Control in the Process of the Building Construction by Means of Stationary Terrestrial Laser Scanning

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Abstract. This study will give a contemporary method for Quality Assurance or as-build during the construction of a building in Sofia, R. Bulgaria by using High Definition Survey (HDS) or more known as terrestrial Laser Scanning. Analyses were done on concrete casted elements (Floors, Ceiling Slabs and Columns) for the first eight floors which were already constructed during the time of field measurements. As a reference - data are obtained from the original design in native AutoCAD format, while field data were acquired by using 3D laser Scanners and they are represented in a form of Point Cloud. All data (design and measured) are acquired in local coordinate system and were later georeferenced in to the already established object coordinate system. The study will show the workflow for data preparation, post processing, and the results from 3D Inspection and Analyses. All tasks were implemented by two survey crews within 10 working days (four days for field work and 6 days for post processing analyses and reporting). During the laser scanning a total of 3 679 440 634 points were surveyed form 368 stations. After the post processing the number of points was reduced to 2 515 520 148 with relative accuracy after registration of individual scan worlds of +/- 3-4 mm. The accuracy for the data transformation in to the object coordinate system is +/- 7.5 mm. In order to have better data visibility and understanding of the deformations and displacements casted concrete elements were inspected separately floor by floor where ceiling and floor slabs were inspected in 1D (Z direction) while columns were inspected in 2D - (XY) inspection for the position. Thus some will say that the results are within accuracy limits of the classical measuring techniques we should not forget the fact that the percentage of inspected elements/surfaces is more than 95%.

1. Introduction
In the past decade a big leap in development of hardware and software for surveying and construction has occurred. On the software side a lot of new software platforms have been developed allowing the architects to design more complex and more construction demanding objects. All of this demands big resources not only during the design phase but also during the construction and later on during the exploitation of the object. BIM platforms allow combining and managing all of this data in one place.

Precise implementation of the design on the field is one of the critical tasks without which the designed object can't be built in reality accurately. Today's "classical" surveying hardware and
surveying methods can keep up with the construction progress and provide setting out of the construction elements within the required tolerances [1, 2]. In cases where the object is very complex and the construction pace is very fast, e.g., some construction techniques allow casting of a single floor every 5-7 days, determining possible construction flaws and conducting quality assurance of the constructed elements on time is essential [3, 4]. This can put a lot of pressure on the QA team because using classical surveying equipment requires a lot of measurements on specific places in order to determine if the real situation corresponds with the design one [5, 6 and 7].

The measurement process is additionally obstructed by passing workers, construction materials and equipment on site etc. which slows down the inspection process even more. This can lead to a slow construction progress of the whole project since without proper QA next phase cannot begin and the implementation plan for construction is prolonged [8, 9]. Last but not least every breach of a deadline and prolongation of the project means not only lost time but lost money, both for the investor and the implementer. On top of all every construction error not spotted on time can lead to big delays and expenses later on during the construction. One of the possible solution in overcoming the above mentioned problems is applying of Terrestrial Laser Scanning (TLS) technology. This technology has been highly developed in the past decade and is opening new possibilities in acquisition of three dimensional (3D) information on various kinds of surfaces [10]. This combined with the corresponding software platforms minimizes the time required for field data capture and provides possibilities for more detailed analyses in the office, thus eliminating the errors from subjective factors.

2. Experiment

This study will give a detailed explanation of the technological process and analyses of the achieved results for High Definition Survey (HDS) measurements on the A building in Sofia, R. Bulgaria for the purpose of 3D Inspection of the current state/As Build of the casted concrete elements (Floor and Ceiling Slabs and Columns) at the first already constructed 8 floors.

Figure 1. 3D Model - Design phase - Concrete elements

Figure 2. 3D model and Measured Point Cloud
The first phase of the activities was to make a field reconnaissance prior of conducting the survey. In short test area can be described as follow:

- Design data were not positioned in the object coordinate system
- Approximate dimensions of the building floors are 75x40m
- In total 8 floors are subject of survey
- Survey control network exists on the field and will be used for geo referencing of all measured and design data

Field activities were realized as described below.

- One instrument Leica BLK360 is used for HDS survey of the inside parts (floors, ceilings columns) of the building. Manufacturer stated ranging accuracy of the device is 4mm@10m
- One instrument Riegl Vx 2000i is used for scanning the outside part of the building. Additionally this instrument was used for scanning the inside of floor no. 8
- Outside of the building was scanned form 17 (seventeen) field stations
- Inside of the building was scanned form 298 (two hundred and ninety eight) field stations with Leica BLK360 (floors 1-7). Additional 43 (forty three) stations were surveyed for floor no. 8 using Riegl Vx 2000i
- The stairs inside the building were surveyed from 17 (seventeen) field stations with Leica BLK360
- 41 control markers/hds targets are set on the building and are used for registration and transformation of the point clouds in the object coordinate system
- Determining the 3D position of the markers/hds targets was done from the existing control network by means of Total station with stated manufacturer accuracy of 2" arc sec for angle and 2mm+2ppm for distance measurements.

All of the equipment was examined prior to project deployment.

Tripods and Tribarachs were inspected for stability, plumb alignment, and height verification.

3. Data processing

Data processing was done using Leica Cyclone software with the following modules:

- Scan - for acquiring data and controlling the scanner functions
- Register - for registering the point clouds from different stations and for transformation of the data from local to the reference coordinate system

Deformation and displacement analyses of the objects was done using Leica Cyclone 3DR with the Analyses module.

After the field survey and importing the RAW data in total of 3 679 440 634 points from 368 stations were surveyed in 3D coordinate system.

Since there were points outside the area of interest they were removed manually. Overlapping points were also removed and the final point cloud for analyses is represented with 2 515 520 148 points in total. Since every station on the field was established in relative 3D coordinate system, the first step was to register all ScanWorld data to a single local 3D coordinate system. This was done by using common points from the overlapping areas of the neighboring scans for each station progressively. e.g. (first station 1 and 2 were registered and a new ScanWorld 1-2 was created, than station 3 is added to ScanWorld 1-2, etc. for all stations) after which one single ScanWorld was produced containing points for all currently constructed elements of the building given in a local 3D coordinate system.
Figure 3. Scanner positions and registered point cloud

Accuracy of the 3D transformation of the registration process between the individual point clouds is within the accuracy range of 2-4mm.

748,764,687 points
LEVEL - 1

Figure 4. Example of report form point cloud registration

In order to transform the measured ScanWorld from local to reference (object) coordinate system, measurements on common markers/hds targets were used. Reference coordinates of the markers were
obtained from the existing control network on the field by measuring them with Total Station. In total 25 common points were used. Output accuracy of measured data is +/- 0.0075 m and it is valid for all points. Detailed results are given in Table 1.

Table 1. Transformation of point cloud data to object coordinate system

| Constraint ID | Error  | Error Vector  | Horz  | Vert  |
|---------------|--------|---------------|-------|-------|
| 20            | 0.007 m | (0.001, -0.005, 0.005) m | 0.005 m | 0.005 m |
| 13            | 0.008 m | (-0.007, -0.004, -0.001) m | 0.008 m | -0.001 m |
| 14            | 0.015 m | (0.008, -0.012, -0.005) m | 0.015 m | -0.005 m |
| 7             | 0.006 m | (0.006, 0.002, 0.000) m | 0.006 m | 0.000 m |
| 8             | 0.014 m | (0.011, -0.006, -0.005) m | 0.013 m | -0.005 m |
| 9             | 0.012 m | (-0.009, -0.008, -0.001) m | 0.012 m | -0.001 m |
| 6             | 0.012 m | (0.002, 0.012, -0.002) m | 0.012 m | -0.002 m |
| 21            | 0.004 m | (-0.002, 0.001, -0.004) m | 0.002 m | -0.004 m |
| 16            | 0.013 m | (-0.005, -0.008, 0.009) m | 0.010 m | 0.009 m |
| 27            | 0.005 m | (-0.005, 0.000, 0.000) m | 0.005 m | 0.000 m |
| 28            | 0.002 m | (-0.001, 0.002, 0.000) m | 0.002 m | 0.000 m |
| 24            | 0.009 m | (0.004, 0.008, 0.001) m | 0.009 m | 0.001 m |
| 25            | 0.001 m | (0.000, 0.001, 0.000) m | 0.001 m | 0.000 m |
| 34            | 0.015 m | (0.007, 0.013, 0.002) m | 0.015 m | 0.002 m |
| 23            | 0.008 m | (-0.003, 0.004, -0.006) m | 0.005 m | -0.006 m |
| 29            | 0.011 m | (-0.010, 0.004, -0.001) m | 0.011 m | -0.001 m |
| 32            | 0.006 m | (-0.002, 0.005, -0.001) m | 0.006 m | -0.001 m |
| 33            | 0.008 m | (0.001, -0.005, -0.006) m | 0.005 m | -0.006 m |
| 30            | 0.002 m | (-0.002, 0.000, 0.001) m | 0.002 m | 0.001 m |
| 31            | 0.005 m | (-0.001, -0.002, 0.005) m | 0.002 m | 0.005 m |
| 37            | 0.006 m | (-0.004, -0.003, 0.003) m | 0.005 m | 0.003 m |
| 41            | 0.008 m | (0.002, 0.005, -0.005) m | 0.006 m | -0.005 m |
| 38            | 0.011 m | (0.005, -0.008, 0.005) m | 0.009 m | 0.005 m |
| 35            | 0.006 m | (-0.003, 0.003, 0.004) m | 0.004 m | 0.004 m |
| 36            | 0.006 m | (0.005, 0.000, 0.002) m | 0.005 m | 0.002 m |

Design data were transformed in the reference coordinate system in the same manner by using 7 common points. Details and accuracies of the transformation process are given in Table 2.

Table 2. Transformation of design data to object coordinate system.

| Constraint ID | Error  | Error Vector  | Horz  | Vert  |
|---------------|--------|---------------|-------|-------|
| 13            | 0.0118 m | (-0.0116, -0.0010, 0.0018) m | 0.0116 m | 0.0018 m |
| 11            | 0.0145 m | (-0.0092, -0.0108, 0.0031) m | 0.0142 m | 0.0031 m |
| 12            | 0.0128 m | (-0.0124, -0.0001, 0.0031) m | 0.0124 m | 0.0031 m |
| 17            | 0.0114 m | (0.0109, 0.0015, 0.0032) m | 0.0110 m | 0.0032 m |
| 1             | 0.0079 m | (-0.0062, 0.0020, 0.0044) m | 0.0066 m | 0.0044 m |
| 5             | 0.0175 m | (0.0123, 0.0072, -0.0101) m | 0.0143 m | -0.0101 m |
| 7             | 0.0172 m | (0.0163, 0.0012, -0.0056) m | 0.0163 m | -0.0056 m |
4. 3D inspection analyses

Inspection of the measured data and deformation analyses is done for each building level separately for the floor, ceiling and columns. Inspection algorithm is given on the Figure 5.

![Figure 5. Inspection algorithm](image)

Reference Objects are defined as 3D meshes and were obtained from the delivered AutoCAD Design data. With this procedure we obtain "ideal" or so called nominal object which later on is used to compare the measured data. Previously described surveyed HDS data were imported. Both Reference and measured data are already aligned in the object coordinate system using the transformation matrix obtained during the geo-referencing process.

This comparison tool computes the Data-to-Reference deviation on all Measured Data Points and produces a color map showing the minimum and maximum deviation set to +/- 15mm.

All measured data and post processing results are 2-3 more accurate (2-3 sigma) than the required inspection/building tolerance which allows us to determine the residuals with high statistical confidence. Detailed graphical and tabular report which contains all parameters and data analyses is also produced. Individual measurements can also be taken and shown on the display.

Output results/examples are shown on Fig. 6, 7 and table 3.

![Figure 6. Inspection of floor elevation and flatness/graphical representation](image)
5. Conclusions

- HDS (High Definition Surveying) or also known as laser scanning nowadays is already a mature surveying technology which is able to provide to the end user millions of detail points with survey grade accuracy.

- For 3D inspection surveys, laser scanners have already proven to significantly reduce the survey time compared to traditional survey methods.

- The Leica BLK360 and Riegl Vx 2000i are one of the latest laser scanner models and are characterized with exceptional speed and outstanding versatility.
Field survey took only 4 working days and only one survey crew which is much more economical approach. Having in mind that the inspection has been conducted on more than 95% of the constructed area of the elements there is no room for comparison between this and the traditional surveying methods in the process of QA and As Build surveys.

Furthermore by using the TLS/HDS technology the output reports are more detailed and more suitable for reporting and documenting of the constructed objects.

What is of an essence is that this type of surveys with this technology minimizes the subjective human factor because the inspection process is almost automatic and it is conducted all over the area of interest and not only on specific or randomly selected places.

This method and technology can be applied not only on buildings but on almost all construction objects like roads, channels, steel constructions etc.

Same point cloud data can be used for different type on analyses depending of the requirements (e. g. deformations, floor or asphalt flatness, crack detection and so on) and the big advantage is that the inspection process is conducted in the office and can be easily shared between different parities.

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