

COMPARISON OF THE ACCURACY OF DATA COLLECTION USING GROUND PHOTOGRAMMETRY AND LASER SCANNING WITH THE SUBSEQUENT CREATION OF A 3D MODEL OF THE WATER MANAGEMENT OBJECT

Jonáš Kačerovský*¹

*jonas.kacerovsky@fsv.cvut.cz

¹Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 2077/7, 166 29 Praha 6

Abstract

This article deals with the comparison of data collection using ground photogrammetry and laser scanning. Sample standard deviations were calculated and subsequently compared to evaluate the accuracy of both methods. Points focused using the Leica MS60 Multi-station were selected as the correct values. The ideal data collection method for a structured object was determined after comparing the individual methods. In the next step, a 3D model with BIM parameters of the targeted water management facility was created from data collected using ground photogrammetry. The modelling process took place in the REVIT program, where flexibility was tested on such a specific object.

Keywords

Ground photogrammetry, laser scanning, polar method, BIM, 3D models, digital twin

1 INTRODUCTION

For many industries today, it is important to find a suitable alternative to connect and simplify communication in project design and planning to prevent data loss. For this reason, the creation of an exchangeable format for drawings, designs and plans in the BIM format was a major step forward.

The great benefit of BIM is its open approach to involve all parties of the design and management of buildings, this ensures easy and smooth collaboration between different disciplines through the shared data feature. However, the individual information that is collected in the exchange format is also of great benefit both to preserve the data and to be used for clearer management. This is because the information, or data, is shared in the online space in the cloud storage, and thus each discipline has easy and quick access to up-to-date information about a given object. As a result, there are no problems with project timeliness or extensive changes.

This paper discusses the appropriate method of data collection on a structured object. This uses the method of terrestrial photogrammetry and laser scanning. The time required for field data collection and subsequent processing of the results is also evaluated. Two different methods were used and compared using sample standard deviations which were calculated through control points that were first oriented using a Leica MS60 multistation and then interpolated from the individual point clouds.

The goal of the whole work was to create a 3D documentation of the water management object from the acquired data using terrestrial photogrammetry in the BIM format in the LOD 300 range.

LITERARY OVERVIEW/DESCRIPTION OF THE PRESENT STATE

The text refers to the differences between a BIM model and its digital twin [1]. Furthermore, the article deals with the processing of the obtained data and the subsequent modelling of the 3D model in the BIM format similar to [2] or [3].

2 METHODOLOGY

All testing was conducted at the water management facility, which was chosen because of its difficulty in data collecting. This was due to the object's ruggedness and diversity.

Ground Photogrammetry

A Canon EOS 6D Mark II digital camera with a Canon EF 28 mm f/2.8 IS USM lens was used to collect data (images) using the ground photogrammetry method. In addition, the use of a Canon SpeedLite 430EX III-RT flash was needed due to insufficient lighting on the lower floors of the building.

Taking photos of the object was separated into two parts. In the first part, the exterior of the object was photographed with the bases at an approximate distance of 5 m and an approximate distance of 10 m from the object. The intervals were chosen to be lower at the corners of the building due to the need for greater image overlap. Furthermore, at each base, the images were taken at different height levels and different angles (both perpendicular to the object and diagonally). In this way, an approximate overlap of more than 70% was maintained on each image.

Once the detailed exterior photography was completed, the photography was moved to the interior of the building. A similar technological procedure was followed here, except that the imaging was chosen to be more detailed than the exterior of the building. More complicated structural elements which overlapped needed to be photographed and would therefore not be shown in multiple images. In addition, the building contained a large amount of pipework and various technical equipment that extended into most of the interior spaces. For this reason, the choice of bases was difficult and multiple images had to be taken. The whole object was captured with 1,568 frames, where the resolution of each frame was 26 Mpx. Following the whole object being photographed, the images were processed, and a 3D model was created.

Laser scanning

Data collection using laser scanning was realized by measuring with a Leica device, specifically a Leica P40 scanner.

The principle of polygon was used in targeting the object using the laser scanning method. This scanning method works on the principle of a sequence of positions and with it, the scanner can calculate where it is approximately located in the created model. The scanner was placed on the first tripod, which was used to orientate a signal target that was placed on the second tripod. Once the orientation to the signalling target was completed, scanning began. To ease the post-processing work, the tripod was hidden after the orientation had been returned to it not to be in the scanned area. A new tripod, on which the signalling target was located, was placed forward after the scanning was completed. Once the orientation was set to the newly set up tripod, the scanner was moved to this tripod. This process was repeated cyclically until the entire target was locked (in a polygon sequence).

The scanned object was divided into two independent polygon series for better transparency and further work with the data. The exterior of the object was focused in the first polygon and the interior in the second. This division was also chosen because of the time required to scan the object, which took place on 2 different days. The individual positions of the polygon series, on which the scanner was built, did not need to be stabilized in the field, because the connection of the exterior and interior of the object was done only during the processing of the clouds in the program. The whole object was scanned from 25 positions. The point cloud was not coloured with true colours since no images were taken during the scanning process. This was chosen because of the high time required to take the images using a Leica P40 scanner. Furthermore, due to the subsequent work with the model from ground photogrammetry, the point cloud was not reduced and was of full quality.

Comparison of the individual methods

In this chapter, the variety of outputs and their different accuracy were investigated. The water object was measured by two methods. The first method used was implemented using ground photogrammetry and the second method was implemented using laser scanning. From both measurement methods, the output resulted in an oriented point cloud showing the overall object. Subsequently, a BIM model was produced as the final product of the article, which was modelled based on the point cloud from photogrammetry. The main idea of the paper was to compare different data collection methods and to find out which method is the best suitable for the orientation of a water management object.

Additionally, the time required for data collection was investigated. The time needed to acquire data using laser scanning was approximately one time longer than that needed for the use of the ground-based photogrammetry. Further, there was a problem in targeting areas that were less accessible for scanning, in which case the measurement using the laser scanner took longer. The great advantage of photogrammetry was its flexibility to accommodate more complex terrain.

Another rating criterion was the time needed to process the data. In laser scanning data collection, the output is a measured point cloud which only needs to be interconnected in the software, provided that no complications or errors occurred during the measurement. These errors could be caused by inattention to the meter or by the instrument itself. In such case, the subsequent processing is very fast. When collecting data using photogrammetry, the first step is to count the point cloud from the images taken, which can take up several hours. The processing time always depends on the number of images taken. Once the point cloud was created, the procedure was similar to working with a point cloud from a scan. Lastly, the two methods did not differ in terms of processing time. It involved removing unwanted noise and cropping the object under research so that the computation caused by the large extent of the surroundings is not a burden during the eventual processing.



Fig. 1 Focused control points on the object.

When comparing the models, the aiming points were determined to be correct using the Leica MS60 multistation. Then the points located at the location of the aiming point were interpolated on each model (Fig. 1). A .txt file containing a list of control point coordinates was created and uploaded with each model to Cloud Compare in order to make it easier to locate the point in the model. This procedure was carried out in the same way for both calculated models (Fig. 2). As great emphasis was placed on making the model as detailed as possible, the clouds were not reduced, and the raw models were used. There was a problem in displaying the laser scan model in Cloud Compare due to the size of the data, and therefore it was necessary to split the model by individual slices into multiple smaller models, which were further uploaded in sequences.

The next element compared was a BIM model produced by Revit. Here, the interpolation was considerably easier due to the well-placed control points. It was only necessary to display the coordinates of the focused edges.

The sampling standard deviation was calculated for the X, Y, Z coordinates according to the formula (1) to evaluate the accuracy of each model [4]:

$$\sigma_v = \sqrt{\frac{\sum_{i=1}^n v^2}{n-1}} \quad (1)$$

where n = number of measured points, $v = dY, dX, dZ$.

The sample standard deviations were calculated from the mean according to the formula (2):

$$\sigma_{dxyz} = \sqrt{\frac{\sum_{i=1}^n dxyz^2}{(n-1)-n}} \quad (2)$$

where n = number of measured points, $dxyz$ = spatial length.

Tab.1 Comparison of results.

	Ground photogrammetry standard deviation	Laser scanning sampling standard deviation	Model sample standard deviation
σ_y	18.73 mm	12.92 mm	14.52 mm
σ_x	15.29 mm	14.61 mm	13.41 mm
σ_z	19.23 mm	17.64 mm	14.67 mm
σ_{dxyz}	4.05 mm	2.85 mm	3.03 mm

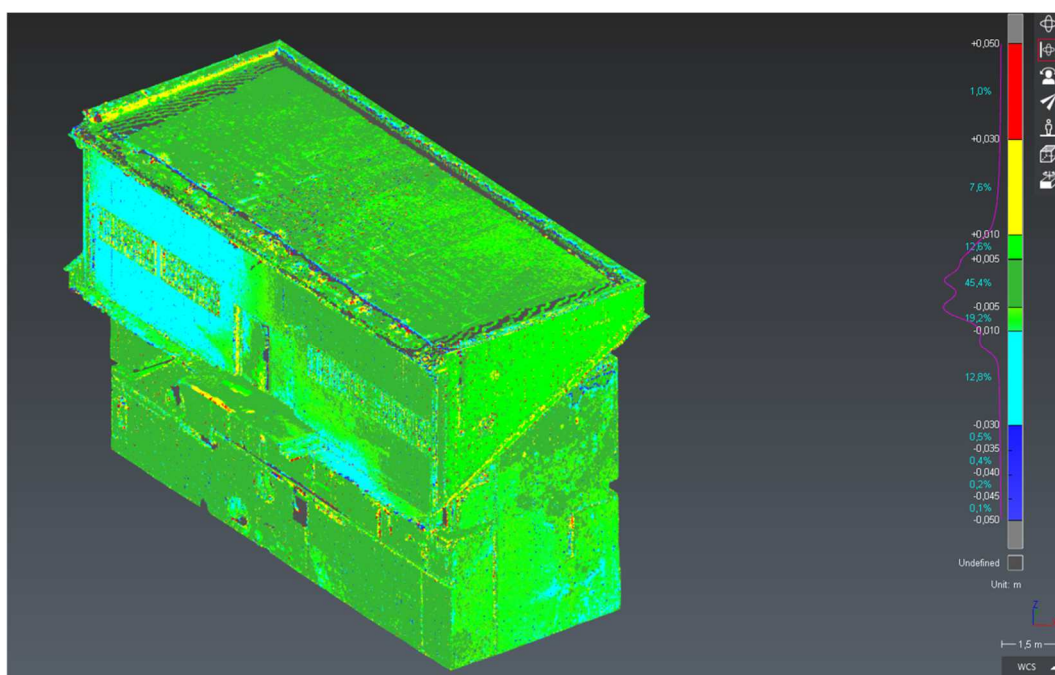


Fig. 2 Comparison of single clouds.

3 RESULTS

BIM

BIM, or Building Information Modelling, is a process in which different professions participate, interact and collaborate, such as architects, engineers, real estate developers, contractors, manufacturers and other building professionals. The result of the collaboration is the creation of one comprehensive 3D model that contains detailed information about the building. All this is achieved by bringing together various professions that are actively involved in the creation of the project. As a result, a high level of expertise is achieved even for small elements, for example, when constructing individual building elements, it is important to know their composition or material type, which is subsequently reflected in the model as a defined attribute. Only thanks to the expertise of the individual professions the desired result can be achieved. The difference between a BIM model and a 3D model is in the detail of the individual attributes. The individual attributes in BIM contain specific information about the materials used (composition, construction, thickness). They are simply interpreted in attribute tables in contrast to CAD, where their clear description is severely limited.

A big step in the development of BIM was the transition from CAD programs, which offered far more options for describing data. A large number of users now work in programs that support BIM modelling, and this makes the job easier and offers great benefits. This development of technology has attracted the attention of even the highest-ranking companies such as ČKAIT (Czech Chamber of Chartered Engineers and Technicians Engaged

in Construction) and CCA (Czech Chamber of Architects). This ensures future cooperation on the design of buildings in the BIM format. There are already increasing requirements for the creation of BIM models in many sectors. This is due to the fact that the model created in the BIM environment consists of the position and shape of individual structures, which are supplemented by a detailed description of the precisely specified structural elements. This results in an accurate documentation of the building, which is a major shift from the existing elaboration.

Resulting from the development and gradual expansion between industries, it can be assumed that the future of construction, building operation and management lies in this exchange format. Such clear documentation becomes more applicable in building management, which consists of long-term monitoring of the expenses of running a building. The advantage of creating this model is that different types of documentation can be automatically generated during the design process, for example: construction execution documentation (DPS), building permit documentation (DSP), and documentation of the actual construction (DSPS). The individual documents are linked to the accuracy of the BIM model, which is referred to by the acronym LOD (see next chapter). Another application lies in the construction practice of apartment buildings, where, thanks to the knowledge of the type and price of materials (these attributes are written in the model), it is easy to price the living spaces. For example, if the price of a material changes suddenly, the change in the price of an apartment can be analysed quickly and easily.

A great facilitation in collaboration between disciplines and their coordination on large-scale construction sites can be achieved by storing the BIM model on a common data environment (CDE-common data environment), which is a cloud-based storage. These repositories can be accessed by the individual disciplines, ensuring that the individual drawings are always up to date. Industry Foundation Classes (IFC) was created as a suitable exchange format that could be shared. In this format, data and individual information are shared in plain text. Since 2013, it has been an ISO-certified international code (ISO 16739-1:2018) [6] in the construction industry. As a result, different industries can be equipped with other software for creating a BIM model, but they must have the ability to work with the IFC format [5].

The concept of a digital twin and its difference from BIM needs to be introduced at this point. The term digital twin is introduced when a digital model of a building or structure is extended, essentially it is an operational model. This is because the model contains real-time data of the elements throughout the operation of the building, where this information makes it easy to trace and find out the current status and to look at previous operational data. The main purpose of the digital twin is to interpret how day-to-day operations affect the structure or individual building elements in real time. This information is further important in planning repairs when building elements wear out. BIM is suitable as a basis for a digital twin, which collects more detailed data about the building's operation and performance by incorporating sensors. This can be used to improve and manage building performance, increase efficiency and automate repairs [1].

Geodesy is an indispensable discipline when creating a BIM model for existing buildings. This discipline produces a detailed survey of the building, which is interpreted in the output as a point cloud. There are several options for data collection, depending on the size and detail of the building. This issue is further discussed in the following chapters.

Before starting the construction of a new object, it is necessary to know the terrain on which the object is to be located, for this reason a geodetic survey is needed already in the preparatory stages. However, it is not about creating a BIM model, but only as a basis for the designer. The use of geodesy focuses on delineation and surveying during the construction phases (e.g. foundation slab delineation, checking the verticality of elevator shafts, etc.). Subsequently, geodesy is applied only during the final construction phase for the measurement of the actual construction, or in the creation of the GP (geometric plan).

Creation of the model

The generated cloud was used by collecting data using ground-based photogrammetry for the creation of the model.

Once the origin determination was completed in Recap, a project was created in Revit in an architectural template, and 2-point clouds were loaded into the template. The first point cloud contained the exterior of the target object and the second contained the interior. Uploading the model in 2 parts was done to make the data easier to work with, e.g., when modelling the interior, the first model would only cause clutter and burden the computer memory.

Next, the models needed to be connected via the starting point we had already determined in Recap. In the program on the (Manage) tab, the option (coordinates at the point) was selected and the system coordinates in S-JTSK were entered by right-clicking on the middle window. It was necessary to enter the coordinates in mm because of the Revit definition.

After setting the origin of the drawing, the first views were defined in the (Architecture) tab, (Views), the first-floor level was set to intersect the model at the level of the entrance door to the building. The next level was

defined as the lowest floor level and the last ceiling of the building. As the work progressed, floors were added to the building as needed, e.g., for levels of landings, columns, and various technical equipment (16-floor levels were created). To improve the clarity of the building, the view at the ceiling level was defined so as not to prevent clear visibility. Due to the challenging structure of the building, the project also needed to define temporary sections that divided the building into smaller and more detailed parts in which details were visible.

The individual features were modelled by taking a measure from the point cloud using the measurement function, which had to be rounded off in places due to the inaccuracy of the point cloud, and defining the individual feature. Due to the infeasibility of measuring the wall thickness below the surface, measurements were taken from the uncovered part of the building. In addition, the individual structural attributes of the wall were approximated: thickness of masonry, plaster, and paint application.

During the creation of the model it was necessary to define families in Revit, under the name of the family an individual element was defined (for example, the size and shape of doors, windows ..), important in this step was the creation of a duplicate of the element and the subsequent modification was made. For example, when creating an entrance door (more like a door in an object), it was necessary to completely change the geometry.

When creating the individual pipelines, it was important to prepare all the species in advance to maintain individual continuity. For example, in the design of the pipe elbows, each family was assigned a type to which the joint would be connected, and then for the different types of joints. If these connections were not set up in the pipe type drop-down menu they would fail to connect appropriately. Thanks to this the connections were adjusted automatically, e.g., when connecting a pipe to an elbow, the program immediately reports if the connection is possible at this angle, if not, the program suggests a solution via another element.

Once the model was completed, the drawing needed to be exported in a suitable format. In the first place, the individual sections were exported in several exchangeable formats – .pdf, .dwg (Fig. 3, Fig. 4). The .pdf format was chosen due to its low complexity to open in different platforms, whereas the .dwg format was chosen for its ability to open the sections in different drawing software. Furthermore, the whole project was exported in the interchangeable .IFC format, which supports communication between different software. It was important to first specify what classes were to be exported.

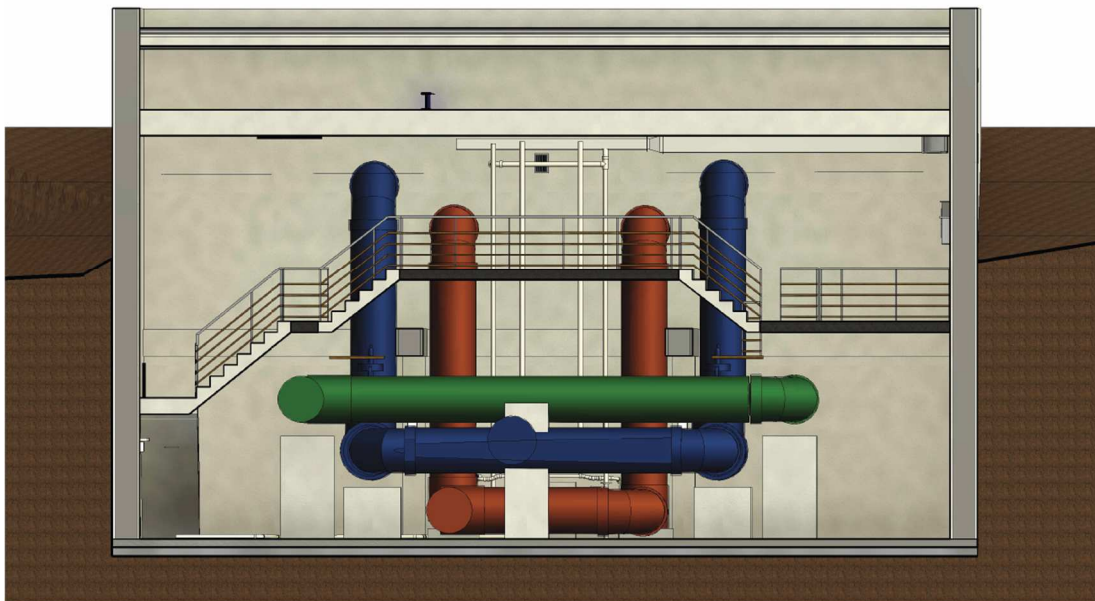


Fig. 3 A chart.

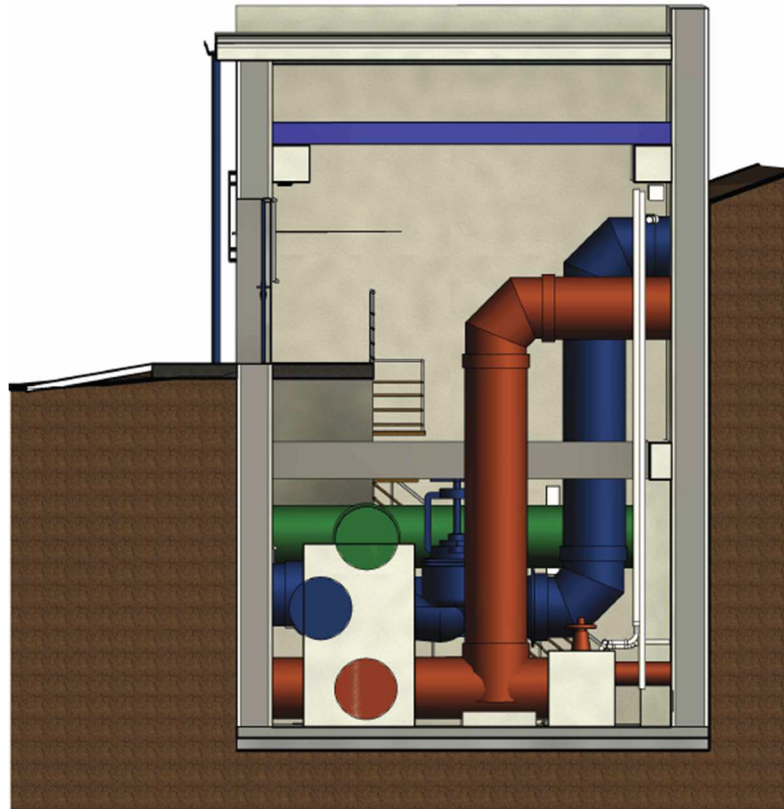


Fig. 4 Sidebar.

4 DISCUSSION

This paper compares two data collection methods and found which one was suitable for such a rugged object. In other articles [2], [3], such a specific object was not found for subsequent processing in the BIM format. Due to this, some difficulties in the orientation and subsequent processing of the model were found.

Based on the comparison, both methods came out almost identical in accuracy, so it can be concluded that both are suitable for data collection in such a rugged object. It is proposed to evaluate in which cases to use each method, for example, when collecting data using terrestrial photogrammetry, the great advantage is the speed and flexibility of data collection in difficult areas, but the disadvantage is the time-consuming data processing. On the other hand, when collecting data using laser scanning, it is difficult to lay out the ideal positions where to place the scanner, but data processing (measurement) is much faster.

Subsequent creation of a 3D model in the BIM format were possible from both methods. The individual clouds were formed with a high point density of 85 points per square centimetre. For surveying, more accurate modelling than LOD100 - LOD300 should be specified due to the need for professional collaboration from other disciplines. The resulting model can be easily exported in an interchangeable .IFC format or in individual sections, where the creation of an individual section takes no more than 15 minutes.

5 CONCLUSIONS

The result of the work was to determine the internal accuracy of the different data collection methods for modelling in BIM format. When the accuracy was determined through focused 54 control points that were determined by the spatial polar method using a Leica MS60 instrument and subsequently individual points were interpolated from the clouds.

It can be seen in Tab. 1 that the average accuracy of the laser scanning ($\sigma_{dxyz} = 2.85$ mm) differs from the ground-based photogrammetry ($\sigma_{dxyz} = 4.05$ mm) only in the order of millimetres. For this reason, the method of data collection for the water object using terrestrial photogrammetry which showed several advantages, was chosen. For example, when a point cloud is produced, even small features that occur in multiple images are easily traceable thanks to the photos. Furthermore, the method is more flexible in targeting inaccessible areas and the speed of taking images of the whole object is much faster than taking individual scans. The size of the point cloud is much smaller with almost the same predictive value as a laser scanning point cloud.

A major difference between the two methods was the time required to process the measurement data with the laser scan data being processed more than half as fast as the ground photogrammetry data. When processing the interior from the photogrammetric data, the calculation took several hours, even assuming a powerful computer (about 4 hours). In contrast, when processing laser scanning data, the processing time was within 1 hour (about 45 minutes). It is therefore necessary to take into account the extent of the object to be targeted.

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