Experimental evaluation of iPad Pro LiDAR, for building modeling and possibilities to connect with AI technologies

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Abstract: Measuring buildings is a recurring task when recording construction progress and existing buildings in BIM-models. LiDAR (Light Detection and Ranging) surveying systems allow fast and precise recording of environments but are usually not attractive in terms of price of widespread use. Nowadays, modern mobile devices equipped with LiDAR sensors offer a cost-effective alternative for measuring environments or structures. This Paper experimentally investigates to which extent the iPad Pro, with its various software solutions and the LiDAR technology available today, can be used to create building models. Four experiments were conducted to reflect real-life situations: (i) scanning closed space, (ii) scanning loop of a larger area, (iii) the range of the LiDAR sensor, and (iv) its accuracy as well as the functionality of direct automatic modeling of BIM-models compared to professional systems. The experimental investigations show that the iPad Pro can already be used to capture point clouds with minor quality reduction. Furthermore, the post-processing of the scan data using artificial intelligence is being investigated to derive further research questions on how the scan data can be automatically evaluated and the quality of the derived 3D building models can be improved.

Keywords: BIM, LiDAR, Point-cloud, iPad Pro, AI

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1 Introduction

Many engineers and architects might find that as-built surveys can be carried out more efficiently with 3D laser scanners. With a variety of LiDAR devices offering different accuracies, ranges, and features, the opportunities for innovation are enormous. The low-cost system of the iPad Pro was selected for the study compared to a professional system, the BLK2GO from Leica. The iPad Pro offers many new possibilities due to its low purchase price. For example, it increases distribution and availability, is easy to use, serves as an alternative to professional systems, has versatile applications in the construction industry, and promotes development and research in the field of LiDAR technology because it is affordable for everyone. However, the most important question is how accurate the generated data is and what can be done with this data. To this, the experimental studies aim to use the iPad Pro to explore its applications, identify the most effective software solutions, and determine the accuracies of the system. Through four different experimental investigations, we will find out how this technology can improve today's construction industry and make it more digital. The experiments are divided into: (i) scanning a closed space, (ii) scanning a loop of a larger area, (iii) evaluating the range of the LiDAR sensor, and (iv) its accuracy as well as the functionality of direct automatic modeling of BIM-models. The collected data will be analyzed to determine which applications are best suited for further research into the evaluation of scan data using artificial intelligence, up to and including the BIM-model, thus paving the way for groundbreaking advances. The state-of-the-art section of this paper establishes a link to previous publications, highlights progress to date, and outlines important points for future developments. In addition, it shows how AI can further improve the processing of the recorded data and what possibilities already exist today. The methods section provides background information on the experiments carried out. The results section presents the analyzed data and the paper concludes with a discussion of the results.

2 State-of-the-Art

2.1 LiDAR

There are already evaluations of the performance of the LiDAR scanner in the iPad Pro, such as those by Teo and Yang [1]. The results are evaluated in terms of the potential for the subsequent creation of 3D BIM-models. The investigations in the study were divided into dynamic and static tests. As a result of the study, it was found that the LiDAR scanner installed in the iPad Pro was able to achieve accuracy of up to 1 mm concerning a reference plane in static tests, explicitly related to a straight wall and mounted on a tripod. Furthermore, it was found that the deviations in the dynamic test, which was carried out as a loop, were within 80 % of the recorded points generating a deviation of 1 cm with the iPad Pro. As a result, it was concluded that it is possible to create precise point clouds with the iPad Pro under certain conditions. However, the accuracy was not sufficient to achieve the accuracy required by the USGSA BIM guidelines for 3D point clouds. In the USGSA BIM guide, the accuracy is divided into four different levels and ranges from ± 3 mm to ± 51 mm [2]. The technology was used for large-scale structures in a publication by Luetzenburg, Kroon, and Bjørk [3], measuring a coastal cliff in Denmark. It was found that the LiDAR sensors installed in the iPhone 12 achieved an accuracy of ± 1 cm for small objects with a side length of > 10 cm. For larger objects with dimensions of 130×15×10 m, the system achieved an absolute accuracy of ± 10 cm. A study by Vacca [4] is based on the evaluation of the LiDAR sensor built into the iPad Pro in relation to the documentation of architectural and cultural heritage. The investigations were carried out using software applications from Polycam, Sitescape, 3DScannerApp, and Scaniverse. As a result of the study, it was found that the Apple LiDAR sensors can be used to document and create 3D models, but the shape and texture should not be complex.

2.2 AI technologies

The approaches to as-built surveys do not only refer to the data basis of point clouds, BIM-models or components are created from construction drawings using AI models. Al-Wesabi [5] describes an approach for extracting information from German infrastructure projects. The study presents promising results for the automatic creation of digital building models but does not provide a definitive solution. Further areas are covered in a publication by Schoenfelder, Stebel, Andreou, *et al.* [6] which dealt with the extraction of text information from as-built plans. A data set for text recognition from floor plans was created, applied, and compared with various deep learning algorithms. In the end, the study shows which algorithm performed the best text recognition and explains of further development. The acquisition of data from the 2D-floor plans is carried out as described in a publication by Gard and Barreiro [7] by first converting the plan information into the Json-format. The data obtained in Json-format is then converted into a 3D model and saved in Ifc-format. Components such as walls, ceilings, floors, windows, and doors are recognized. The BIMKIT-project also describes Ifc-model generation, which, according to the forward schematic description, is converted from Json-format into an Ifc-model using AI. However, according to the current project status, no training data is yet available for the AI [8]. Furthermore, there are similarities to the BIM-SPEED project, in which there is an application that automatically models walls within a point cloud, in line with the topic [9]. However, the overall picture after recording a point cloud up to the parameterized building model is missing. Initial approaches can be found for infrastructure structures. As-built surveys are usually carried out using laser scanners, as described by H. Mischo [10]. The further modeling and processing of the data is still carried out manually. In a publication by Jaekel, Goelzhaeuser, Schmitt, *et al.* [11] the manual modeling is transformed into a partially automated generation of digital infrastructure projects. A first approach is shown in which an existing bridge for maintenance management was successfully digitized. Another promising approach to partial automation is provided by Bednor [12] or Qin, Zhou, Hu, *et al.* [13], where the process, from data acquisition through laser scanning to export, i.e. the provision of modeled data, is explained. It is also established that it is possible to derive BIM-models from 3D point clouds. In a further study on point cloud recording in indoor areas by Stojanovic, Trapp, Richter, *et al.* [14] two different DL-algorithms are described. These are the DL-algorithm PointNett++ [15] and the Inception V3 [16] algorithm. The study by Stojanovic et al. shows that both algorithms are suitable for the segmentation of point clouds from mobile scanning systems.

3 Methodical

The LiDAR scanners are evaluated through various experimental analyses. The experiments are designed to obtain information on the accuracy of the different applications and systems. The software applications in Table 1 were selected based on the export formats. The .ply format was used for the investigations of the point clouds. For automatic model generation, the focus was on the Ifc-format. Experiment (i) was carried out as part of a semi-dynamic investigation on a tripod with the device swiveling and rotating around its axis. Experiments (ii), (iii), and (iv) were conducted in a dynamic experiment to provide the slam algorithms with sufficient data to process the scans. Figure 1 shows the experiments, which reference is taken, and the used applications with the analysis process of the data. To analyze the point clouds, the apps 3DScannerApp [17], RTAB-Map [18], and Scaniverse [19] are used. For experiment (iv) the applications Magicplan [20] and Metaroom [21] were chosen.

Table 1: List of iPad Pro applications and export formats for LiDAR-Scanning, which were compared, based on the export formats.

Application	Export format
Polycam	.dae, .dxf, .fbx, .gltf, .las, .obj, .ply, .pts, .raw, .stl, .usdz, .xyz
Magicplan	.ifc, .obj, .usdz
3D-Scanner-App	.e57, .glb, .gltf, .las, .obj, .pcd, .ply, .pts, .stl, .usdz, .xyz
Canvas Lite	.dae, .dwg, .ifc, .kit, .plan, .rvt
OpalAi	.e57, .glb, .gltf, .las, .obj, .pcd, .ply, .pts, .stl, .xyz
Metaroom	abc, .dae, .dxf, .fbx, .glb, .gltf, .ifc, .obj, .rdf, .skp, .stl, .usd, .zip
SiteScape	.e57, .ply
3D-Scanner	.dae, .glb, .obj
Metascan	fbx, .gltf, .laz, .obj, .ply, .stl, .usdz, .xyz
Scaniverse	.fbx, .glb, .las, .obj, .ply, .ply, .stl, .usdz
RTAB-Map	.ply
LiDAR-Scanner	.ohj, .ply, .stl, .usdz

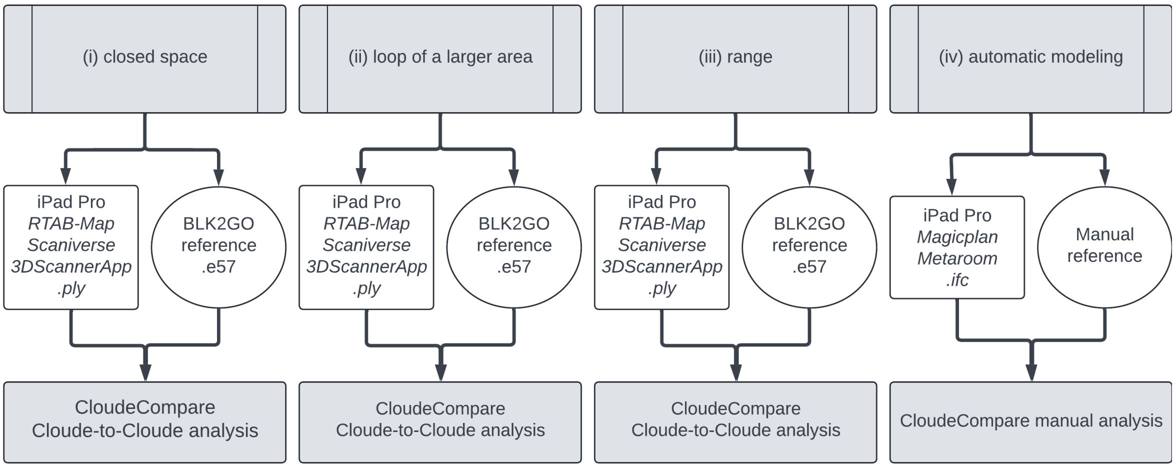

Figure 1: Sequence of the proposed experiments with implementation components, export formats and result analysis. The graphic applies to all experiments carried out in this work.

4 Results

Experiments (i) and (ii) were carried out in comparison with the professional BLK2GO system. In (i), an error was detected in the reference point cloud, shown in Figure 2, which influences the maximum distance of the point deviation. However, the error does not affect the average deviation of the point clouds, as it occurs consistently and only increases the error of the maximum distance. Apart from the error described above, the process was carried out quickly and efficiently using the iPad Pro. After aligning the scans from the experiment (ii), it became clear that the generated point clouds from the iPad Pro software applications are inherently distorted, as shown in Figure 3. The phenomenon of inclined positions would lead to major errors in the model in later modeling. For this reason, no modeling was carried out in this regard. Only by interpreting an assumed course of the spatial lines would the model become usable. In both cases (i) and (ii), the smallest deviations were found in the application of RTAB-Map.

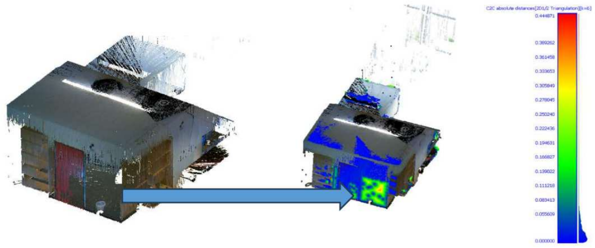

Figure 2: Error in experiment (i), showing a missing Wall in the scanned reference point cloud, scanned by the BLK2GO system, the error depends on the static scan process.

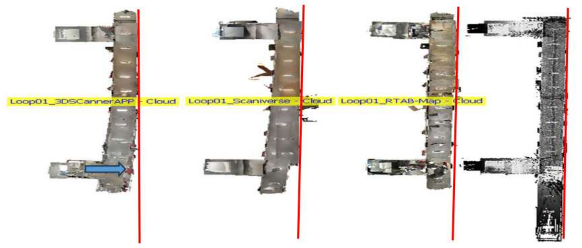

Figure 3: Scanned loops, out of experiment (ii). Shows the inclined positions, of the scanned point clouds. From left to right side: 3DScannerApp, Scaniverse, RTAB-Map, BLK2GO.

The experiment (iii) was evaluated by manually selecting points on the targets, shown in Figure 4. The left picture shows a point cloud, generated with the iPad Pro LiDAR, and the right side is a point cloud generated by the BLK2GO, to compare both clouds. The reference values for the distance between the targets were determined using a laser distance meter. During the experiment, it was also recognized that the LiDAR applications in the iPad Pro are no longer able to generate sufficient data from a distance of 3 m when used statically, shown in Figure 5. A dynamic approach was chosen for the further execution of the experiment (iii). The RTAB-Map application delivered again the lowest deviations.

Figure 4: Process of the manual measuring in the point clouds, between the used target markets in experiment (iii), to get the length between target markets in the Software CloudeCompare. From left to Right side: Scaniverse, BLK2GO.

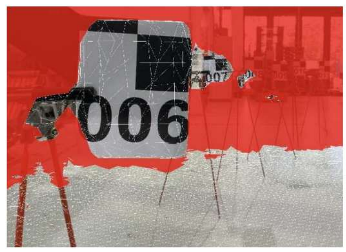

Figure 5: Example out of a static scan experiment, which didn´t work to get the length of 5 m, only 2 m. The density of the point cloud was too low, experiment (iii).

In experiment (iv), models were generated by a modeling process automated by the software using edge detection, shown in Figure 6. These models were compared with reference values using a laser distance meter. The iPad Pro was hand-held and dynamically moved through the room, to represent realistic use. A trivial geometry consisting of rectangular structures, a window, and doors was captured. No problems were encountered during the survey. In a second run, the detection of a structure with sloping roofs was evaluated. With the applications listed, it was not possible to capture the sloping structures and transfer them to an Ifc-model. The roof pitches are not shown in the model, see Figure 7, only the knee walls are shown. The interesting fact is that the edge detection and the storage of three-dimensional objects in the form of Ifc objects usually have higher accuracy than the point cloud for a closed recorded space.

Figure 6: An example, of how the automatic modeling process is shown in the App Metaroom, on the left side. On the right side an example of the Ifc-Model from the measured room, the same application and room.

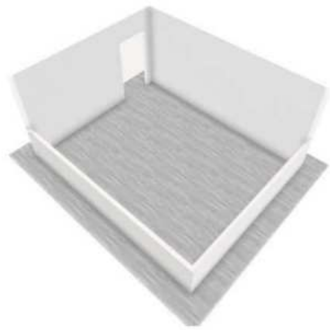

Figure 7: Exported Ifc-model, from experiment (iv), shows the knee wall and the missing sloped walls.

For the intended comparison between the professional system (BLK2GO) and the iPad Pro, meaningful values can be taken from investigations (i), (ii), and (iii). In general, the recorded deviations of the systems are far apart. The deviations of the iPad Pro range from 1.3 cm to 9.2 cm across all applications used, while for the deviations of the BLK2GO, the average deviations are within a narrow range of 0.1 to 1.03 cm. The applications for automated model creation are currently in an experimental state and are not suitable for commercial use. This is due to the limited possibilities for further processing and the lack of capabilities for recording more complex spatial geometries. However, according to the USGSA, the accuracy would be sufficient for an inventory in individual rooms for the Metaroom application. The results of the deviations are shown in the Table 2 presented.

Table 2: Evaluation results of all experiments, with a comparison of the results for existing work

Experiment	**Dim.** [m]	**Dev. Ref.** [cm]	**Dev.** [cm] USGSA	[cm] Producer	[cm] Luetz.	**Total** [cm]
(i) closed space all	5.4x4.6x2.6	1.90	± 0.6- ± 1.3	-	-	1.3-0.77
(i) Scaniverse	5.4x4.6x2.6	1.88	± 0.6- ± 1.3	-	-	1.28-0.75
(i) RTAB-Map	5.4x4.6x2.6	1.35	± 0.6- ± 1.3	-	-	0,75-0.05
(i) 3DScannerApp	5.4x4.6x2.6	2.48	± 0.6- ± 1.3	-	-	1.88-1,18
(ii) loop all	66x2,5x2,2	12-17	-	-	± 10	2-7
(iii) range Apple	1	1.8	-	± 0.8 for 50	-	1
(iii) range Apple	2	3.4	-	± 1.8 for 150	-	1.6
(iii) range Apple	3	3.4	-	± 5.3 for 300	-	1.9
(iii) range Apple	4	8.8	-	± 5.3 for 300	-	3.5
(iii) range Apple	5	9.2	-	± 5.3 for 300	-	3.9
(iii) range BLK2GO	1	1.03	-	± 1	-	0.03
(iii) range BLK2GO	2	0.1	-	± 1	-	-0.9
(iii) range BLK2GO	3	0.1	-	± 1	-	-0.9
(iii) range BLK2GO	4	0.9	-	± 1	-	-0.1
(iii) range BLK2GO	5	0.4	-	± 1	-	-0.6
(iv) Metaroom	4.3x4.4x2.7	0.3-1.3	0.6-1.3	-	-	-0.3-0
(iv) Magicplan	4.3x4.4x2.7	2.8-22.5	0.6-1.3	-	-	2.2-21.2

5 Discussion and Conclusion

The various tests have shown how the deviations of the LiDAR scanner in the iPad Pro turn out in rooms of different sizes or complexity. The results clearly reflect that there are still differences between the low-cost system of the iPad Pro and the professional system, the BLK2GO. The recorded deviations can also be verified with values from other related publications. Thus, from the perspective of the study (i), a statement by Teo and Yang [1] can be confirmed. It can be concluded that the iPad Pro is suitable for recording point clouds in rectangular, single rooms. However, it should be noted that the accuracy of these point clouds are not sufficient according to the USGSA. When recording loop (ii), the tolerance is exceeded many times over, which is why this investigation is not discussed further in connection with such a statement. An average deviation of 14.9 cm was achieved in the examination of loop (ii) from the corridor. In terms of accuracy alone, this appears to be an acceptable deviation in the point clouds. It should also be noted that it is difficult for algorithms to ensure the correct alignment of point clouds in corridors, for example. In the evaluation of the experiment, it was also determined that the point clouds recorded using the iPad Pro are twisted within themselves. Based on this observation, it does not make sense to use (ii) for subsequent modeling. In the evaluation and segmentation of point clouds, there are many different approaches for increasing efficiency using AI. However, there is a lack of an overall standardized approach to the parameterized building model according to the BIM-concept. There are also AI applications for analyzing buildings from point cloud data and for processing as-built plans into BIM-models. In further research, the entire procedure for automated model creation from point cloud data could be viewed from a new perspective. Does the data have to be represented as currently known parameterized components or is a mesh/volume-based approach within the point cloud with the addition of the required semantic information sufficient? Furthermore, the automatic creation of models should be considered, with regard to the possibilities of data set generation for machine learning. By scanning with iPad Pro per LiDAR, a model and the corresponding point cloud of trivial structures can be generated directly. In coming research articles we take a look into getting clean point cloud Data from the commonly available AI models. We are going to train and test the commonly available AI models for as-built survey construction with these data.

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