ANALYSIS OF POSSIBLE GEODETIC APPROACHES FOR 3D MODEL CREATION IN BIM

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KEY WORDS: BIM, Photogrammetry, Laser scanning, Measurement, HBIM, 3D, Model.

ABSTRACT:

The topic of this paper is the description and analysis of technologies for generating a geometric basis for BIM. The main element is an analysis of the capabilities of mobile laser scanning and the outputs of this method compared to other methods. The selected interior space was measured by different technologies, laser scanning, classical geodetic using total station, and manual measurement. The main device tested was the ZEB-REVO. It is a handheld mobile laser scanner, carried by an operator. It has a range of 40 m, with the accuracy in measured lengths is 1-3cm per 10 m depending on the type of surface. The scanning speed is 43,000 points per second. The device is equipped with an inertial measurement unit (IMU) and uses SLAM technology for trajectory definition. The device does not have a camera in the simplest configuration and the operator cannot monitor the scanning status. Nevertheless, measurement with this scanner is very simple. The instrument is mainly used for surveying construction objects, but it can be advantageously used for documentation of underground spaces or in e.g., forestry for defining DBH or volume of stockpiles. This device is not equipped with a GNSS unit, and the typical scanning time is 20-30 min without model deformation. Accuracy and output analysis was performed for all technologies used. The results are presented in tables and show the suitability of PLS (personal laser scanner) in general.

1. INTRODUCTION

With the development of laser technology and the possibility of using it for measuring purposes, the mobile method gradually began to develop. Mobile laser systems (mobile mapping systems - MMS) were initially used only for mapping work, as mainly vehicles were used as a carrier for a laser scanner and other instruments. Their development already began in the nineties of the 20th century. This was due to the size and weight of the system components. With the miniaturization of components and the power of electronics, handheld laser systems were developed approximately ten years ago (PLS – personal laser system), and their development was very fast. Currently, there are co-existing MMS located on cars, airplanes, or other transportation platforms, intended for mapping work of a larger scale, and also manual systems (PLS) for smaller objects and especially for indoor spaces where there is no GNSS signal.

In indoor areas, SLAM (Simultaneous localization and mapping) technology has started to be used. It is a solution for mobile measurement inside buildings or underground where continuous positioning of the device is not possible. It consists of creating a real-time map of the environment from which the position of the instrument is simultaneously derived. From the data that is measured, several landmarks are continuously observed from which the position of the instrument must be calculated at the same time.

Documentation of a construction object and other activities that result in the production of construction documentation, information for the owner of the object to be measured or a terrain model are now an integral part of the construction industry. There are a variety of methods to carry out this work, from conventional measurements with a tape measure or a handheld electronic rangefinder to measurements with a laser scanner or using photogrammetry. The choice of the method is mainly influenced by the complexity of the object, the time required and the financial possibilities.

The geodetically processed data provides specific and detailed information that is the basis for today's BIM (Building information modelling) technology. The method of data acquisition always requires a certain amount of time both for the measurement itself and for the processing of the measured data. Therefore, manufacturers of modern equipment design products to be very simple and intuitive for the user to use and to keep the time required to do the work short. These requirements have led to the design of mobile mapping systems. In the field of BIM, these are mainly personal mobile laser scanners. Several companies have developed handheld mobile laser scanners based on the requirements of fast and accurate documentation of objects, thus noticeably expanding the possibilities of point cloud acquisition and the possibilities of producing documents for other civil engineering purposes. These are mostly floor plans and sections of a building, typically used in the construction industry. However, the acquisition of a point cloud or geometric modelling of an object does not mean the creation of BIM. To this, a lot of additional data needs to be added and a system should be created that effectively and economically helps to manage the object throughout its lifetime (Poloprutský, 2019a; Poloprutský, 2022b; Boboc et al., 2022; Bregianni, 2013; Sacks et al., 2011).

A common technology for acquiring the geometric basis for BIM is laser scanning. The point cloud, as a result of laser scanning, needs to be processed for measurement and construction documentation in the form of, for example, a 3D model, plans or cross-sections, from which drawings can be created by vectorisation. It is a bit of an anachronism that most 3D data processes produce 2D data (plans and cross-sections) from which a new and simplified model is often created for BIM, for example in Revit or SketchUp. Modern research focuses on the direct conversion of information from a 3D point cloud to sub-primitives and units in BIM. For example, contributions (Xiong et al., 2013; Ochmann et al., 2016) describe an algorithm that

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https://doi.org/10.5194/isprs-archives-XLVIII-5-W2-2023-77-2023

automatically converts raw laser scanning data into a complete model usable in BIM.

In the following, the current state of the art technologies and the possibilities of indoor targeting are discussed from different perspectives such as data size, accuracy, and time.

2. TESTING OF TECHNOLOGIES

The usability of geodetical technologies was tested in a project where parts of the basement of the CTU Faculty of Civil Engineering were targeted. The test space was divided into three areas to contain elements of varying complexity, and for each area, work time was measured separately. The different areas are shown in Figure 1. Area A is a separate room with an area of 30 m^2. Area B includes this room and the adjacent corridors within one floor of the building. The area includes C includes an additional staircase. The areas differ in the complexity of the elements and the time required for their focusing. 15 targets were placed in the areas to connect the clouds points during processing.

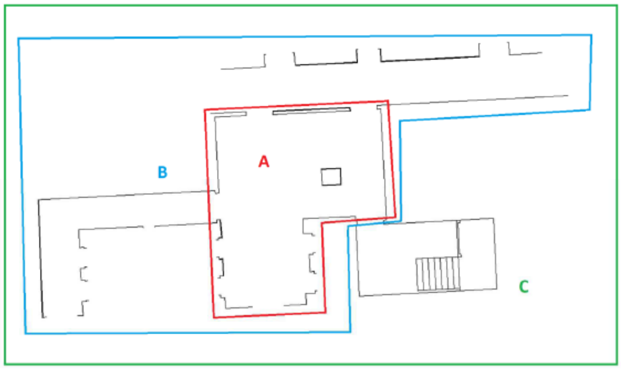

Figure 1. Basement of the CTU FCE, targets for laser scanning, and measurement scheme.

The measurement results were compared with other instruments and technologies in terms of accuracy and time consumption. The ZEB-REVO was tested with Surphaser 25HSX and Leica BLK360 laser scanners as well as with classical geodetic measurements using total station and manual measurement using tape or a hand-held distance meter. The results are described in the following text and Table 1.

2.1 Classical approach - manual measurement

Inside the premises, specific measures were measured with a handheld Leica Disto A5 electronic rangefinder (Figure 2). Measurements with handheld electronic rangefinders are subject to error from non-hydraulic intent, which was partially compensated for in this case by the spirit level included in the instrument. Very short sighting distances of tens of centimetres, which cannot be determined with this instrument, were measured with a tape measure. To measure longer distances where it is not possible to reflect the laser beam from the object or to keep the meter horizontal, two meters are required.

Figure 2. Leica Disto.

2.2 Geodetic measurement

The instrument used for testing the polar method was a Leica total station TCR 307. Since this total station is not robotic, the measurements must be carried out by two surveyors to ensure that detailed points are located with sufficient accuracy. A total of 121 detailed points from 5 positions were targeted.

2.3 Laser scanning

Three types of laser scanners were used in the project (Glennie et al., 2013)

2.3.1 Leica BLK360: Another static scanner used was the Leica BLK 360, which weighs only 1 kg and therefore can be measured by only one operator. All communication with the instrument is wireless, which is a disadvantage when downloading large volumes of data (Figure 3).

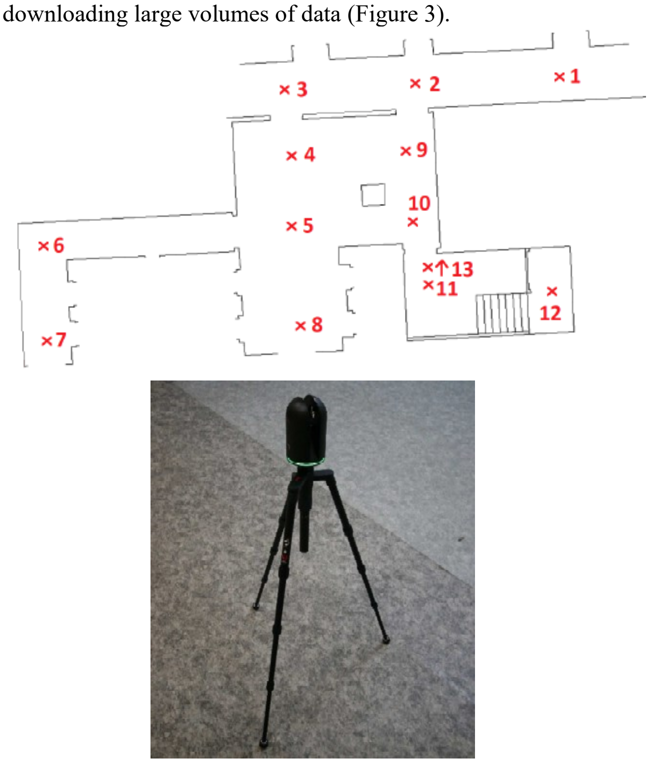

Figure 3. Scanning positions and the laser scanner Leica BLK360.

The new type already has an improved solution via cable and a very good quality system of online scan linking via tablet. The scan parameters are set using the BLK 360 Data manager software.

2.3.2 Surphaser 25HSX: The Surphaser 25 HSX is the most accurate static laser scanner used for testing. The instrument itself weighs 11 kg and, together with the tripod, is difficult for a single surveyor to handle. An external battery and a computer with Surphexpress standard software, which is the hardware key, must be connected to the instrument at the same time. The scanner is not equipped with a camera. Prior to the scanning process, the Preview option can be used first, where the scanner performs a quick scan of the surroundings, and the operator can select only a certain part of the image. This option reduces the time required for scanning and the volume of the resulting data, however, when testing was not used (Figure 4).

Figure 4. Scanning positions and the laser scanner Surphaser 25HSX.

2.3.3 ZEB REVO: In 2013, the ZEB1 handheld mobile scanner from CSIRO, one of the entities that later became GeoSLAM, appeared on the market. In 2016, the ZEB-REVO handheld mobile laser scanner was launched. The development went on and the scanning speed and accuracy increased, the camera was added (e.g., ZEB Horizons).

Figure 5. ZEB REVO and ZEB1 (GeoSLAM, 2023).

The ZEB-REVO is a handheld mobile laser scanner that has been manufactured and distributed by GeoSLAM since 2016 (Figure 5), (Matoušková et al., 2021). The instrument consists of a scanning head and a handle. The rotating scan head includes a Hokuyo UTM-30LX-F 2D laser scanner coupled to an IMU, which is in the handle and attached to the motor. By rotating the scanning head with the 2D scanner 360 degrees and measuring the tilt of the device with the IMU, the resulting 3D point cloud is acquired. Operation of the instrument is simple and intuitive. As with other MLSs, the advantage of the ZEB-REVO lies in the speed of scanning, as it eliminates the position measurements required for static laser scanners, and in its weight, as the scanning head itself weighs only 1 kg. Other components needed for data acquisition and processing are the ZEB-DL2600 data storage device with a backpack for carrying it, cables for data registration and download, USB device and external battery (GEOmedia, 2016 and Cabo et al., 2018).

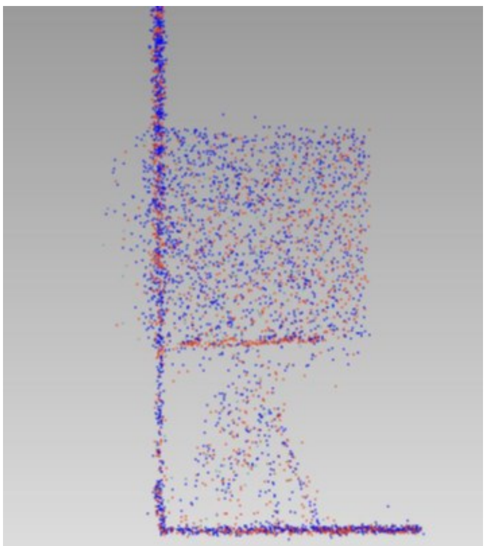

Figure 6. Data from ZEB-REVO, the target from Figure 1.

The instrument is very easy to measure. It is necessary to start and end at the same point, the scanning speed is 43,000points per second, the field of view is 270° × 360° and the accuracy is 1-3cm at 10m (the range is about 30m).

Targets were placed throughout the corridor (Figure 1 and Figure 6). The ZEB-REVO mobile scanner was operated by only one meter. The corridors that are part of the measured areas are long and their profiles are the same in different places (Figure 7). This can cause miscalculation of the SLAM algorithm, but this can be avoided by placing several objects according to the recommendations of the GeoSLAM manual; this was done (open doors, placement of targets and slides or boxes), (GeoSLAM, 2020).

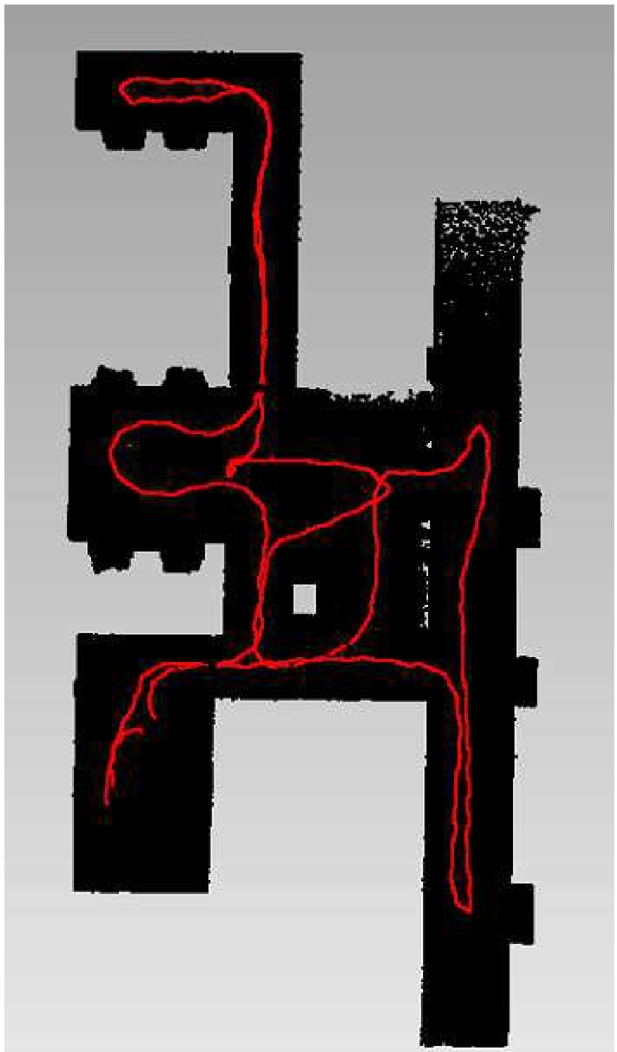

Figure 7. Indoor measurement trajectories - ZEB-REVO.

3. RESULTS AND DISCUSSION

The measured data were processed into vector drawings in dwg and dgn format. For the purposes of comparison of the methods, the resulting drawings include the perimeter of the masonry, dimensions, and staircase, thus these are not a complete measurement documentation with all the requisites.

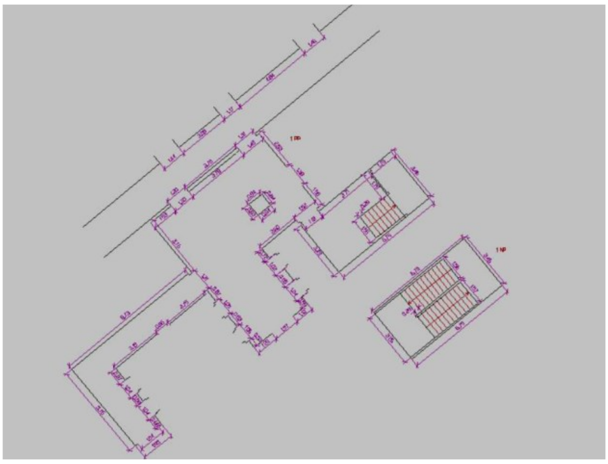

Figure 8. Sample drawing.

For manual measurements, the drawing was constructed directly from the gauges and cross-gauges in Geus software.
Measurements with a Leica TCR 307 total station in gsi format were processed in Groma. In the notebook of measured angles and lengths, the measurements in both positions were processed and the oblique lengths were reduced to horizontal lengths. The coordinates of the detailed points were calculated from the adjusted data (Figure 8).

The measured data from the Surphaser scanner in c3d format were processed by Surphexpress standard and converted to xyz format using a batch file. The point clouds contained 741,477,204 points, which corresponds to approximately 50 million points at one site. Their processing was performed in Geomagic Wrap. Parts outside the region of interest and inaccurately determined points based on the set distance from other points were removed. The source of some inaccuracies was, for example, incorrectly determined lengths after reflection from glazed surfaces. For a smooth and high-quality work, the clouds were shaded, and the total number of points was reduced to 201 785 735.

The data from the BLK360 scanner had a total of 642 157 841 points and was processed by the BLK 360 Data Manager. The point clouds were further processed with the Leica Cyclone Register 360, which offers the possibility of automatic cloud registration based on correlation the position of the points and the deployed targets, which were also identified by automatic process (Figure 9-10), (Leica Geosystems, 2023).

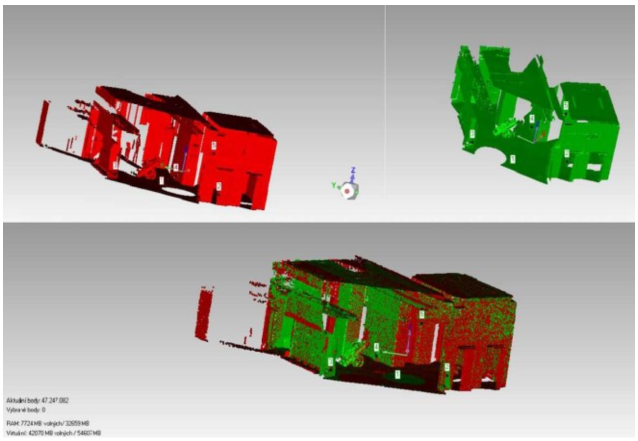

Figure 9. Manual registration in Geomagic software (for Suphaser, no automatic scan joining was used).

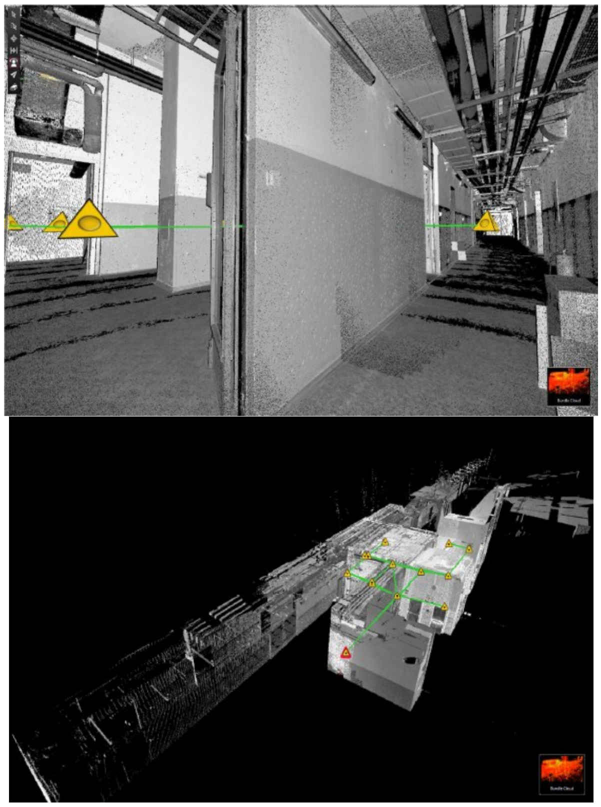

Figure 10. Data from BLK360 and created model (Leica Cyclone Register 360).

Measurements with ZEB-REVO were carried out by walking around the measured area and automatically evaluated in the Geroslam Hub software. Cross-sections or floor plans can be easily vectorized in the Geoslam Draw module (Figure 11-12).

Figure 11. Data from ZEB REVO, the basement of FCE (Figure 1).

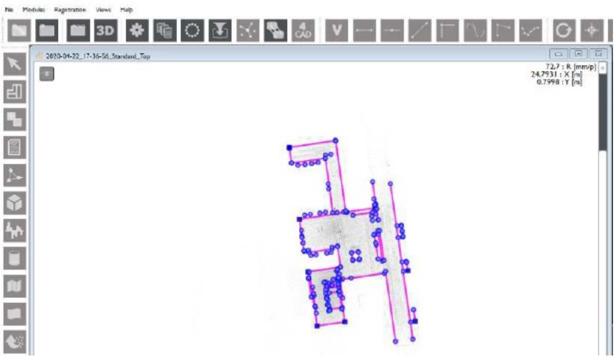

Figure 12. Vectorisation of the measured and processed point cloud (Geoslam Draw).

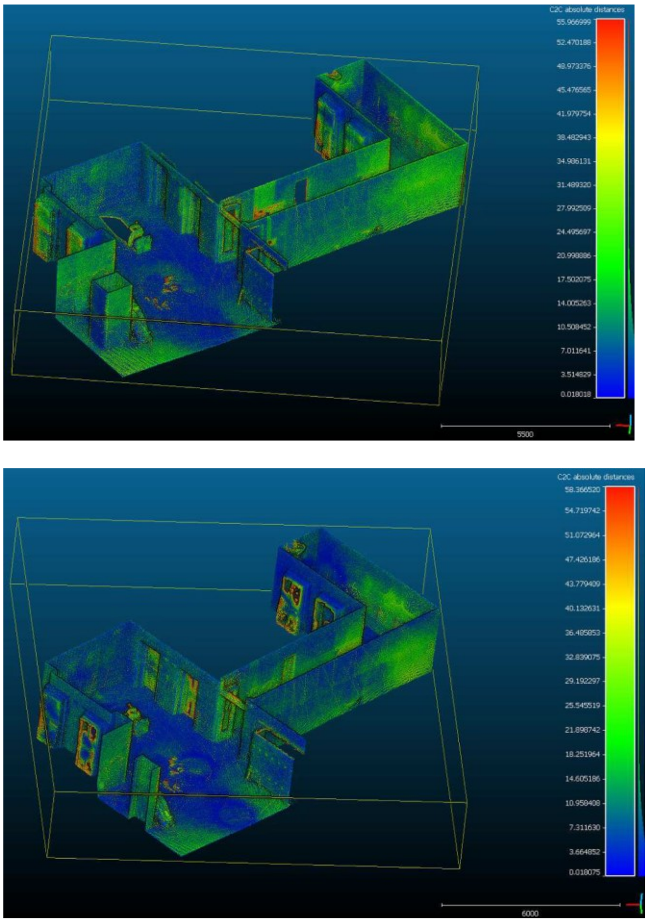

Figure 13. Point cloud comparison - Surphaser 25 HSX (top) and ZEB-REVO and Leica BLK 360 and ZEB-REVO (bottom).

In the outputs produced by all five tested methods, the dimensions on which the comparison was made were selected. These dimensions are shown in Figure 7.4. Dimensions A, B, C represent the lengths of the selected wall segments and D, E are the dimensions of the selected openings. The results of the comparison are shown in the table 1. And on Figure.13. The results of the tested technologies are summarized in Table 2, (Šartner, 2020).

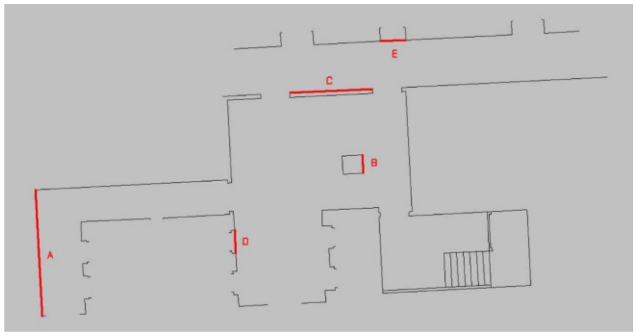

Figure 14. Overview of tested dimensions.

Instrument	A[m]	B[m]	C[m]	D[m]	E[m]
LeicaDistoA5	5.761	0.835	3.771	1.048	1.166
LeicaTCR307	5.758	0.835	3.758	1.056	1.174
Surphaser25HSX	5.761	0.836	3.781	1.049	1.169
LeicaBLK360	5.767	0.833	3.775	1.043	1.164
ZEB-REVO	5.785	0.85	3.779	1.028	1.174

Table 1. Comparison of analysed dimensions from different technologies.

Instrument	Costs [USD]	Processing - time consuming	Measured data volume
Leica Disto A5	450	3 hours 20 min	0 B, hand-held
Leica TCR 307	3000	3 hours 30 min	17 kB
Surphaser 25 HSX	90000	12 hours 10 min	17 GB / no camera installed
Leica BLK 360	44000	7 hours 48 min	23 GB with images
ZEB-REVO	44000	2 hours 26 min	0.4 GB, no camera installed

Instrument	Reported accuracy of the instrument [mm]	accuracy of the point cloud [mm]	accuracy of the drawing [mm]
Leica Disto A5	1.5	single points / 1-3	3
Leica TCR 307	2 + 2 /10^6 distance.	single points / 2	5
Surphaser 25 HSX	0.6 / 10 m distance.	1	2
Leica BLK 360	4 / 10 m distance. 7 / 20 m distance.	6.3	5
ZEB-REVO	10-30 / 10 m distance.	15-20	13

Table 2. Time, price, and precision analysis.

The usability of the ZEB-REVO device was tested in a project described above. With the ZEB-REVO, the volume of measured data is many times lower compared to other laser scanners tested, which can be an advantage for archiving data for many projects.

The lower number of points makes it easier and smoother to work with point clouds, and the computing performance may not be as high as when processing point clouds from the Surphaser 25 HSX and Leica BLK 360. A major advantage of the ZEB-REVO is the speed of data acquisition and processing. The time consumption was the lowest of all the methods tested in this work and was 5 times lower than that of the Surphaser 25 HSX static scanner. The associated GeoSLAM Hub software used to process the data is very easy to use and the GeoSLAM Draw outputs make post-processing easy for the user.

The above-mentioned advantages of ZEB-REVO come at the expense of price and measurement accuracy. The prices of the laser technology are generally several times higher than those of the instruments used in conventional methods (direct measurement and polar methods). Taking the cost of the equipment used as a basis, the cost of producing a drawing from the data taken by ZEB-REVO was up to ten times higher than for the polar method but three times lower than for the Surphaser 25 HSX scanner.

The accuracy of the data from the mobile laser scanner is the lowest of all the instruments tested. It was 1-2 orders of magnitude lower for both point cloud and vector outputs than the Surphaser 25 HSX scanner and the IBMR generated point cloud. However, in terms of output acquisition speed, ZEB-REVO is by far the fastest. Plan creation is 10 times faster than conventional surveying and is significantly faster than conventional laser scanners (up to 5-times faster).

The ZEB-REVO mobile scanner can be used for surveying the interior of buildings. It is also partially applicable for documentation of historical monuments or mapping of rugged areas such as forests, where, however, the measurement is limited by the range of the scanner. It is suitable for quick reality capture, for example in the event of a traffic accident. SLAM technology allows scanning of underground areas where results can be more accurate than using a total station. The possibilities of using the instrument in underground areas where hazardous substances are present have not been identified.

The low accuracy makes it impossible to perform any work requiring accuracy in the millimetre range or higher with the ZEB-REVO scanner. The instrument is not suitable for monitoring displacements and deformations of structures, measuring details or creating 3D models of small objects. In addition, SLAM technology requires an environment that is not variable and monotonous. Moving people or objects may cause the instrument to misjudge the position. The resulting data may also be subject to errors if the instrument is subjected to sudden movements or measured in narrow and homogeneous spaces such as long corridors. Some of the instrument's shortcomings, such as range, cloud colouration or georeferencing, are compensated for in newer GeoSLAM products.

Verification of the accuracy of ZEB REVO was performed using targets that were classically geodetically acquired by a total station. Measurements with PLS were performed twice inside the building in the basement of the faculty. The first time, various objects were placed in the relatively homogeneous corridor for SLAM orientation as recommended, while the objects were not placed during the second measurement. For the second measurement, an error occurred after processing in the GeoSLAM HUB software that was easily detectable - part of the object was significantly deformed and the standard software settings were unable to eliminate this error. The erroneous parts of the point cloud were successfully corrected in the software by directly reconfiguring the processing parameters of the primary point cloud (Figure 15).

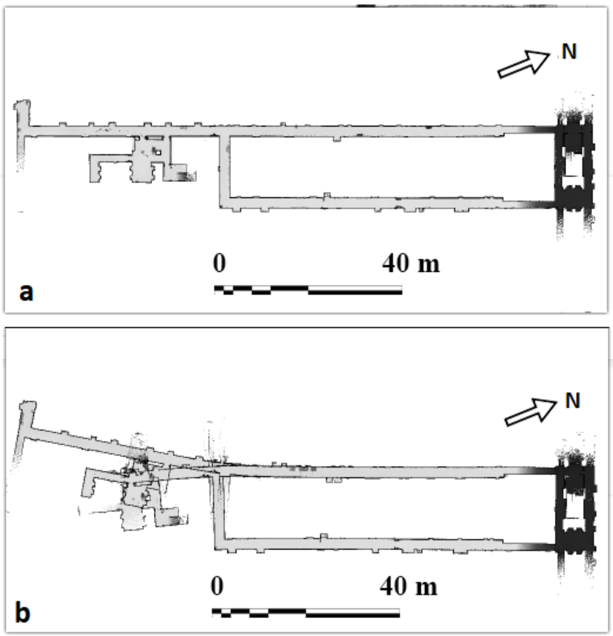

Figure 15. Data from ZEB REVO, the basement of FCE (Figure 1); first measurement with scattered objects in the corridor (a), second (b) without objects. The visible distortion was corrected by changing parameters.

In total, 8 targets were measured within the polygon with a mean error of less than 1cm. From the differences between the coordinates of the target centres extracted from the point cloud and the calculated coordinates of the target centres from the total station measurements, the mean pointing error was calculated using the ZEB-Revo handheld personal scanner. The total station measurement is logically more accurate and was considered as a reference.

After calculating the transformation, the mean unit error on the 8 transformed points was 0.0154 m. The deviations at the other points that were designated for checking were within 1-3 cm, which corresponds exactly to the accuracy declared by the manufacturer. This accuracy is more than sufficient for the intended use of the equipment.

4. CONCLUSION

The ZEB-REVO Go is one of the simpler but very powerful and usable devices for obtaining construction drawings, especially of buildings, in a very short time and with the usual required accuracy. It is excellent in mapping underground spaces where no texture is required. Nowadays, there is a new range of similar devices on the market, including GeoSlam products, which have better parameters but also much more data. The comparison of technologies and various devices for obtaining geometric data for BIM (H-BIM) was carried out on a case study in the premises of the Faculty of Civil Engineering of the Czech Technical University. The validity of the results was then tested on several sample projects in practice. Based on the analysis, it can be said that, in general, mobile personal mapping devices are ideal for basic data acquisition for geometric modelling, which is the basis of BIM (H-BIM).

ACKNOWLEDGEMENTS

This project was supported by a grant CTU FCE SGS2023 - SGS23/052/OHK1/1T/11 (Pavelka).

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