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APPLICATION OF TLS AND UAV DATA INTEGRATION TO SPECIAL OBJECT MODELLING

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Summary

Contemporary measurement techniques facilitate the rapid and highly precise development of three-dimensional models of any spatial object. Terrestrial laser scanning (TLS) stands as one of the most precise methodologies. Nevertheless, instances arise wherein restrictions imposed by the terrain configuration or infrastructure design impede the acquisition of comprehensive information regarding its geometry. In such scenarios, the optimal resolution lies in the integration of data sourced from diverse measurement instruments.

In the context of working with large objects, the optimal approach to capturing comprehensive data, particularly pertaining to the upper parts, involves utilising an unmanned aerial vehicle (UAV). The high resolution of images acquired at a low altitude enables the generation of a point cloud with remarkable accuracy, delivering a satisfactory outcome.

When it comes to the modelling of special objects, such as brine graduation towers, the selection of suitable software that facilitates the creation of realistic three-dimensional models is of paramount significance.

The study utilised the integration of data acquired from a low altitude using the DJI Air 2S Fly More Combo unmanned aerial vehicle. Diverse mission types were employed, and the data was subsequently recorded using a terrestrial Leica ScanStation P40 laser scanner.

The research was conducted on a brine graduation tower situated above the Nowa Huta reservoir in Kraków. The tower's dimensions necessitated the incorporation of TLS and UAV data. This study analyses three 3D models of the brine graduation tower in Nowa Huta. The models were generated using various computer programmes, namely MeshLab, Agisoft Metashape, and Cyclone 3DR, each of which demonstrated specific capabilities and suitability for modelling a special object like a brine graduation tower. The accuracy of the constructed three-dimensional model of the tower was determined by comparing sections that were measured in the field on the structure between photographic points marked by discs and the equivalent points on the model. Eighteen sections were measured, yielding a mean error of 0.039 m.

Keywords

point cloud • TLS • UAV • data integration • LIDAR • 3D model

1. Introduction

Three-dimensional (3D) modelling of diverse objects is currently mainly based upon data (point clouds) procured from laser scanning conducted at various altitudes: airborne (ALS) [Kwoczyńska et al. 2018], terrestrial (TLS) [Gawronek and Mitka 2015] and mobile (MLS) [Kukko et al. 2012]. Laser scanning generates point clouds that offer high accuracy in studies due to their resolution, among other things. Extensive research has been conducted globally for many years on the application of laser scanning for registering and cataloguing architectural objects, as demonstrated in [Cantoni and Vassena 2002, Boehler and Marbs 2004, Mitka and Szelest 2013, Bernat, Janowski and Rzepa 2014, Bęcek et al. 2015].

The accurate data acquired through laser scanning allowed for a number of analyses included in the studies, including [Buckley et al. 2006, Lichti and Gordon 2007, Pyka and Rzońca 2006, Uchański and Soerensen 2010, Mitka, Klapa and Pióro 2023, Liakos and Panagos 2022, Janus and Ostrogorski 2022].

However, data regarding spatial objects can also be obtained in many other ways, including using aerial photogrammetry [Kwoczyńska 2019] and terrestrial photogrammetry [Boroń et al. 2007]. Commonly used data acquisition tools include Unmanned Aerial Vehicles (UAVs), which are witnessing an exponential surge in popularity, ubiquity and use [Salandra et al. 2023, Pádua et al. 2022, Stal et al. 2022]. UAVs have become one of the basic tools used in modern engineering. These tools are utilised not merely for recreational and sporting activities, but have also evolved into instruments of measurement employed by professionals and specialised researchers [Mitka, Klapa and Pióro 2023].

Frequently, the location of the examined object, its shape and dimensions, in addition to its inherent characteristics, create circumstances that do not allow for the acquisition of comprehensive shape information. In such scenarios, integrating data from diverse measuring instruments presents as the optimal solution. For instance, in the pursuit of creating a comprehensive three-dimensional model of an architectural object, the optimal approach to supplement the data frequently involves the utilisation of an unmanned aerial vehicle as the resolution of images taken at low altitudes, allows to obtain a satisfactory outcome in the form of a point cloud [Kwoczyńska and Małysa 2022, p. 311].

The aim of the research was to present the utilisation of integrated data acquired from an unmanned aerial vehicle and terrestrial laser scanning technologies. This data was employed to generate a three-dimensional model of a brine graduation tower situated by the Nowa Huta reservoir in Kraków (Fig. 1 and 2). The distinctive design and construction of the tower provided an ideal testing ground for evaluating the capabilities of software programmes specialising in the creation of three-dimensional graphics, such as MeshLab, Agisoft Metashape, and Cyclone 3DR.

Source: Authors' own study

Fig. 1. Brine graduation tower located by the Nowa Huta reservoir in Kraków (profile view)

Source: Authors' own study

Fig. 2. Brine graduation tower located by the Nowa Huta reservoir in Kraków (top view)

2. Measurement methods

Relatively novel measurement methods, each complementing the other, were utilised to acquire data. The photographs were captured with the DJI Air 2S Fly More Combo UAV (Fig. 3), and the terrestrial laser scanning with the Leica ScanStation P40 scanner (Fig. 4).

Source: Authors' own study

Fig. 3. DJI Air 2S Fly More Combo drone terrestrial laser scanner

Source: Authors' own study

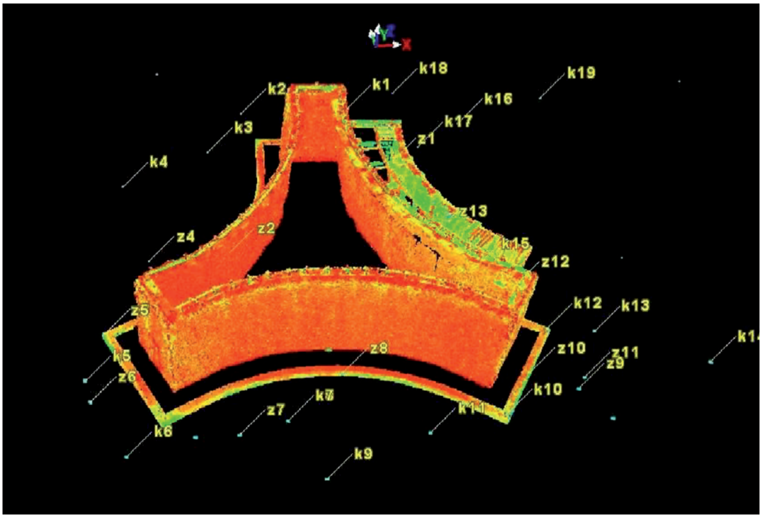
Fig. 4. Leica ScanStation P40

2.1. Terrestrial laser scanning

The object was subjected to terrestrial laser scanning from seven distinct locations. Reference balls positioned within the field and target markers affixed to the object in the form of discs were utilised for orientation purposes (Fig. 5). A scanning resolution of 0.01 at 10 metres was utilised, employing the 'scan plus photos' scanning mode. The scanning process at each station lasted approximately four minutes. Photographs were captured to obtain a colourized point cloud. To expedite the measurement process at each station, the angular range of measurement was manually selected to encompass only the object with a small margin on either side, thereby minimising the acquisition of redundant data that would not contribute to the 3D model. The orientation of the point clouds was performed in the Leica Cyclone software, achieving an accuracy of 0.002 metres, as illustrated in Figure 6.

Source: Authors' own study

Fig. 5. Location of the measurement control network on the test object



Source: Authors' own study

Fig. 6. Cleared point cloud after orientation in Leica Cyclone

2.2. Unmanned aerial vehicle flyby

Thanks to the possibility of flying a drone, it became feasible to procure measurement data of the object's upper section that was inaccessible to terrestrial laser scanning.

The flyby was executed at a relatively low altitude, approximately 8 metres, in a reasonably well-covered area; however, the weather conditions hindered the acquisition of photographs with sufficient longitudinal coverage.

It was decided that recording the flight and subsequently exporting individual photographs from it would facilitate the generation of an SfM point cloud (Fig. 7). Although the camera was oriented parallel to the object, some photographs inadvertently captured additional data in the form of sections of the graduation tower walls.

A total of 198 photographs of the flyby were acquired in parallel rows. Owing to the strong wind conditions, making precise photographs turned out to be impossible, a video was recorded that encompassed the graduation tower within its frame. The images were taken with a field pixel of 0.001 m.

The orientation and processing of the photographs were conducted in Agisoft Metashape Professional software. A precision of 0.22 m was obtained in the location of control points and 0.04 m in the distances between points.

Additionally, as in the scanning process, measurement discs were utilised as shared integration points, positioned parallel to the ground. These discs were placed on the ground, as well as on the wall and benches around the tower.

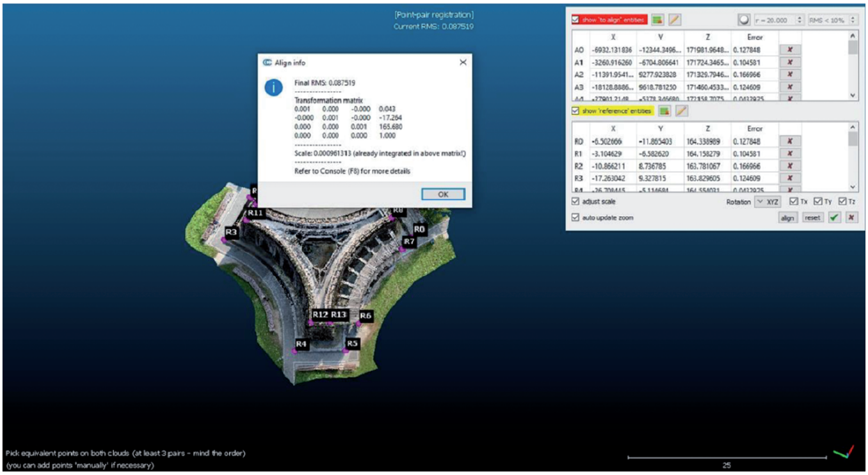
Source: Authors' own study

Fig. 7. Dense point cloud generated in Agisoft Metashape

3. UAV and TLS data integration

A crucial component employed for the amalgamation of photographs and point clouds derived from scanning procedures in subsequent camera works involved the utilisation of the aforementioned 16 targeting markers, which were placed upon the components of the examined object.

Furthermore, the integration of point clouds was executed within CloudCompare software. This particular application demonstrated its indispensable value when handling two distinct point clouds oriented along different axes. With one option, the clouds were mutually positioned and scaled to facilitate their integration into a unified whole. The orientation of the clouds was achieved through the utilisation of the common point function (Fig. 8). This approach facilitated the selection of a cloud to serve as the base object, and another cloud was adapted to it in terms of size and spatial orientation. A total of 9 common points were employed. The RMS of the differences at the common points was determined to be 0.087 metres.



[Point-pair registration]
Current RMS: 0.087519

Align info

```
Final RMS: 0.087519
----------------
Transformation matrix
0.001    0.000    -0.000   0.043
-0.000   0.001    -0.000   -17.264
0.000    0.000    0.001    165.680
0.000    0.000    0.000    1.000
----------------
Scale: 0.000961313 (already integrated in above matrix!)
----------------
Refer to Console (F8) for more details
```

☑ show 'to align' entities

r = 20.000

RMS < 10%

	X	Y	Z	Error	
A0	-6932.131836	-12344.3496...	171981.9648...	0.127848	✘
A1	-3260.916260	-6704.806641	171724.3465...	0.104581	✘
A2	-11391.9541...	9277.923828	171329.7946...	0.166966	✘
A3	-18128.8886...	9618.781250	171460.4533...	0.124609	✘

☑ show 'reference' entities

	X	Y	Z	Error	
R0	-6.502666	-11.865403	164.338989	0.127848	✘
R1	-3.104629	-6.582620	164.158279	0.104581	✘
R2	-10.866211	8.736785	163.781067	0.166966	✘
R3	-17.263042	9.327815	163.829605	0.124609	✘

☑ adjust scale

Rotation XYZ ☑ Tx ☑ Ty ☑ Tz

☑ auto update zoom

Pick equivalent points on both clouds (at least 3 pairs – mind the order)
(you can add points 'manually' if necessary)

Source: Authors' own study

Fig. 8. Orientation and scaling of two-point clouds

4. Results

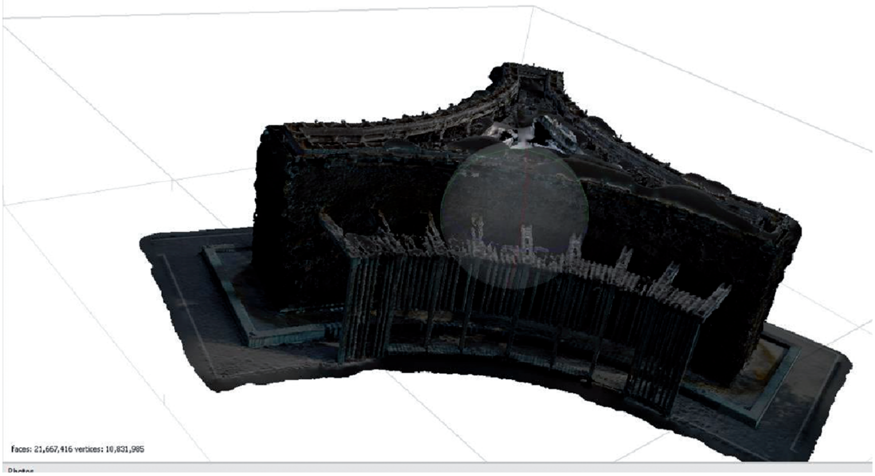
Due to its unique characteristics, the brine graduation tower was modelled using three distinct computer programs, namely MeshLab, Agisoft Metashape, and Cyclone 3DR. This allowed for a comprehensive demonstration of each software's capabilities, highlighting their utility in the modelling of special objects such as brine graduation towers.

The integration of multiple point clouds into a single cohesive entity is a functionality that is now increasingly accessible across various environments. While this process was initially introduced in Cyclone 3DR, technical challenges related to cloud integrity hindered its applicability for iterative workflows, such as additional cloud editing. Therefore, the utilisation of the MeshLab programme (Fig. 9) proved to be of substantial benefit. This software is extensively employed by the 3D graphics community due to its open-source licence, which renders it widely accessible. The execution of the cloud merging action yielded a materially enhanced product that exhibited superior visual attributes compared to the one produced in Cyclone 3DR. Subsequently, the object generated through this method was exported to facilitate its utilisation in the creation of a model across three distinct software applications.

4.1. Model of the brine graduation tower developed in the Agisoft Metashape programme

The generation of a mesh in Agisoft Metashape software is a relatively straightforward process, as it primarily entails the selection of a single option from the taskbar. However, a significant limitation of this programme is the absence of substantial options that would enable the modification of parameters associated with the generation of a 3D model. Consequently, the process is almost entirely dependent on the pre-programmed mode for creating spatial visualisation.

An additional complication arising from the use of Metashape is the inherent inability to disable the application's auto-fill capability for gaps and inconsistencies within a given model. In simpler terms, the software necessitates the creation of a complete object devoid of any gaps, as exemplified by the mesh illustrated in Figure 9. Consequently, this situation leads to the generation of planes and protuberances characterised by singular structures and continuity, bearing no resemblance to field structures in any manner.



faces: 21,667,416 vertices: 10,831,985

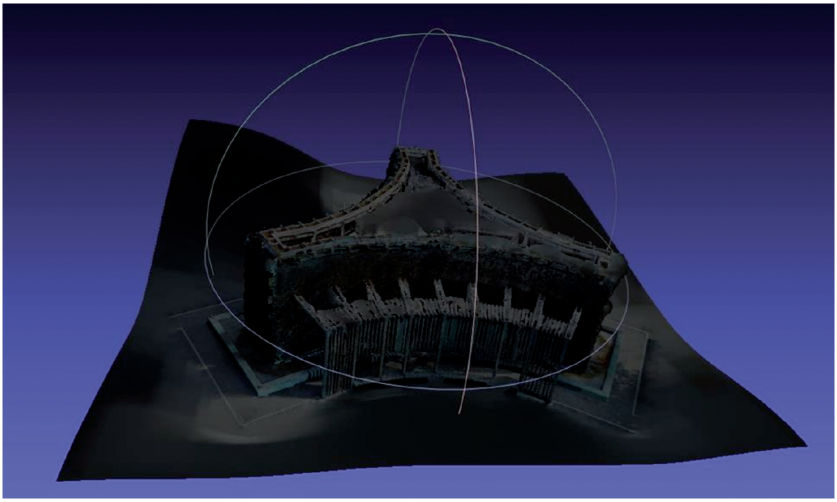
Source: Authors' own study

Fig. 9. Model of the Nowa Huta brine graduation tower made in the Agisoft Metashape programme

4.2. Model of the brine graduation tower developed in the MeshLab program

Despite being a publicly available open-source environment, this application does not lag behind its commercial competitors. This programme has its own mode of generating models, although it is hidden behind a rather complicated and non-intuitive interface.

In contrast to Metashape, the environment lacks a comprehensive system for choosing mesh generation techniques and editing parameters, yet it boasts a significantly larger size. Similar to the Agisoft program, the generated model (Fig. 10) is a solid entity, devoid of the capability to create holes. This limitation leads to the formation of distinct bulges in the 3D visualisation, resulting from the automatic filling of gaps. Furthermore, a reduction in detail is discernible in the model created using MeshLab.



Source: Authors' own study

Fig. 10. Model of the Nowa Huta brine graduation tower made in MeshLab

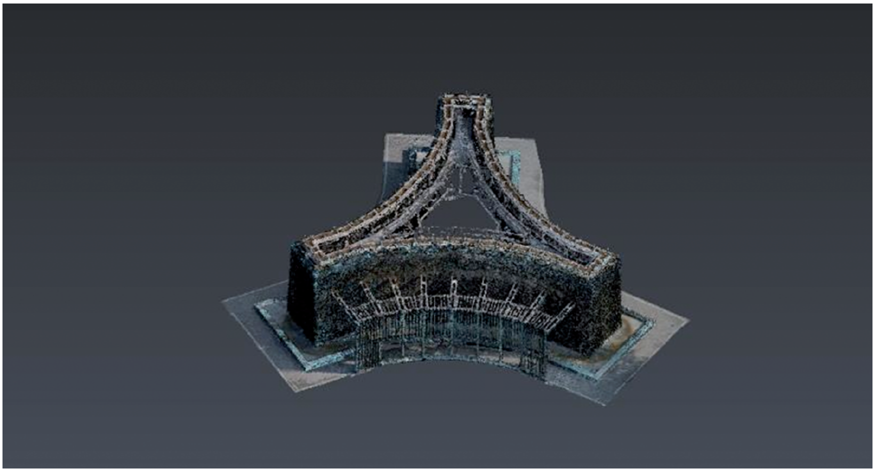
4.3. Model of the brine graduation tower developed in the Cyclone 3DR program

Among the three programs, Cyclone 3DR offers the most extensive capabilities for generating meshes, coupled with a wide array of options for customising each method in terms of parameters. The Regular Sampling method, which has been selected, is comparatively simpler than the alternatives, yet recommended by experienced Leica users. This recommendation stems from the fact that the other methods are designed for specific objects or devices utilised during measurements.

Unlike the other models, the model generated in the Cyclone 3DR programme (Fig. 11) does not utilise the auto-filling feature. Consequently, in this programme, it is not mandatory to merge objects into a single cohesive entity. This facilitates the creation of three-dimensional visualisations that incorporate empty spaces. The programme establishes connections between cloud points within specified distances based on the chosen parameters. In some instances, this process inadvertently generates unwanted holes in the object, which can typically be filled with relative ease. Unfortunately, this mainly applies to cases where buildings have the form of simpler geometric figures or at least consist of a large number of flat walls.

In the case of an object such as the selected brine graduation tower, the programme had a problem in selecting neighbouring vertices, because the geometry of the structure in question was very irregular, rarely having relatively simpler geometric elements.

Consequently, the model generated in Cyclone 3DR possesses numerous gaps that would necessitate a substantial investment of time to fill. Moreover, employing alternative model generation methodologies yielded even less satisfactory outcomes. Additionally, attempts to enhance the precision of connecting adjacent vertices beyond the threshold of 4 centimetres, as constrained by the utilised computer hardware, resulted in programme failure.



Source: Authors' own study

Fig. 11. Model of the Nowa Huta brine graduation tower made in the Cyclone 3DR program

The accuracy of the developed 3D model of the brine graduation tower was determined by comparing sections measured in the field on the facility between photo points indicated by discs and the corresponding points on the model.

A total of 18 sections were measured, as listed in Table 1. The mean error was determined to be 0.039 m.

Table 1. Summary of measured sections on the object and model

Denoting the Boundaries of the Section	D – distance on the object [m]	D1 – distance on the model [m]	Difference D–D1 [m]
point 6 – point 7	6.627	6.6	0.027
point 6 – point 13	2.145	2.139	0.006
point 5 – point 6	8.947	8.918	0.029
point 4 – point 5	10.043	10.025	0.018
point 4 – point 15	2.205	2.205	0

point 4 – point 3	6.696	6.589	0.107
point 15 – point 16	9.806	9.819	–0.013
point 16 – point 3	2.274	2.315	–0.041
point 2 – point 3	8.381	8.31	0,071
point 1 – point 2	10.61	10.587	0,023
point 1 – point 10	6.612	6.595	0,017
point 14 – point 10	3.062	3.054	0,008
point 14 – point 12	6.228	6.2	0,028
point 14 – point 8	7.643	6.615	0,028
point 12 – point 8	3.744	3.722	0,022
point 12 – point 11	6.147	6.199	–0,052
point 11 – point 8	4.747	4.721	0,026
point 11 – point 7	3.104	3.091	0,013
Average			0,039

Source: Authors' own study

5. Conclusions and discussion

The use of various measurement techniques in obtaining data about often complex and special objects is now becoming widely used. The integration of data gathered through these measurements frequently enables the extraction of comprehensive geometric information about the object, subsequently facilitating the construction of an accurate 3D model of the evaluated object.

The use of various methodologies and instruments in the modelling of the brine graduation tower in Kraków facilitated comparative analyses of the generated models and allowed the illustration of potential benefits or limitations of the utilised software. The following conclusions were drawn from the research:

- The observed disparities among models produced within individual programmes are highly noticeable, and the utility of these models for subsequent work, without additional modifications, is relatively small;
- The Agisoft Metashape programme provides users with the ability to generate high-quality 3D models through its straightforward and intuitive interface. However, its limited capacity for editing model generation parameters and automatic gap-filling may render it less appealing to professional graphic designers;
- Cyclone 3DR possesses an intuitive user interface that offers various methods for mesh acquisition and parameter modification. However, it does have the drawback

of being resource-intensive and reliant on the capabilities of the computer hardware being utilised;

- The MeshLab application may present operational challenges initially; however, its free licence provides access to numerous instructional resources, including those contributed by users. Regrettably, the program lacks robust customization options for model generation attributes. Similar to Agisoft, it automatically generates a uniform model that fills larger gaps.

The conducted research has led the authors to conclude that there is presently no suitable programme available on the market, or it is challenging to obtain one, that can generate three-dimensional images with the intricate detail and geometry of an object akin to the chosen brine graduation tower in Kraków, which would generate a high-quality 3D model that would not necessitate further modifications by graphic designers.

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