TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 64, Issue IV, November, 2021

ANALYZING THE ACCURACY OF 3D MODELS GENERATED USING PHOTOGRAMMETRY COMPARED TO TERRESTRIAL LASER SCANNING. CASE STUDY OF A WATER TREATMENT PLANT LAYOUT

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***Abstract:** This paper aims to highlight the efficiency of photogrammetry generated 3D models used as mesh referenced intended for rapid factory planning within computer-aided design software. The case study has been applied to a water treatment plant that has been 3D scanned using a terrestrial laser scanner. The terrestrial laser scanning mesh has been used as a reference to compare the accuracy and mean deviation of the 3D model generated using photogrammetry. The proposed methodology has been validated through a case study that involved the redesign of a water reservoir and associated piping and fiting elements.*

***Keywords:** photogrammetry, terrestrial laser scanning, CAD, layout planning, point clouds*

1. INTRODUCTION

Production facilities represent some of the essential elements of a business. These facilities integrate a wide variety of equipment to produce various goods and services. A properly designed production facility that is modular and can be reconfigured with easy represents can represent an important competitive advantage.

Factory layout design represents a multidisciplinary task that is of vital importance in today's globally competitive market. Researchers have highlighted that the need to construct new factories or reconfigure existing factory layouts has increased primarily because of the fast changes in customer demands and production quantity [1].

The process of designing and planning a factory layout represents a complex task that involves multiple components such as buildings, machinery, equipment, material storage, and handling equipment, and various work areas. If the factory is being constructed from scratch, various organizations and stakeholders are involved in the planning and construction process of either the plumbing, electricity, ventilation or equipment installation, as well as for meeting requirements from various management systems [2]. These organizations or stakeholders usually have different views of the proposed layout, and they oftenly use different software to design and plan their assets and/or process flow.

In case of existing production facilities that require reconfiguration, the factory layout planning represents a more difficult task due to the degree of interdependency between various assets. For instance, maintaining various piping and equipment represents a significant task for the case study treatment plant that is being modernized.

The main objective of the proposed paper is to analyze if it’s enough to perform handheld photogrammetry of a factory layout when dealing with a complex piping system. The case study presented in this paper, that showcases a treatment plant, uses a workflow methodology that compares the 3D mesh acquired using photogrammetry techniques with an accurate terrestrial laser scanning.

Modern surveying technologies, such as terrestrial laser scanning and photogrammetry,

Received: 30.09.21; **Similaritie**s: 10.11.21: **Reviewed**: 02.11./04.11.21: **Accepted**:24.11.21.

are capable of providing accurate measurement. Thus, during the last decades, these technologies have started to be implemented in a wide variety of fields such as architecture, civil-engineering [3] industry, geomorphology [4], geographic data and information [5], and archaeology [6].

2. DATA ACQUISITION

Both terrestrial laser scanning and close-range photogrammetry are non-contact techniques that can provide dense cloud points and even 3D textured meshes, using various software and equipment. Although in the last decade, these technologies have evolved, the most significant improvement is related to the software and specific algorithms that align and define the final 3D models. As presented by other researchers, both techniques are capable of providing meshes composed of millions of points that are measured on the surface with millimeter accuracy [3].

Other researchers have used photogrammetry based techniques to define the 3D reconstruction of both straight and curved pipes [7].

As other researchers have presented, photogrammetry represents a measuring technique that can be used to obtain accurate 3D digital replicas of real-life assets using only photographs [3].

The authors decided to use a water treatment plant as a case study for this research paper, mainly because of a high amount of overlapping pipes and systems connecting various tanks and reservoirs.

2.1 Terrestrial laser scanning data acquisition

Multiple scanning positions were taken for the treatment plant using the Z+F Imager 5010x terrestrial laser scanner (Fig. 1). A total of 22 scanning positions were defined at various locations and at different heights to acquire the factory interior.

As presented by other researchers, although the TLS measurement is accurate, the final meshes are subject to measurement noise, which can be influenced by the environmental conditions between each scanning position [8].

Fig. 1 *The proposed methodology*

2.2 Photogrammetry data acquisition

Data acquisition of the treatment plant interior made use of a Canon 5DSR DSLR camera paired with the Canon 24-105 mm f/4-22 lens mounted.

A total number of 833 photos have been shot handheld. The camera settings were adjusted accordingly to the poor lighting conditions within the treatment plant. The authors decided not to use any external light sources or a tripod to speed up the photogrammetry process, thus making it more similar to the terrestrial laser scanning process that doesn't require special attention regarding the lighting illumination. The ISO was set between 1250 – 2000, the aperture stop F-stop 4/ and an exposure time ranged between 1/15 up to 1/20.

3. METHODOLOGY

The proposed methodology used to define and compare the 3D mesh generated through photogrammetry techniques with the 3D mesh generated with the help of terrestrial laser scanning techniques is illustrated in (Fig. 2).

The first step is to acquire the data in situ; in our case, it is done both with the terrestrial laser scanner act and with the camera. In step two, the raw data are processed: at the terrestrial clearing, point clouds resulting from the individual scanners are aligned and filtered; the photogrammetry aligns the photos generating the point cloud. In step three, point clouds are generated and processed, which are then converted to 3D mesh. In the case of terrestrial scanning, an independent software solution was used to generate the mesh: Bentley Context Capture. The Deviation Analysis tool was used to evaluate the accuracy of the two meshes. After generating the two meshes and comparing them, the mesh obtained by the photogrammetry method was used for 3D modeling of the pipe system in Catia V5. The diameters and position of the resulting pipes are then compared with the information extracted from the 3D mass obtained by terrestrial laser scanning considered standard.

4. 3D MODELS GENERATION

4.1 Terrestrial laser-scanned 3D model generation

The first step in obtaining a 3D mesh from a terrestrial laser scan is to process and align the point clouds. In this case, the Z+ F Scout application was used. After aligning the 22 point clouds using both positioning targets (Fig. 3) and Cloud to Cloud alignment.

The alignment of the 22 scan positions is shown in (Fig. 4).

Figure 5 shows the final point cloud composed of the 22 independent scans.

The point cloud generated in Z + F Scout is exported in .e57 format and then processed Bentley Contex Capture, where the 143.3 million points are transformed into a mesh.

The resulting textured mesh has been filtered and optimized and is defined only using 7 million vertices and has acquired the whole interior of the factory, including the walls.

4.2 Photogrammetry 3D model generation

In order to obtain a good quality result, were made 833 photos with the highest resolution possible at different zoom and angles; an overlap of over 60% [9] was attended between as many photos to ensure more tracking points, the total number of photos are illustrated in (Fig. 7) as blue planes.

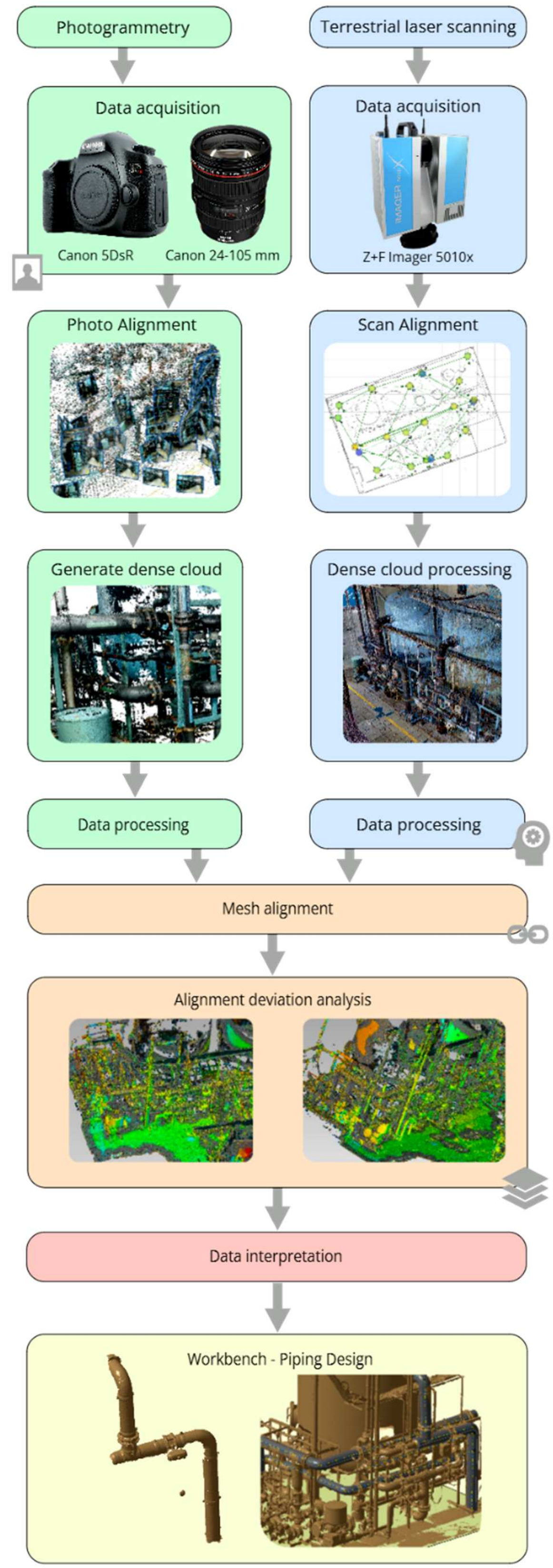

Fig. 2 *The proposed methodology*

Received: 30.09.21; **Similarities**: 10.11.21: **Reviewed**: 02.11./04.11.21: **Accepted**:24.11.21.

Fig. 3 *Target used in TLS*

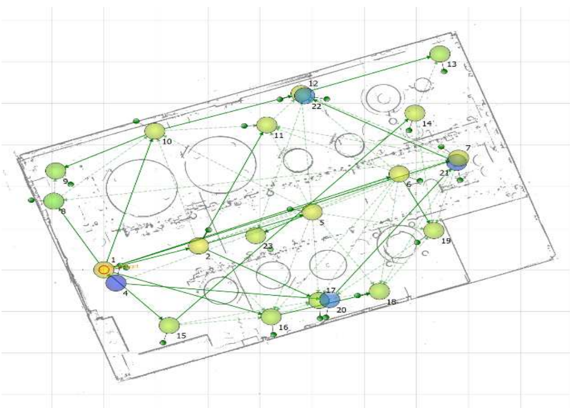

Fig. 4 *Final alignment for TLS*

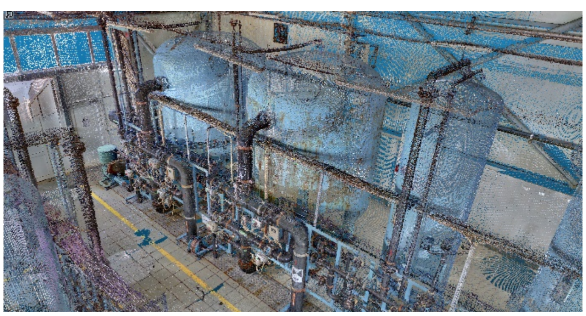

Fig. 5 *Final cloud point form TLS*

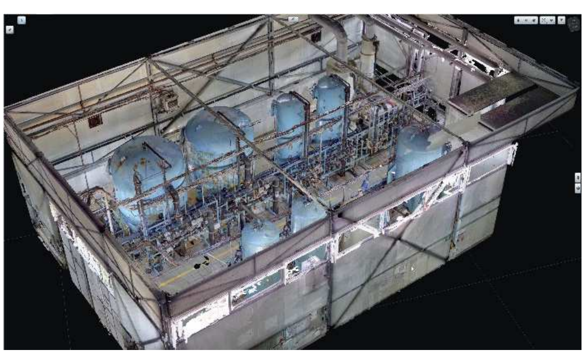

Fig. 6 *Final mesh form TLS*

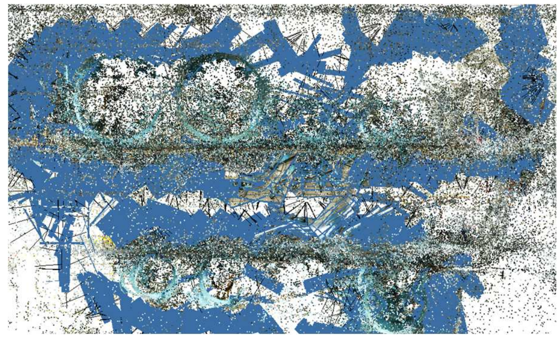

Fig. 7 *Top view of cameras position and angle in the treatment plant*

The resulting image was entered in photogrammetry software Agisoft. The highest settings possible were applied at first photo aligned to ensure an excellent result. The total processing time was 11 min and 50 seconds and was generated 668,666 points; a closeup PrintScreen is presented in (Fig. 8).

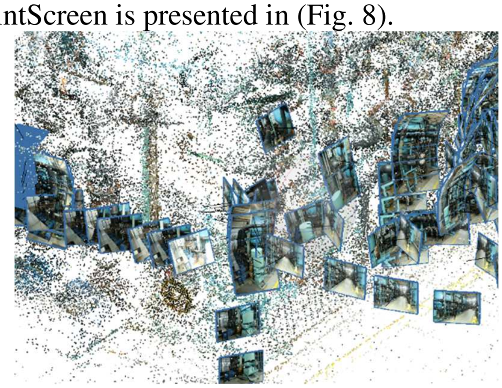

Fig. 8 *Close up view of photos taken in the water treatment plant and points generated after the first alignment*

Due to high alignment, there wasn't any failed aligned photo; no intervention with reference points was needed to help the alignment. Instead, a clean-up was necessary around the pipe system, and a focus volume space was applied only on the pipe system with tanks, excepting the building, to ensure easy high cloud processing. The clean-up was effectuated manually with a drag to select tool and selected the points that weren't necessary or were outside the focus area.

At the next step (dense cloud points), due to the computer performance, have been chosen a high-quality setup to increase the matching point between photos to generate a good quality dense cloud. The total time at this step was 1 day and 12 hours and were generated 171,495,868 points. The resulting dense cloud points are illustrated in (Fig. 9**)**. From the total time of 36 hours, 2 hours and 26 minutes were required for the generation of the depth maps.

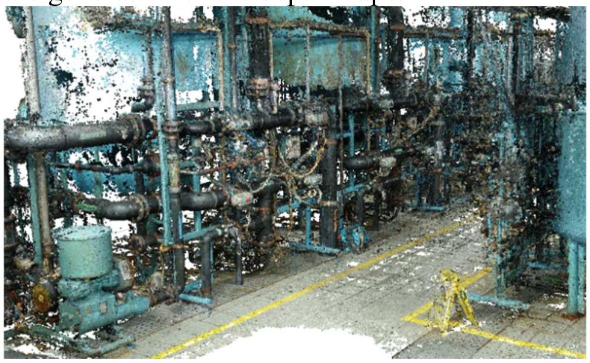

Fig. 9 *Dense cloud points*

The final step, mesh generated, was done using two methods to be able to compare the quality and select the best method to proceed to the final comparison between laser and photogrammetry.

The first method is generating mesh by depth maps. That was done in 46 minutes at high quality. The mesh generated using Depth Maps is illustrated in (Fig. 10).

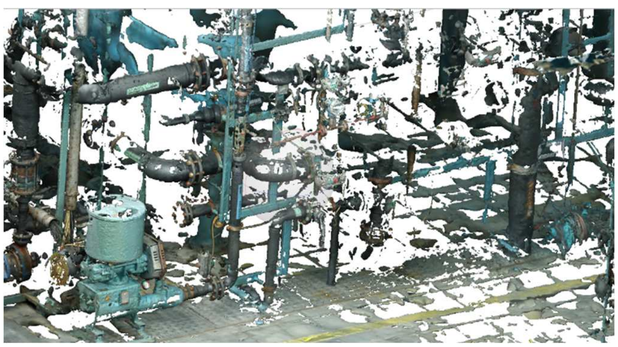

Fig. 10 *Mesh generated by Depth maps*

After interpreting the data, the conclusion was that the mesh had multiple missing referenced surfaces. Using this mesh would make it very hard to measure the pipes or to see their direction; thus, the 3D cad process would require additional measurements.

The second 3D creation method was done by using dense cloud points as a reference; this method was done in 2 hours at the same quality as the first method;

After the interpretation, the conclusion (in this case) was that the pipes are much better defined; tracking direction or size, it's easier.

There are some missing parts, also with this method, where it was too hard to take photos, behind some pipes. The final mesh generated using Dense clouds is presented in the figure below.

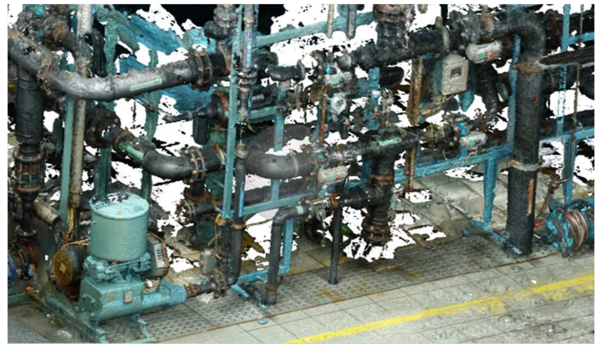

Fig. 11 *Mesh generated by Dense clouds*

The mesh generated using dense clouds was the optimal mesh generated based on photogrammetry techniques.

5. COMPARISON METHODOLOGY

The two meshes have been imported within the same session of Geomagic Wrap for a deviation Analysis. The first imported mesh was the mesh-generated scanning of the treatment plant. This mesh has been aligned to the viewport, and it was verified that the mesh was imported at the correct scale.

The second mesh generated using photogrammetry techniques has been scaled and aligned with the initial terrestrial scanner. A closeup section of the two resulting meshes is illustrated in the figure below.

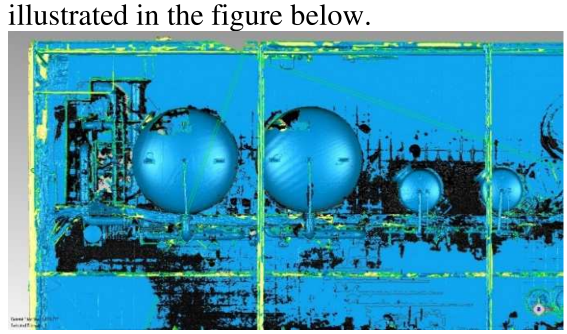

Fig. 12 *The two overlapped meshes: terrestrial laser scanned mesh (blue) and photogrammetry mesh (black)*

The mesh acquired using TLS equipment has defined the whole factory interior, including the boundary factory walls. For the deviation analysis, only the overlapping elements have been analyzed; thus, the model generated using TLS equipment has been cropped to eliminate

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the walls, to analyze better the essential elements such as the piping and the reservoir tanks. The overlapping cropped areas of the two analyzed meshes (photogrammetry generated and TLS generated) are illustrated in the figure below.

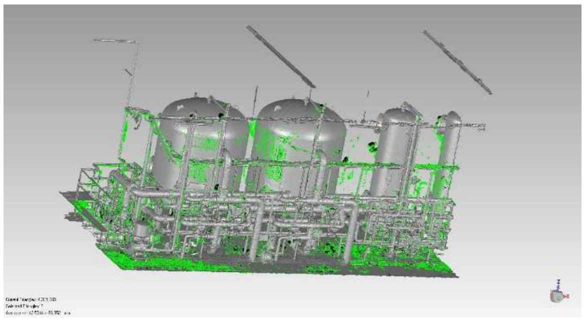


Fig. 13 *The grey 3D mesh represents the TLS, and the green elements represent the photogrammetry mesh*

The area colored in green has an average deviation of ±5 mm for the mesh generated using photogrammetry techniques compared to the accurate TLS mesh. The maximum positive deviation is highlighted in red and has a value of around 113 mm, and these are in areas around the tanks, where insufficient photos of the treatment plant have been taken. The same regions display the maximum negative deviation, which is colored in blue. The overall deviation analysis of the cropped area with multiple pipes connecting various reservoirs is illustrated in(Fig. 14).

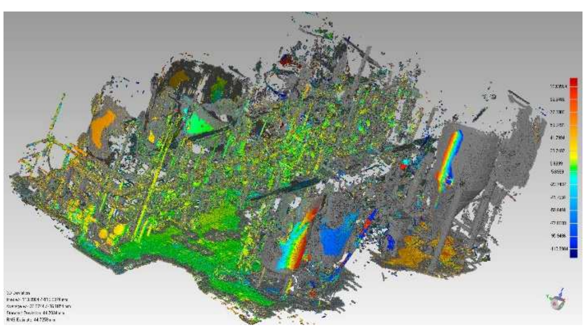


Fig. 14 *Results of the deviation analysis between the photogrammetry mesh and the TLS mesh*

The deviation analysis has highlighted that handheld photogrammetry can easily acquire the existing treatment plant equipment that consists mainly of various reservoir tanks and associated pipelines.

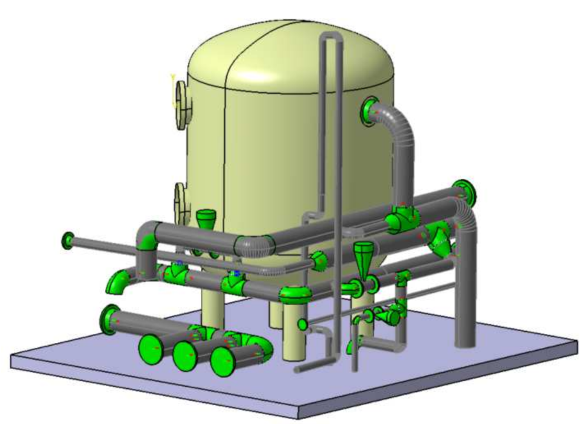
The pipelines obtained using photogrammetry are mainly within the ±5 mm deviation, enabling them to be used as a general reference for the computer-aided design redesign of the treatment plant based on the existing layout.

The mesh obtained using photogrammetry techniques has around 36 milions points, for the following step the resulting mesh can be filtered, thus enabling a much smoother and faster workflow within Catia V5.

6. 3D PIPING REDESIGN BASED ON RESULTING MESHES

The 3D mesh obtained using photogrammetry techniques has been imported in Catia V5, and the 3D model has been redesigned within the piping design workbench. The result CAD model of a reservoir tank and associated piping elements are illustrated in the figure below. Catia V5 represent a multi-platform software solution that can be used to optimize CAD models for various engineering domains [10].

The pipes paths have been identified to a large extent, as well as the diameter of the pipe. Because all the standard elements have been redesigned within a dedicated module, 3D assets were used directly from the CAD software database for the tee, tee reducers, elbows, caps, and adapters. There were slight differences between some elements of the existing mesh reference and those available within the CATIA V5 piping library. The entire piping structure has been redesigned using Catia V5 piping assets.



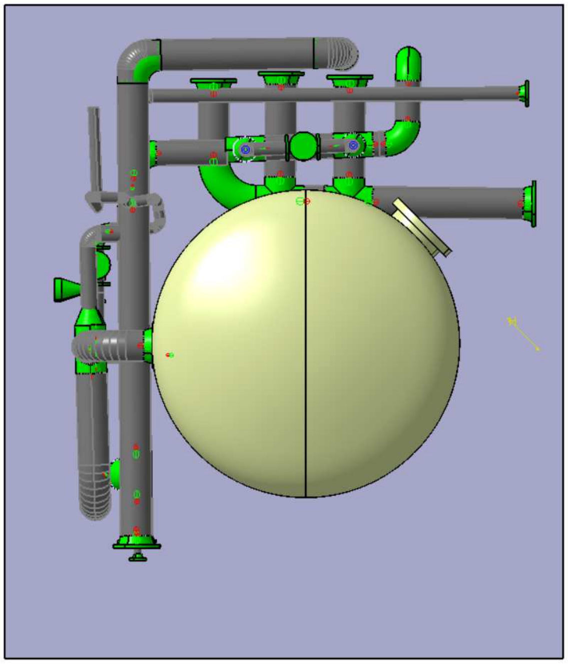


Fig. 15 Results of the deviation analysis between the photogrammetry mesh and the TLS mesh

7. CONCLUSIONS

The objective of the research paper was to investigate the accuracy of the 3D model obtained using the photogrammetry technique.

The case study was applied to a water treatment plant. The authors' intention was to analyze the possibility of using a low-cost solution (photogrammetry) to obtain the 3D mesh of the pipes and equipment within the water treatment plant. The resulting 3D model was compared to the 3D model obtained using terrestrial laser scanning equipment.

The deviation analysis between the two models demonstrated that the 3D model obtained using photogrammetry can be used successfully as a 3D mesh reference in computer-aided design.

If the 3D design of the pipe system is done using a dedicated software solution. In that case, the proposed working method represents a fast and straightforward approach, and it can successfully replace the classic survey method for pipe systems.

In some situations, if there is no P&ID to identify the diameter of the pipes or if the pipes are insulated, then the pipe diameter must be identified correctly before the 3D design can be generated. The piping routes can be easily modeled if the software solution allows the creation of points on 3D meshes. Catia V5 enables the intersection of a portion of a mesh with a plane and the conversion of the mesh into a surface-type element that can then be processed.

Most CAD software solutions dedicated to piping allow the design and offset of a line. Using this feature, the user doesn't have to model directly over the reference mesh; he can design the model next to the reference position and only move the line, thus the 3D model elements after in the final position using offset functions.

The use of photogrammetry 3D mesh to perform surveying measurement represents a feasible solution. Still, our recommendation is to use a combination in which the terrestrial laser scan is used as a master model, and the photogrammetry is used for detailing. There are various situations in which the photogrammetry method fails to align the photos perfectly; thus, manual alignment can be performed if there is a master reference model. For the case study presented within the paper, a terrestrial scan could have been performed using only 6 positions, which would have significantly reduced the time and costs of the process. The resulting point clouds mesh could then be completed using the one obtained using photogrammetry.

8. ACKNOWLEDGMENT

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project number TE 132 15/09/2020 - PN-III-P1-1.1-TE-2019-2203 (Atop), within PNCDI III.

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ANALIZAREA PRECIZIEI MODELELOR 3D GENERATE FOLOSIND FOTOGRAMETRIA ÎN COMPARAȚIE CU SCANAREA LASER TERESTRĂ. STUDIU DE CAZ AL UNEI STAȚII DE TRATARE A APEI

Rezumat: Această lucrare își propune să evidențieze eficiența modelelor 3D generate utilizând tehnici de fotogrammetrie, aceastea fiind folosite ca și elemente referință destinate pentru planificarea rapidă în cadrul unei etape de reproiectare a unei fabricii utilizând soluții software de proiectare asistată de computer. Studiul de caz a fost aplicat unei stații de tratare a apei care a fost scanată 3D cu ajutorul unui scaner laser terestru. Modelul 3D rezultat în urma operației de scanare laser terestră a fost folosit ca și element de referință pentru a compara acuratețea și deviația geometrică a modelului 3D generat obținut prin fotogrammetrie. Metodologia propusă a fost validată printr-un studiu de caz care a implicat reproiectarea unui rezervor de apă și a elementelor de conducte asociate.

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