COMPARISON OF THREE ACCURATE 3D MEASUREMENT METHODS FOR EVALUATING AS-BUILT FLOOR FLATNESS

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ABSTRACT:

One usual complaint about building quality is flatness of a floor. If deviations from planar could be discovered before construction is completed, savings counted in time, money or reputation, can be noticeable. However, finding the possible deviations exceeding the tolerances may be time consuming using the traditional methods.
We have tested three accurate 3D measurement methods; photogrammetry, laser scanning and tacheometer, for evaluating as-built floor flatness. An experimental work was done and measuring accuracy, time and expenses were compared in order to illustrate, how realistic these methods are for construction companies.
All the methods proved to be suitable for the purpose and gave rather similar results for flatness of the test floor. Laser scanner gave the most detailed information of floor flatness. Photogrammetric and tacheometric measurements were the most accurate.

1. INTRODUCTION

As-built floor flatness is one of the many issues that may cause afterward complaining of building quality. The reparation of construction errors can be expensive and time consuming. In addition, immaterial loss should be taken into account, because the reputation of the constructor might be hurt.

The most profitable would be, if the possible deviations from planar could be discovered right after casting of a concrete floor and before installation of finishing material. This way, wasting of expensive finishing material like parquet, could be avoided.

Floor surface tolerances are traditionally evaluated by checking that a gap under a 3 m straightedge placed anywhere on the floor does not exceed given tolerances. This method is simple but deficient when large floors are to be measured. It is also arbitrary, subjective and generally non repeatable because coordinates of the measured locations are not recorded. (Pub. No. EM 1110-2-2000, 1994).

A more modern instrument for floor flatness measuring is a Dipstick, developed by Allen Face. It was first seen in the UK around 1983. The Dipstick measures elevation differences between the two points as it is walked across of a floor. (Hulett, 2005) The development of a Dipstick was a stride forward in floor flatness measurements but the elevation differences were still measured manually point-by-point.

There are also some automatic measuring devices that move around a floor and calculate flatness values. An example of a mobile robot, which measures lengths and angles with an optical device, is presented by Valera, Nava and Miranda (2004). This device is especially suitable for large surfaces.

Besides of currently used methods, also other measuring methods such as photogrammetry, laser scanning and geodetic measurements, are potential for practical floor flatness detection. Tacheometers are common equipments in construction sites. High accuracy of geodetic devices ensures good quality, but the single point measuring method causes long on-site measuring times.

Even if photogrammetric measurements have long traditions in 3D modelling, the operational applications for observing floor flatness are missing. However, currently available commercial close-range software makes modelling easy for even non-professional users. Fast image acquisition times increase the usability of photogrammetric methods.

Terrestrial laser scanners (TLS) have become popular for modelling building and environment. The advantages of TLS are the dense sampling rate and immediate production of 3D data. Because TLS are the most suitable for modelling any surfaces, the potential for detecting floor flatness is obvious. In addition, the strength of TLS is that it can be used for many purposes in construction sites and it may replace or complement various special equipments designed only for one specific construction task.

In this paper, workflows for evaluating the floor flatness with photogrammetry, laser scanning and tacheometer are presented. The results from different methods are compared. In addition, expenses and measuring times are compared in order to illustrate, how realistic these method are for construction companies.

2. MATERIAL

The test area was chosen from a building that was built in 2004 -2005. The area of interest located in the lobby that was designed also for representatives. The floor was based with a concrete board and the surface was covered with a plastic carpet. The size of the test area was 23 m².

For photogrammetric measurements 40 sticker targets were attached to the floor in order to simplify image observations and to ensure accurate results (Figure 1). The targets were photographed from various viewing angles. In total 31 images were captured from distances of approximately 2 to 7 m (Figure 2). The camera applied was Nikon D100 with the image size of 3008 by 2000 pixels. The camera was calibrated using calibration targets provided by the iWitness (Fraser and Hanley, 2004).
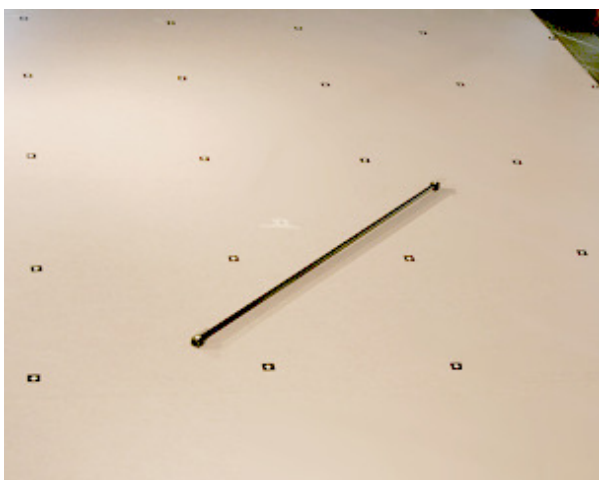

Figure 1. The area of interest was covered with photogrammetric targets and equipped with a scale bar. The approximate distance between targets was 0.80 meters.
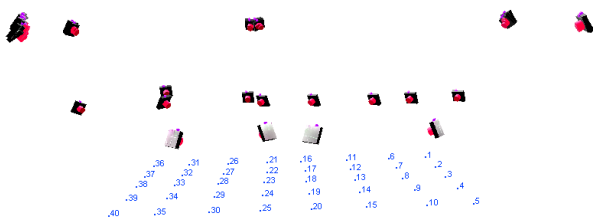

Figure 2.Camera positions relative to the area of interest.

The applied terrestrial laser scanner was FARO LS 880 HE80, which is based on phase measurements providing high-speed data acquisition. Technical parameters of the scanner include maximum measurement rate of 120000 points/s, laser wavelength of 785 nm, vertical field of view 320°, horizontal field of scan view 360°, and linearity error of 0.003 m (at 25 m and 84 % reflectivity), see also www.faro.com. Used scanning resolution produces 40 million points per full scanning, at 10 meters the point interval is 6,3 mm. Accuracies and performances of various types of laser scanners have been reported earlier e.g. by Fröhlich and Mettenleiter (2004). The

laser scanning points were acquired from four stations; one in the middle of the photogrammetric targets and three from different sides and distances of the targets (Table 1, Figures 3 and 4). It has to be pointed out that the laser scanner performance was somewhat deteriorated causing larger deviation than usual in laser points, which could also be seen in post-processing results. Soon after these scanning the scanner was sent to the manufacturer for maintenance. The laser scanning data was post-processed using Faro Scene 4.0 and Geomagic Studio 9 and Qualify 9.

Scanning ID	4	5	6	7
Distances [m]	2.1 - 8.4	1.4 - 3.9	2.0 - 8.3	5.7 - 9.0
Angles [deg]	37 - 9	63 - 19	40 - 10	14 - 9
Number of points [10^6]	1.8	10.4	2.4	0.2

Table 1. Properties of acquired laser scannings of the area of interest. Angle is the angle between floor plane and incoming laser beam.

Figure 3. Laser scanning of the floor. Laser scanner on tripod in front of the image (station 6), photogrammetric targets on the floor behind the scanner, spherical reference targets on the floor (left) and on tripods (right) and one paper reference target on the wall (upper left).
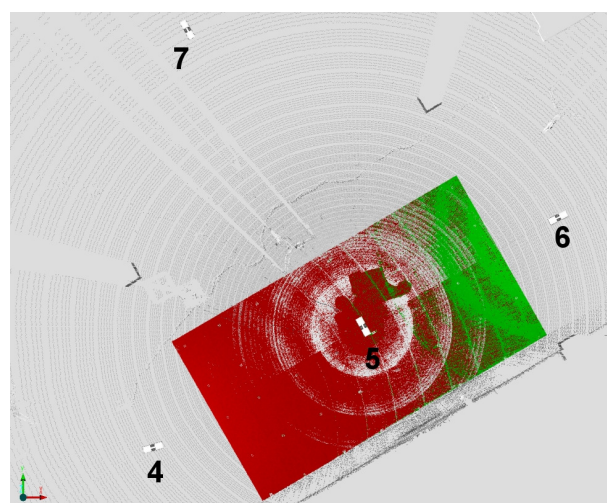

Figure 4. Laser scanning stations 4 to 7 and the area of interest (top view).

The photogrammetric targets were also measured with Leica TCA2003 tacheometer and WILD GPR1 prism from one station. The measuring distance was 3.8 to 11 m

3. METHODS

The photogrammetric targets were measured from the images in semi-automatic way. Approximate locations of targets were pointed manually and the exact coordinates of the target centers were calculated automatically by sub pixel accuracy.

The image observations were added to the least squares block adjustment for solving image orientations. The adjustment was calculated using the iWitness software (Fraser and Hanley, 2004). The targets on the floor were used as tie points between images. In the block adjustment both image orientations and the 3D coordinates of the tie points were solved. Because of the free image network set-up, the scale of the 3D model was uncertain. Therefore, one scale bar, 1.96366 m in length, was placed on the floor (Figure 1). The used scale bar was made from carbon fiber and the length of it was measured accurately with laserinterferometer.

The 3D points from photogrammetric measurements were transformed to the coordinate system of the tacheometric measurements. This way the measurements could be directly compared to each other. The transformation was done using four corner points of the test area.

Elevation grids were created from photogrammetric and tacheometric measurements (Figures 5 and 6).

The laser scanning derived 3D point clouds were georeferenced using spherical and paper targets, whose coordinates were obtained from tacheometer measurements. Before the laser point clouds were used for measurements, laser data was filtered using two filters in Faro Scene software. Firstly, dark points were eliminated due to the gross errors in distance measurements when the returning laser intensity was very low. These points were mainly the points from black photogrammetric targets. Secondly, possible outliers remaining in the data were filtered using a 9x9 window; if a point deviated more than 10 mm from the neighbourhood, it was eliminated.

After this pre-processing laser data was imported to Geomagic software. The laser points around the photogrammetric targets, were selected and cropped using a circle 15 cm in diameter, and a plane was matched to the cropped points. The centre of matched plane was used as target coordinates. The targets on the edge of the floor were left out, because they were next to the grating seen on Figure 3. This computation was carried out for all four scannings individually. A fifth case was computed by first finding the best fit between cropped areas between the scan 5 and three other scans by least squares matching using 20000 sample points from cropped areas and then merging all laser points and computing the coordinates as described earlier. In order to make corresponding data with tacheometric and photogrammetric measurements, this last method was used to compute the target heights to create similar elevation grid (Figure 7). Systematic 65 mm elevation difference compared to tacheometric reference heights was eliminated. Later this case will be referred as "Matched".

The point clouds of the whole area of interest were also used to create a polygon surface model of the floor. Again, other scanns were matched to scan 5 using the least squares matching and

1500 sample points from the whole area of interest. Using the polygon model, heights can be measured freely on the whole area of interest. The model heights on the location of photogrammetric targets were measured. The complete data set gives more detailed information of floor flatness (Figure 8). This case will later referred as "Model".

4. RESULTS

As mentioned earlier, the laser scanner performance was somewhat deteriorated, which could be seen in post-processing results as added noise in laser point distance measurements which also led to larger residuals in target matching in georeferencing. The manufacturer recalibrated the scanner soon after these scannings. Anyway, there are some shortages in the manufacturer's calibration and the accuracy of laser scanning can be significantly improved by more extensive calibration, as shown by Lichti and Licht (2006). The systematic deviation in phase based laser scanner distance measurement can be seen in figure 8 as circular patterns around the scanner stations. More research is needed to achieve better understanding of the effect of distance, incident angle and intensity of the laser points to the accuracy of laser scanner measurements.

4.1 Comparison of results

The elevation grids of the floor, created using the three different methods, look quite similar. The grid size of the model is about 0,8 m and the color of the grid cells corresponds to the heights. Also, the polygon surface model derived from laser scanning measurements gives similar shape to the floor (Figure 8).

7,9	9,7	9,4	7,8	9,8	8,0	6,0	3,6
11,7	8,7	8,8	7,6	6,7	4,4	0,8	2,1
10,8	8,8	8,5	4,8	4,0	1,6	0,2	2,0
13,1	8,4	7,2	5,5	4,1	7,0	7,6	8,6
10,8	12,4	10,3	8,7	9,1	9,3	8,0	9,1

Figure 5. Photogrammetric elevation grid (mm). The cell size of the grid is about 0,8 m.

8,1	9,1	8,5	7,1	9,2	7,9	5,4	3,4
10,8	8	8,2	7,2	6,2	4,2	0,6	1,9
10	8,3	8	4,7	3,6	1,5	0,1	1,9
12,8	8,3	7,1	5,3	4	6,9	8	8,6
10,6	12,4	9,9	8,6	9,3	9,3	8,2	9,3

Figure 6. Tachoemetric elevation grid (mm)

-	-	-	-	-	-	-	-
9,8	9	8,5	5,5	4,4	3,1	-0,5	-1,5
8,5	11,5	6,5	3,6	2,9	1,6	2,4	1,2
13,8	10,6	5,9	3,6	4,9	7,5	11,0	9,8
10,8	10,4	10,3	8,3	9,9	11,2	9,3	10,0

Figure 7. Laser scanning elevation grid (matched scannings, systematic error eliminated). Targets on the edge of the floor were omitted from the analysis.
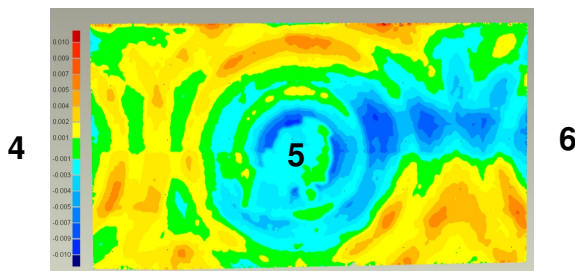
Figure 8. Laser scanner derived floor model deviation from plane (green area ± 1 mm, blue min -10 mm, red max 10 mm). Systematic deviation in laser points can be seen as circular patterns around scanning stations 4, 5 and 6.

The maximum height difference of the floor grid points was 12,7 mm – 15,3 mm depending on the measurement method; in tacheometer measurements it was 12,7 mm, in photogrammetric measurements 12,9 mm and in laser scanning measurements 15,3 mm.

The maximum height difference of adjacent grid points, was bigger than 7 mm with all measuring methods.

An average difference between photogrammetric and tacheometric measurements was 0,3 mm and maximum difference was 0,9 mm. When laser scanning and tacheometric measurements were compared, average difference was 6,5 mm and after removing the systematic error from laser scanning data, the maximum difference was 3,4 mm.

In Figures 9 and 10 individual target rows from photogrammetric and laser scanning measurements are compared with tacheometric measurements. Photogrammetric and tacheometric profiles seem to fit very well together. In laser scanning measurements, there is a detectable systematic height error but the shape of profiles is approximately congruent with tacheometric profiles.
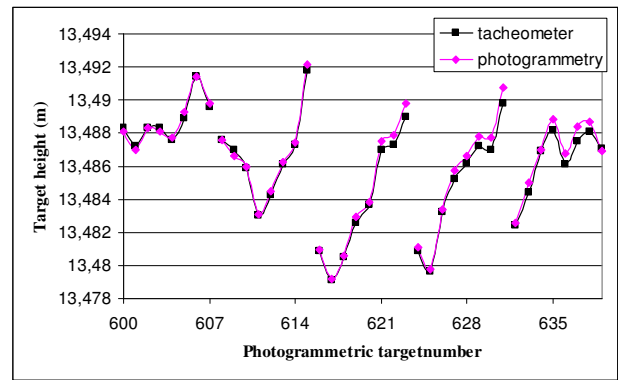
Figure 9. Comparison of the heights of the photogrammetric targets measured using a tacheometer and photogrammetry.
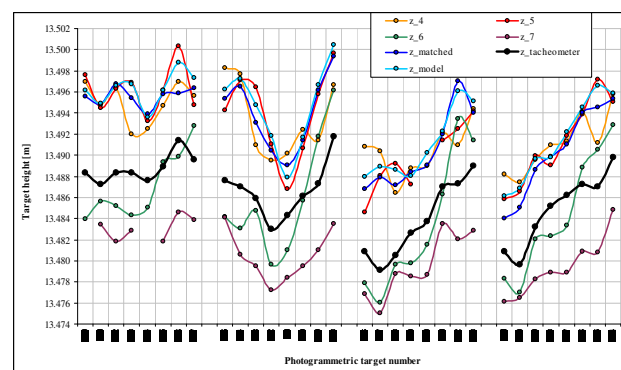
Figure 10. Comparison of the heights of the photogrammetric targets measured using a tacheometer, four individual scannings, matched scannings and a laser derived surface model.

4.2 Accuracy

Overall accuracy (RMS 1-sigma) for the photogrammetrically measured points, given by iWitness software, was 0,12 mm for height coordinates and 0,13 mm for planar coordinates.

The corresponding accuracy (RMS 1-sigma) for points measured with tacheometer was 0,2 mm for height coordinates. The prism stick was manually placed in the center of a target points approximately with 1-1,5 mm accuracy.

Accuracy of laser scanning compared to tacheometric reference measurements is presented in Table 2. The results are given for four scans independently (4, 5, 6 and 7), for matched scannings (Matched) and for computed polygon model (Model). The absolute accuracy of laser scanning measurements is dependent on the georeferencing accuracy as can be seen in Table 2. For example, scans 4 and 6 have practically similar measuring geometry relative to the area of interest (Table 1, Figure 4), but as the georeferencing accuracy of these scans is different, the overall accuracy varies. Although the systematic height error is smaller for scan 6, the acquired point cloud is slightly tilted compared to tacheometer measurements (see Figure 10), resulting in larger error values. Scan 7 has far less points and the incident angle to the floor is the most gentle of all scannings, but the accuracy is the best.

Scan ID	4	5	6	7	Matched	Model
Number of targets	32	31	32	30	32	32
Systematic height error	6,4	6,8	-0,9	-5,4	6,5	7,3
Std (sigma)	2,0	2,1	2,9	1,4	1,6	1,6
Max negative difference	-2,8	-4,3	-3,5	-2,9	-3,4	-3,7
Max positive difference	4,8	3,8	7,0	3,6	3,2	2,9

Table 2. Accuracy of laser scanning in mm, heights of targets compared to tacheometer measurements after eliminating the systematic height error.

5. ADVANTAGES AND EXPENSES OF DIFFERENT MEASURING METHODS

Measuring times and expenses were compared in order to help to estimate total costs of the different measuring methods.

5.1 Photogrammetry

In photogrammetry data capturing is rapid and can be done in few minutes.
The use of photogrammetric targets ensures accurate results and makes the measurement possible also when surface lacks identifiable texture. However, attachment of targets can be time consuming if there are hundreds of them. In our test area, there were 40 targets and attaching them took less than 10 minutes. An alternative for using physical targets is to use projected dots. A large amount of dots can be projected fast onto a surface with a slide or a laser projector. The use of projected dots allows also an easy customization to different dot densities and sizes and physical contact to surface can be avoided (Maas, 1992; Ganci and Brown, 2000).

In our example, the image measurements were done semi-automatically in few hours. The measuring time could be reduced considerably by eliminating human interaction and using automatic measurement process (Fraser, 2000).

The camera used in this study was a digital system camera costing about 1000 €, but also cheaper compact cameras can be used. A useful photogrammetric software can be purchased for 1000 – 2000 €.

5.2 Laser scanning

The advantages of the laser scanning measurements are that no targets are needed on the surface of an object and a highly dense point cloud describing the surface can be captured quickly. For example, the scanner parameters used in this study produce a point density of about 30 points per 1 dm^2 at the distance of nine meters thus covering an area of 250 m^2 of floor in less than 10 minutes. Post-processing time is highly dependent on the used programs and the experience of the operator. Scanner calibration is necessary in order to obtain reliable accuracy.

The current price range for laser scanners is wide. The price depends on the device and its properties, but typically it is between 25 000 –100 000 € (http://www.dirdim.com/ prod_laserscanners.htm). The software for post-processing of laser points, which was use in this experiment, costs about 20 000 €. There are also other corresponding softwares available. (http://www.dirdim.com/prod_software.htm).

5.3 Tacheometer

Tacheometric measurements are commonly used in construction surveying. The measurement method is accurate and offers reliable results. Data capturing can, however, be time consuming because points are measured one by one on the site. The measured points must be targeted with reflectors or pointed with a prism, but there are also instruments, which work without reflectors.

Price for tacheometer is about 10 000 e.

6. CONCLUSIONS

The aim of our study was to compare three measurement methods in terms of their accuracy, fastness and expenses when evaluating flatness of a floor.
All the methods proved to be suitable for the purpose and gave rather similar results for flatness of the test floor.

The most accurate results were obtained from photogrammetric and tacheometric measurements, whereas laser scanning gave the most detailed model of the floor surface.

There were no big differences in data capturing times on the test site, because the area was relatively small.
In photogrammetry and laser scanning, measuring time can be reduced significantly by using automatic measuring process. Many photogrammetric and laser scanning softwares include semi-automatic and automatic functionalities which facilitate the work of an operator. The advantage of automation is significant especially in case of large floor areas.

When purchase costs of the measuring systems are compared, laser scanning equipment and software are still the most expensive.
Laser scanner requires also a more extensive calibration to ensure accurate results.

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