Selected aspects of using terrestrial laser scanning technology as the source of additional data for building information modeling

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Building Information Modeling is the concept of a digital presentation of the physical and functional properties of an object. This paper presents proposal of use of terrestrial laser scanning technology to complement and verify created three-dimensional models of objects. The issue of the article focuses on the technical aspects of data collection from terrestrial laser scanning and its use in the information system of the building. During the field work authors carried out an experimental measurements of office space by phase laser scanner Z+F Imager 5006h. These data were treated as experimental material to test common methods of calculating the transformation parameters of three-dimensional systems, which are used in the calibration of individual scans and fitting them into the given coordinate system. This step is have a significant effect on the accuracy of the spatial model. The measurement experiment confirmed the need for calibration point clouds based on the largest possible number of tie and enabled to propose an inventory technology of long and slender buildings. It uses the connection between terrestrial laser scanning and conventional tacheometric measurements. This solution will reduce errors transferred to another position in the construction of the traverse. The article also deals with problems related to inventory of architectural and construction aspects of buildings and vectorization integrated point cloud in order to develop plans for the buildings or the measurement of specific surface areas. Creation of the models, on the basis of spatial point cloud built from the line of discontinuity is difficult due to: the impact of calibration errors, causing the displacement between scans and blur single scan points belonging to the same surface. Based on the performed studies it was found that the most important advantage of terrestrial laser scanning is possibility to collect in a short time a large number of points representing the actual state of the object, not the design intent. Using laser scanning we can significantly reduce the time spent directly at site, and perform measurement in dark areas. This technology also has a particular application for creating BIM for the modern buildings with complex geometric form, for which the accuracy and timeliness of the created model can be crucial for cost, speed and ease of execution of individual works. In this paper authors will attempt to assess the effectiveness of the application of the presented technology for building information modeling.

Key words: terrestrial laser scanning, Building Information Modeling

Introduction

Building Information Modeling is the concept of a digital presentation of the physical and functional properties of an object. As defined by the National Institute of Building Sciences: *A Building Information Model, or BIM, utilizes cutting edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/life-cycle information, and is intended to be a repository of information for the facility owner/operator to use and maintain throughout the life-cycle of a facility (NIBS, 2007).* The main feature of this kind of system is the multiplicity of its use. Building information model can be used to generate 3D visualization of facilities and shop drawings. For emergency services and the police it provides an overview of construction projects of protected objects in order to find the location of the gas installation, electricity and water supply, as well as determine the location of potential failure, leakage or escape plan. For managers of facilities it enables management of space, the organization of repair and maintenance, estimates costs and quantities of work materials. Building information model is also used in many phases of the construction process: under the design stage to exclude collision of installation of structural components or during construction stage to check on progress *(Azhar, 2008).*

Due to the multiple use of building information model it contains not just information about the geometry of the 2D space (i.e. length, width and surface) 3D geometry of rooms (i.e. height, wall area, volume, and the relationship between structural elements), but also additional information (i.e. properties of materials, location and installation of equipment, technology of individual components, etc.). Thus, in addition to the three-dimensional visualization of the object, which is the core of the model, system operator collects additional information and updates data about planning and realization of the object, its structure design, structural calculations and equipment in various systems *(Zima, 2013).*

Particular attention should be paid to the fact that the acquisition of information for the model must be a continuous process in the course of the investment, but way of obtaining information is diverse depending on the progression phase of the object. In the design phase the operator uses data directly from industry projects, permits, opinions, engineering analysis and cost calculations in digital or analog form (then need to be entered into the digital model). During the construction phase building information model can be supplemented with additional information such as photos of the construction progress, information derived from the reports of partial acceptance, etc. *(Zima, 2013).* In the case of formation building information model of existing facilities especially important and convenient, from the operators of the system point of view, are technologies that enable to create as-built documentation using modern measuring devices. The most common are: laser scanning technologies, machine-guidance technologies, GPS technologies, Radio Frequency Identification tags *(Eastman, 2011).* These technologies allow to capture the x, y, z coordinates from components of the object, creating CAD documentation of existing facilities, preparation of as-built documentation, performance inspection reports and measurement, and comparison of inventoried detail with the CAD model. However, one has to pay special attention to the fact that BIM is based on assumptions of the project that in the course of construction of the facility are not always fully met due to both technical limitations and uncertainty of execution. The use of modern measurement technologies to acquire data from which the building information model will be built is a better option in terms of the reliability of the model. These techniques allow to simplify, speed up and increase the accuracy of the process of generating three-dimensional models of objects *(Zima, 2013).*

One of the most popular technologies supporting the generation of building information model is a terrestrial laser scanning, which is currently the most rapidly growing surveying technology. Terrestrial laser scanning is based on a remote data acquisition and allows the registration of a set of points, each of which has x, y, z coordinates and additional information such as serial number and intensity of the reflection. Generally laser scanning can be divided into three types: satellite laser scanning (SLS), airborne laser scanning (ALS) and terrestrial laser scanning (TLS). Today, TLS can be considered as an engineering surveying technique, which is used for many and still growing purposes *(Vosselman, 2010).* Examples of the applications of TLS include: as-built surveys of buildings and facilities (industry, architecture, etc.) for the purpose of documentation of their existing condition; documentation of historical monuments (churches, castles, places, etc.) for the purpose of virtual reality (VR) modeling, detailed condition and damage assessment, as well as restoration at any given time in the future in case of damage or destruction, deformation monitoring of engineering constructions and excavations, surveys of tunnels and rail tracks for the purposes of inspection, damage identifications, etc., volume calculations, stability monitoring and geotechnical and geological mapping in mining, rock face surveys forensic investigations; documentation of excavations in archeology *(Reshetyuk, 2009).*

In addition to the above uses of TLS, laser scanning is also associated with the term Reverse Engineering which deals with methods allowing introduction of real objects into virtual reality *(Rychlik, 2007).* Uploading to an existing building model point clouds acquired from terrestrial laser scanning enables direct verification performance of even the most complex forms from geometric arcs, the flatness of the walls to the spatial distribution of the air vents or other system routed outside the walls. Such a comparison may be particularly important for expansion planning or reconstruction of the object, where precise information about the current state may be crucial for the specific project.

This paper presents the terrestrial laser scanning, as a technology which enables to verify and extend three-dimensional models that are created during the construction of building information model. Due to the fact that the terrestrial laser scanners are increasingly being used to obtain information about the location, geometry and structural properties of objects (also for the purposes of Building Information Modeling) there is a noticeable need for research on the effectiveness and optimization of this measurement method. In order to identify the problems associated with the use of TLS as an assistive technology for building information model, authors present the results of an inventory of the office spaces and examples of papers prepared for a various architectural forms. Discussed was the issue of the calculation methods of the transformation parameters of three-dimensional systems, which are used in the calibration of individual scans and seamlessly integrated into specified coordinate system. This paper also presents problems of creating models built with breaklines from point clouds and a broad spectrum of applications of the technology in the objects inventory.

Data acquisition and postprocessing

Data used for this research were obtained using two geodetic instruments: total station Leica TPS 1202 and terrestrial laser scanner Z+F Imager 5006h. Total station Leica TPS 1202 was used to measure the tie points which were targets attached to the walls of scanned office. This instrument is a high quality Total Station and allows horizontal and vertical angles measurement with accuracy of 6^{cc} and reflectorless distance measurement of 2 mm (*Leica, 2009*). Each room was scanned by using terrestrial laser scanner Z+F 5006h. Specification of this instrument is presented in Table 1.

Since the purpose of this study was to evaluate the efficiency of terrestrial laser scanning for inventory purposes, as an object of study were selected some of the rooms located in the Main Building of the Warsaw University of

Table 1. Specification of terrestrial laser scanner Z+F Image 5006h (Z+F, 2013)

Resolution vertical	0,0018°		
Resolution horizontal	0,0018°		
Accuracy vertical	0,0070°		
Accuracy horizontal	0,0070°		
Range noise	Black 10%	Grey 20%	White 100%
Distance to 10 m	1,2 mm	0,7 mm	0,4 mm
Distance to 25 m	2,6 mm	1,5 mm	0,7 mm
Distance to 50 m	6,8 mm	3,5 mm	1,8 mm

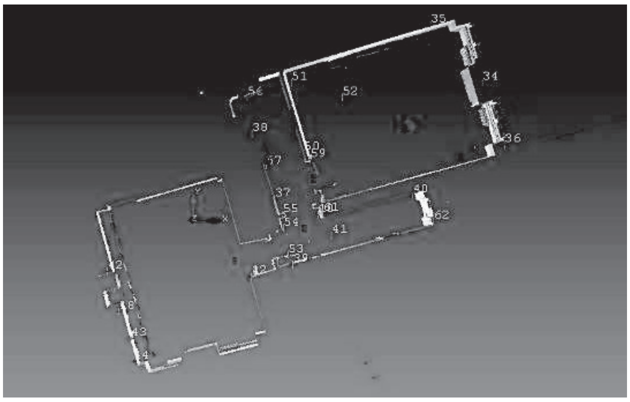

Fig. 1. Positions of stations and tie points

Technology. In the process of selection it was important that the rooms with their arrangement and shape resemble standard office space. Simultaneously, it was ensured that the geometry of the scanned surfaces reflected usually arising practical difficulties.

During the field work two computer rooms, connected by a narrow two-pieces corridor (total of four rooms), were measured. The location of these rooms and their size was considered as representative to carry out the purpose of this analysis. The main problem encountered in the inventory of objects using terrestrial laser scanning is methodology of moving from one room to another in possible quick way to merge all scans during postporcessing phase. Facilities like corridors and hallways, because of their elongated shape and narrow width, sometimes hinder the detailed and comprehensive inventory measurement. Also doors and windows are a big problem. Their size limits visibility of measuring points located in previous rooms from measuring stations located in present room. Allocation of premises and their geometry crucially determine smoothlness and precision of measurement.

Measurement of the office started from indication of minor control in the form of black and white targets dedicated to terrestrial laser scanning. It should be noted that the arrangement and the number of tie points influence the accuracy of the calibration scans. For two independent systems to be mutual oriented there are required at least three common points (*Hausbrandt, 1971*). However, redundancy of tie points is indicated due to the increased accuracy of the fit. Moreover, the tie points should be spaced evenly throughout the measured space (both vertically and horizontally). During the field work targets were marked on the walls of the measured rooms taking into account the two above conditions. In geodetic practice, tie points may be located on the floors and ceilings. Due to the multiple errors appearing during scanning the surface at an acute angle, the targets have not been put on these elements of the building. Earlier studies have shown that the scanning of tie points at too small angle causes slippage of the laser beam or even the lack of its reflection, which in turn generates a lack of data, and makes difficult interpretation of midpoint.

Generally, throughout the measured area 26 of tie points were marked, and the arrangement of these points is shown in Figure 1. Number of targets has increased in the area of transition between the two rooms, which was aimed at increasing the accuracy of the mutual orientation of the scans performed in the hall, with scans done in two adjacent rooms. Large number of survey points guaranteed the possibility of the impact analysis of the number of tie points on the accuracy of the scans mutual orientation and the accuracy of their references to the local system. In practice, as tie points permitted to use details of the facade of an object or objects in the room in order to reduce the field work. This solution increases the efficiency of data acquisition, however, reduces the accuracy of the calibration point clouds. It is not possible to indicate the details of the field with such accuracy as measured marks. In addition, from marks which represent a flat surface, the laser beam is reflected with more intensity than on the edge or curved surfaces, which guarantees distance measurement less saddled with an error.

The next stage was the appropriate planning of measuring stations, to ensure the efficiency and speed of the field work. The instrument should be set up in such places where it would be possible to measure the most recent information from the minimal number of stations. While scanning a single room, instrument should be set in the middle of the room, but if the number of rooms increases it is necessary to use auxiliary positions that complement the cloud of points from the middle station.

The entire measured part of the building was scanned from four measuring stations: one in each of the rooms and two in the hallway. The originality of the used measurement methodology was to complement terrestrial laser scanning technology with the traditional contour survey. At each location, after scanning the room, in the same tribrach total station was inserted in order to comply with reflectorless measurement of tie points. During postprocessing, thanks to tachemetry registration of survey points, were calculated spatial coordinates of 26 tie points in the local matrix of the building. This solution allowed the omission of cross-calibration scans for a benefit of individual fitting scans into created coordinate system.

Table 2. The differences between the two methods of scans orientation obtained by using Z+F Laser Control

Variant	Parametrs	Accuracies obtained from fitting scans in an external frame of reference	Accuracies obtained from the mutual orientation of the scans
I (max. numer of tie points)	Total numer of marks	26	26
	Average error	1,2 mm	0,6 mm
	Standard deviation	0,6 mm	0,3 mm
	Maximum error	2,8 mm	1,2 mm
II (min. numer of tie points)	Total numer of marks	12	12
	Average error	0,6 mm	0,4 mm
	Standard deviation	0,5 mm	0,3 mm
	Maximum error	1,3 mm	1,0 mm
	Error of the average points not taken to align	9,9 mm	16,8 mm
	Maximum error of the points not taken to align	23,8 mm	18,5 mm

Table 3. Comparison of the results Helmert transformation and affine transformation

Parameters		Scan 1	Scan 2	Scan 3	Scan 4
Number of tie points		7	11	18	11
Affine transforma-tion	Average error of adjustment	0,16 mm	0,46 mm	0,72 mm	0,77 mm
	Number of unknown	12			
	Redundancy of observations	9	21	42	21
	The largest average error of observations	0,14 mm	0,31 mm	0,47 mm	0,60 mm
	Average error point after transformation	0,28 mm	0,79 mm	1,24 mm	1,33 mm
Helmert transforma-tion	Average error of adjustment	0,16 mm	0,46 mm	0,72 mm	0,77 mm
	Number of unknown	9			
	Redundancy of observations	12	24	45	24
	The largest average error of observation	0,12 mm	0,29 mm	0,44 mm	0,56 mm
	Average error point after transformation	0,28 mm	0,79 mm	1,24 mm	1,33 mm

The differences between the standard deviation obtained from the individual point clouds fit into the matrix and the standard deviation, which is obtained from mutual orientation of each point cloud is presented in Table 2. The first of the methods generate more errors, mainly due to systematic errors, which cannot be avoided during tachometric survey and alignment matrix signaled by measuring marks. However, the great advantage of this method is the ability to transform data from the scanning relative to other parts of the building, meaning to an external frame of reference.

Orientation of scans both mutual and relative to an external reference system was performed using the Z + F Laser Control in two variants: the first consisted in orientation scans using a large number of tie points, the second – with the use of a minimum number of tie points. Considering only the alignment results it can be concluded that the calibration point cloud based on a smaller number of tie points generates a smaller average error, but similar standard deviations as the calibration based on a larger number of tie points. In the second variant additionally were calculated average and maximum errors of points not involved in the alignment for the two methods of calibration scans. These errors significantly exceed the errors of points that were used in the calculation of the transformation parameters. Obtained results confirmed the need for calibration point clouds based on the largest possible number of tie points. Minimum number of tie points guarantees small errors in alignment, but calculated on the basis of the transformation parameters are subject to large uncertainty.

On the basis of common points to each of the scans rotation matrix and translation vector were calculated. Affine transformation was applied with a scale factor equal to 1. In order to compare the accuracy of the transformation, also Helmert transformation parameters were designated for the same tie points. Summary results of individual transformations are shown in Table 3.

Results in Table 3 show that there is no significant difference between the errors obtained after applying the Helmert transformation and affine transformation. This may be caused by using the preferred positioning of the tie points, the account in the calculation of tie points equally spaced on the horizon, and at different heights. Accordingly, with this set of available data, affine transformation gave equally accurate results as the Helmert transformation. Furthermore, in both methods can be seen increase of transformation errors associated with the transition from

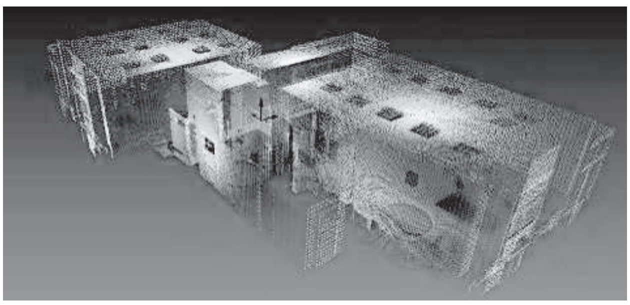

Fig. 2. Oriented point clouds measured in four stations

one location to another. In turn, this results from the fact that the registered positions of the scanner arrangement resemble open traverse suspension geometry, wherein for each additional position errors are transferred from the former. This construction does not allow double-sided alignment. This situation is the most common problem in the inventory of long and slender buildings. The solution could be the use of additional tie points that are visible from several positions through the windows or other openings. If there is no possibility for it then the use of the proposed above classic tacheometric method, will reduce errors transferred to another position in the construction of the traverse.

Application of calibrated point clouds

Typical products of terrestrial laser scanning are vector drawings, orthogonal views of point cloud spatial models, and different types of visualizations and animations. This technology is used not only to draw up the technical documentation, but also to promote and present objects. Carrying out an architectural and construction inventory for the purpose of building information modeling, it must be first specified the sufficient accuracy of the model, which depends on the precision of instrument used, measuring, fitting and generalization of data scans. This type of work is commonly assumed to be done within accuracy of a few centimeters. However, it is worth noting that the building information model is created for modern buildings with a complex structure and form. During the construction of such facilities are used ready-made elements, and sometimes fitting of them requires increase of accuracy up to a few millimeters. An example of it can be glass facades, which assembly involves putting glass elements on steel construction. Created with sufficient accuracy and verified building information model can enhance work with precast and reduce the cost of any improvements.

The basic elements affecting the quality of the obtained point clouds are type of the scanner and the number of scans performed, i.e., the density of measuring stations. During inventory of the objects, one must remember that the protruding elements are a natural barrier for the laser beam, and therefore obscured space are not recorded. For this reason, scanning of geometrically complex objects one has to take measurements from multiple stations, often located very close to each other. Sometimes, adding next positions proves to be ineffective, in such cases occurring gaps can be supplemented by discharges of points from different heights, where the walls were not obscured. It is worth noting that the inventorization of the geometrically simple room by just one instrument position is a quick way to gather all the necessary information. It is worth mentioning that during the inventory of the geometrically simple room it is enough to have just one instrument position for a quick way to gather all the necessary information

Inventory made by terrestrial laser scanning technology in terms of the duration of the field work is much faster than traditional solutions, it only requires experience and spatial ability to see. Efficient eye and imagination allows to properly assess which components are within the scanner and which require a measurement from the other positions so that on further review, it won't turn out that some data is missing. The advantage of terrestrial laser scanning is the ability to obtain a large number of points. This characteristic is especially noticeable during the inventory of complex forms with curves, for which measuring three points is not sufficient, as in the case of flat walls.

Below we present case-studies, carried out for the purpose of building information modeling, which were obtained from the registered point clouds: a horizontal section and an inventory of architectural detail. However, these are not all the possible ways of using data from terrestrial laser scanning, which are also used for moisture testing of object walls, hipsometry mapping of surface distortion, spatial modeling, etc..

Classic tacheometric method commonly used for inventory carried out observations of the selected characteristic points, followed by the drawing section, linking the observed points in one line. While in laser scanning one operates on a set of millions of points making up the object.

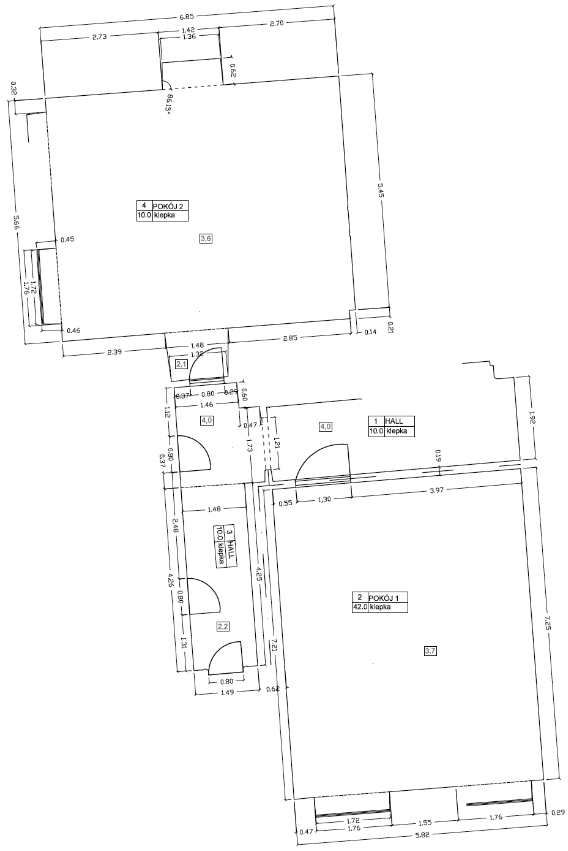

Fig. 3. Horizontal section made on the basis of point cloud vectorization

Fig. 4. Views of vertical cross-sections obtained from the intersection of the point cloud by plane

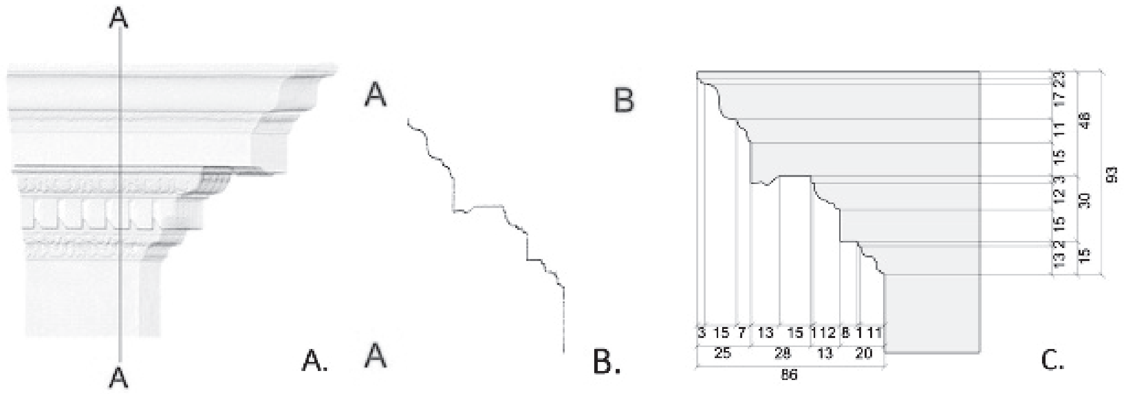

Fig. 5. Architectural detail: A. view of point clouds with the selected site was carried out cross section; B. section of a detail of the resulting point cloud; C. sized section of a MicroStation

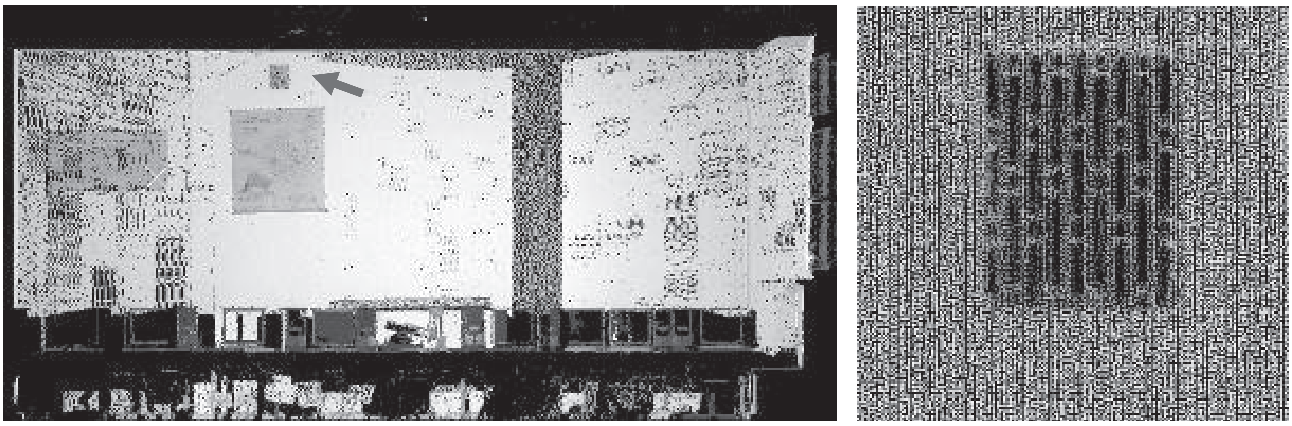

Fig. 6. Resolution of cloud points on ventilation grille

Crossing the wall by the horizontal plane one gets bar filled with points representing the edge. Execution section of the object is thus connected with the need to fit a line to a set of points. It is worth to pay attention to the problem of determining the corners of the walls. Terrestrial laser scanning technology is based on the reflectorless measurement on selected angular intervals. As a result, sent beam not always hit the center of the corner, and even "slides" on it, which is revealed on scan by its chamfer and fillets. Therefore, while interpreting the corners authors used extension line of adjacent walls for their mutual intersection. It must be remembered that when the rounding will be significant the real course of the edge should be verified. An important advantage of the horizontal cross-sections made from scanning, is possibility to precisely determine the thickness of the walls. The only requirement for this condition is to have inter-related scans from both sides of the object – inside and outside.

Sections obtained from point cloud are practically continuous representation of the surface, so it can be seen its deflection and strain. In addition, these sections can be generated at any intervals and directions for the property. Owing to the fact, at any point, one can obtain the information necessary to perform various studies. A point cloud is an excellent documentation of the object.

It is also worth noting that the point cloud can be used both to create a three-dimensional model of architectural detail and to perform anywhere dimensioned vertical and horizontal sections. Such detailed data may in the future be used to reconstruct the destroyed architectural design elements of the object.

Point cloud also allows us to determine the location of the wall elements of different types of installations. The following figure is an example of the scanned wall on which there is frame of ventilation. Density of obtained data allows us to precisely specify its type and position, and thus verify the correctness of its implementation.

It is worth noting that in the interpretation of point cloud fragments very helpful are images recorded by the scanner. As it was already mentioned while doing the sections one often encounter objects disturbing the correct shape of the building. Scanning allows to collect information not only about walls, but also about the elements which obscure them, e.g. paintings, closets. Photos allow for verifications of section taken from the scanning and outline the possible omission of unnecessary object.

Conclusions

Conducted field work and analysis of obtained data confirmed the hypothesis posed at the beginning of this study. Terrestrial laser scanning is an advanced technology that effectively delivers information to supplement BIM. Acquired in that way data shows the actual state of the object, which not only can detect errors in implementation, but also avoid possible conflicts in the process of expanding and redesigning the interior of the building. The measurement experiment confirmed the need for calibration point clouds based on the largest possible number of tie points. Minimum number of tie points guarantees small errors in alignment, but calculated on the basis of the transformation parameters are subject to large uncertainty. In addition, research performed made it possible to propose an inventory technology of long and slender buildings. Carrying out terrestrial laser scanning of this type of spaces authors performed the measurement in two ways. The first proposal is the introduction of additional points that are visible from several positions through the windows and other openings, so that nonadjacent spaces are directly interrelated. In addition, another solution is to use the method described above, which links terrestrial laser scanning and conventional tacheometric measurements. This solution will reduce errors transferred to another position in the construction of the traverse.

Based on conducted analysis it was noted that the magnitude and depth of the unselected data fragments allows for a thorough examination of the object, as well as detection of elements that cannot be observed on the basis of discrete tacheometric measurements made at characteristics point. Acquiring data using terrestrial laser scanner does not require a lot of work, therefore it allows to reduce time spent directly on the object. While scanning simple geometric rooms low resolution can be set, so that the measurement will take only a few minutes. In this case, it appears that the most time-consuming is handling and spacing of the instrument. By reducing measurement time and by automations this technology can be used in constructional emergency situations, because the only task of a man is the spacing of the instrument and run it. It should be noted that the start of the measurement can be done directly or remotely. Terrestrial laser scanning is also characterized by its high efficiency measurement. Scanner through the use of a laser beam can be used in the dark, e.g. in unlit cellars.

A Building Information Model characterizes the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories and project schedule. Data obtained using the laser scanner provides many additional informations about the building. Point clouds are a great source of information about the object, which can be processed in different ways, depending on the current demand. The point cloud, once acquired, can be the basis for a completely independent studies, and various analysis. Point cloud imported directly into the software supporting BIM can be used to verify the condition of the building or any of its parts, as well as to control the location and geometry of the walls, columns and arches. Scans can be made both during the construction process, as well as after its completion, when are used for controlling compliance of the building components of the project. In the case of historic buildings, especially with complex geometry, terrestrial laser scanning is one of the best methods of recording details and architectural ornamentation. They are usually used to generate three-dimensional models, or digital representations of real objects, which can then be imported as a separate layer to the system and provide supplementary material data in BIM.

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