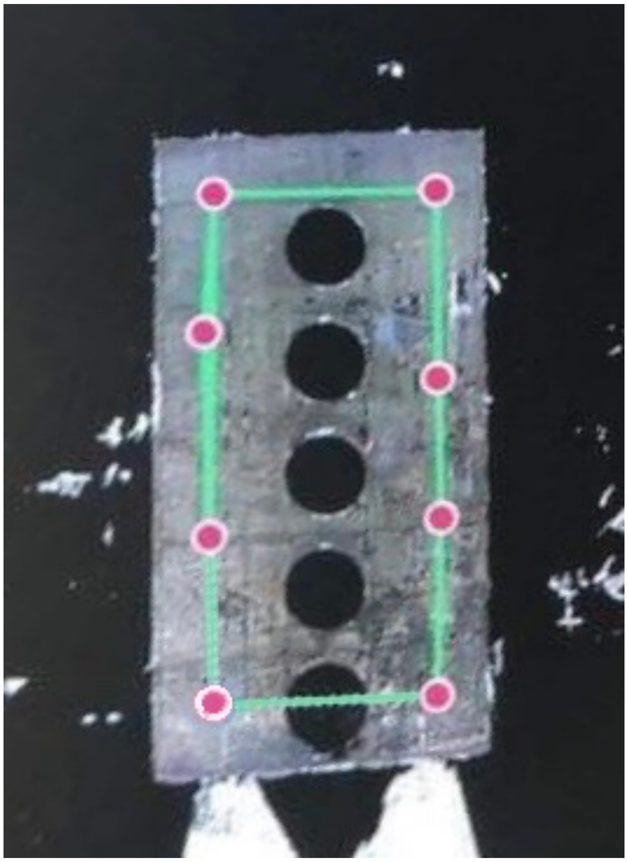

Figure 5: BLK360 scan setup (Register BLK 360.2021.)

4 RESULTS

As the scans conducted by the Government of Alberta had a higher degree of overlap than those conducted by the University of Calgary, the Leica Scanstation P40 model was expected to obtain the highest accuracy (Charlton et al. 2009). The Scanstation P40 also has higher quoted precision from the manufacturer (Leica Scanstation P40 Data Sheet.2022), further strengthening this hypothesis. For comparison, 2 test locations were selected and measurements taken from both models. Manual measurements (via tape measure and calipers) were used to validate the model values. The two locations vary in elevation to show the effect of vaulted ceilings on point cloud dispersion. The measurements are tabulated in Table 2.

Table 2: Comparison of Measurements

Component	Elevation (mm)	Measurement (mm)		
		Hand Tools	MiraCAD Model	University of Calgary Model
Truss Vertical Member	3600	1530	1540	1529
Pipe Diameter	1000	60.3	50	62

The truss vertical member measured a control value of 1530 millimeters, while the MiraCAD model measured 1540 millimeters (Cloud 360 MiraCAD.2020), and the University of Calgary model measured 1529 millimeters. Based on the precisions quoted in Table 1 and using the hand tools measurements as a control (Leica BLK360 Data Sheet.2022, Leica Scanstation P40 Data Sheet.2022), the MiraCAD model result should be between 1527 to 1533 millimeters, and the University of Calgary model result should be between 1526 to 1534 millimeters, theoretically. The University of Calgary measurement is within the theoretical range, however the MiraCAD model is not.

The pipe diameter measured a control value of 60.3 millimeters, while the MiraCAD model measured 50 millimeters (Cloud 360 MiraCAD.2020), and the University of Calgary model measured 62 millimeters. Based on the precisions quoted in Table 1 and using the hand tools measurements as a control (Leica BLK360 Data Sheet.2022, Leica Scanstation P40 Data Sheet.2022), the MiraCAD model result should be 57.3 to 63.3 millimeters, and the University of Calgary model results should be 56.3 to 64.3 millimeters, theoretically. The University of Calgary measurement is within the theoretical range, however the MiraCAD model is not.

The quoted 3 millimetres within 50 meters was not met by the Scanstation P40 (Leica Scanstation P40 Data Sheet.2022), while the quoted 4 millimeters within 10 meters was met by the BLK360 (Leica BLK360 Data Sheet.2022). As seen in Table 2, the University of Calgary model is closer to the control value than the MiraCAD model. In the truss vertical member comparison, The MiraCAD model had a 10 millimeter difference from the hand tools (Cloud 360 MiraCAD.2020), while the University of Calgary model had a difference of 1 millimeter. Due to the short range the two models should have the same or similar results. This discrepancy was again seen in the pipe diameter comparison when the MiraCAD model had a 10.3 millimeter difference and the University of Calgary model had a difference of 1.7 millimeters. Since the large variation is seen in both comparison locations one can not conclude that the error is due the elevation of the measurement. In addition, the MiraCAD Model contains 4 more scans when compared to the University of Calgary Model, which increases the overlap and data available in the point cloud. The experimental results conclude the opposite to the theoretical results (Charlton et al. 2009, Yastikli. 2007). This large error must have another explanation. The same post processing software was used between the models reducing the variation between the models. The major difference is that the MiraCAD model used decimation and the University of Calgary system did not. As previously mentioned, to reduce file size between registration and cloud modelling MiraCAD applied a decimation factor of 3-millimetres to the point cloud, thus decreasing the amount of data available (Smith, 2022). Decimation can result in a loss of topographic data (Veneziano et al. 2018). The 3-millimetre decimation factor means that all data points within 3-millimeters of one another are removed and one data point is left as a result. This directly affects the model as there are less data points present, and the precision can no longer be quoted based on the manufacture’s specifications. Based on the quoted 3 millimeter precision of the Scanstation P40 (Leica Scanstation P40 Data Sheet.2022) and the decimation factor of 3 millimeters, the precision of the MiraCAD model is actually 6 millimetres. The decimation factor in this instance reduced the accuracy of the model. Although the laser scanner used for the MiraCAD model is of higher precision than that of the University of Calgary, the post processing factor greatly affected the model results. Thus, we conclude that the laser scanning technique is accurate and useful in geometric surveying, however if the data are not analyzed appropriately the accuracy of the data can be drastically reduced.

5 CONCLUSION

Technology has led to advances in the BIM industry. Laser scanning is a tool that can lead to more accurate models when combined with other computer modelling programs to produce detailed results (Shanbari et al. 2016). However, validation is required against geometrical surveys due to their limitations. The input of the data is directly correlated to the output data. Laser scanning is a very beneficial tool if used carefully. Preparation for testing is an important aspect. The case study shows that various products have different limitations and tested accuracies. Users must be aware of these issues prior to conducting testing. The data can be used to prepare the site and critical parameters, (i.e., number and location of scans). The number of scans and scan locations are directly related to the amount of obstructions present within the desired scan area. As the obstructions increase the required number of scans increases, as well as the desired location must be strategically selected to obtain an appropriate amount of data within areas that are least affected by obstructions (Baltsavias. 1999, Charlton et al. 2009, Lubowiecka et al. 2009 Yastikli. 2007). Post-processing procedures, like decimation, can affect the results from the data and the expected accuracies. The selection of the appropriate product is dependent on the application. Although laser scanning has its limitations it is a very powerful tool and can ease the mapping of heritage structures substantially, demonstrating the importance of non-invasive methods in the assessment of heritage structures.

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