COMPARISON OF BUILDING SCANNING METHODS

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Abstract

Surveying of buildings can be done digitally/by digitizing. The current technology offers various scanning options and methods. This paper concentrates on scanning of buildings by means of three different scanning methods. By comparing them, final point clouds can be optimized. The result of this scientific work is an evaluation of the most efficient scanning method in terms of time, cost as well as quality. In conclusion, practical guidance is presented for selecting the most appropriate scanning method for specific types of buildings.

Keywords

Terrestrial laser scanning, LiDAR, trigonometry, point cloud

1 INTRODUCTION

Contemporary science and technology allow us to create and materialize real spaces. We have a wide range of options for creating 3D models of interior spaces or even entire buildings. It is possible to scan a space without having to survey it manually.

In the last decade, improvements in surveying techniques (e.g. Terrestrial Laser Scanning - TLS, close range photogrammetry) and in digital data processing and management have allowed to collect different kinds of information about Cultural Heritage objects [1].

The most advanced methods include scanning in 3D which is used for accurate and large objects nowadays. However, due to its short time on the market and its cost, its use has been a research challenge. As technology advances, cheaper measuring, targeting and even scanning methods emerge, and it should be noted thatcheaper does not necessarily mean poor quality. This article aims to compare validated scanning with cheaper 3D scanning options.

2 METHODOLOGY

The aim of this work is to compare three different scanning methods from different aspects and to determine which one is the most efficient. This process involves evaluating the time, accuracy and quality of the resulting point cloud, defining in detail the advantages and disadvantages of each method. The methodology is designed to allow an objective comparison of the technologies and to provide recommendations for their appropriate application to different types of spaces. Emphasis is also put on comparison of point clouds and their precise placement between scans.

As registration of the 3D data to the 3D CAD model is the first—and therefore the most basic—step in the process, any inaccuracy in the placement of the 3D data points into the 3D CAD model could have a negative effect on the subsequent use of the registration results, such as in the matching and comparison of the points in the two data sets [2].

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Scanning methods

Three different scanning methods were selected:

- Faro Laser Scanner's static 3D scanner is characterized by high scanning accuracy and speed, making it ideal for challenging objects with complex geometries.
- Scanning with iPhone 14 Pro, using the LiDAR sensor, is an affordable technology that is easy to use through apps and provides reliable results for simpler models.
- Microsoft HoloLens virtual reality headset, combining augmented reality with 3D scanning, enables an interactive environment and specific use in advanced digital projects.

Each of the three selected methods was applied to the same room to minimize external influences and ensure objectivity of the results. The scanning process involved calibrating the equipment, setting the optimum parameters for the space and accurately capturing the details of the space.

As stated above, the main objective of the research was to compare the expensive and some other rather less expensive surveying technologies. During the scanning process, the time requirements for each method, their ease of use, processing speed and potential technical problems were documented. This information was used to evaluate the overall efficiency of each method.

Point cloud creation

Three-dimensional modelling and representation through laser scanner surveys is a widely used method in the field of architecture and cultural heritage. Through this approach, geometry and appearance of real objects can be recorded with high level of detail and accuracy [1].

All modern laser scanners use LiDAR sensors. The Light Detection And Ranging technique (LiDAR), also called 3D laser scanning, measures distance by sending laser light to the object and calculates the differences of laser return times, signal strength, frequency variation and other parameters. Basedon the differences, three-dimensional shapes of the object are reconstructed [3]. The scanner sends a laser beam towards the object (Fig. 1), which reflects it back to the device [4].

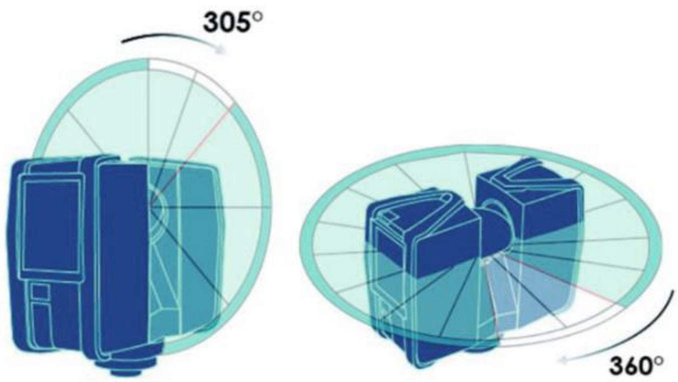

Fig. 1 Vertical and horizontal measuring range of the laser scanner used [5].

The LiDAR sensor must have a direct view of its surroundings. It emits laser beams that reflect off surfaces and return. Thanks to the measured time required for the reflected beam to return, a given device, such as a smartphone, is able to accurately define the distance of a specific point of an object from the camera. This is the basis on which the ToF (Time of Flight) method is constructed. LiDAR is faster and more accurate than ToF sensors, mainly due to the fact that it forms a complex cluster of points in space, the so-called 3D point cloud [6].

These sensors scan the space and create a point cloud. A point cloud is a large number of points from space, from walls and other reflections. They are not surfaces, but points from the surfaces captured in the scan. The denser the point cloud, the more accurate the output data are.

Point clouds can be used as a design background in programs such as AutoCAD, Navisworks or Inventor Professional. In 3D modelling programs, for example Revit or ArchiCAD, a point cloud is a base layout for which it is possible to set views of projections, sections, perspectives or axonometry [4].

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Description of the room

The selected digitized room is a space in the historical building of the Faculty of Civil Engineering. It is located in the campus of the Technical University of Košice. It is a high-equipment room with digital technology which enables digitizing the environment, faculty promotion, measurements and other scientific activities. It serves as the Centre for Digital and Virtual Technologies.

The scanned room has a simple geometric shape of a rectangle (Fig. 2). It has glass/light-transmitting windows and doors on two sides. At the entrance of the room, there is a glass wall with perforated membrane and a double-leaf door. The glass wall is double-glazed for acoustic reasons. It was this wall that caused complications in the scanning during the comparison, mainly due to reflections producing duplicated and inaccurate results.

There are windows facing the exterior opposite this wall. The room is located on the third floor of the Faculty of Civil Engineering of TUKE. It is furnished with simple furniture with a lot of small details.

An important parameter in comparing the measurement methods was the same space, with the same lighting conditions.

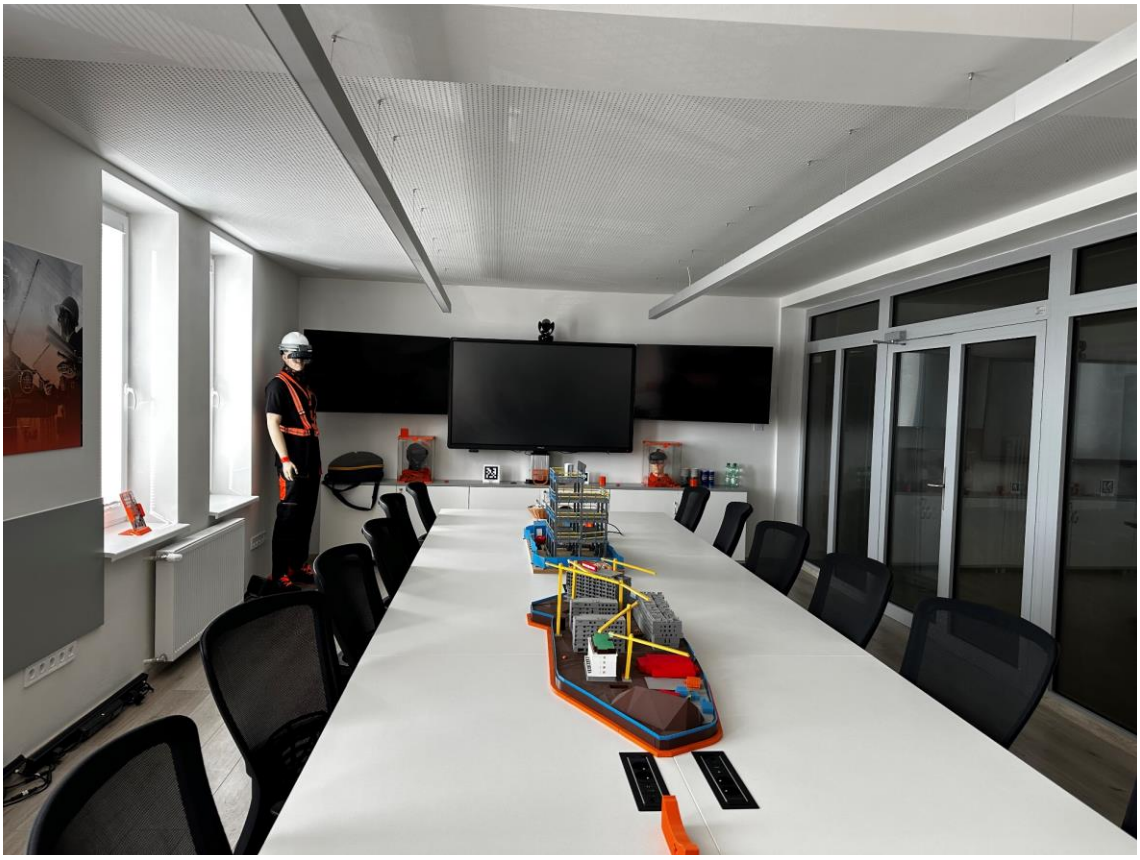

Fig. 2 Photo of scanned room.

3 RESULTS

Data analysis focused on the quality of the resulting point clouds, their detail and consistency, identifying differences caused by the technical limitations of the individual scanners. At the same time, key aspects such as the quality of the outputs, the differences between the various scanning methods and their advantages and disadvantages were examined. The aim was to obtain a comprehensive picture of the efficiency and accuracy of the technologies used.

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Scanning with a professional scanner

The first scanning device chosen was a FARO Focus 3Dx130 professional ground scanner. This scanner is one of the most precise and efficient tools for capturing detailed data in indoor and outdoor areas. It is equipped with LiDARr technology, which enables highly precise distance measurements using a laser ray.

The scanner was placed on a tripod in the room and scanning was done from one position only. The scan profile was set to Indoor 10m with 1/8 resolution and 4x quality. The scan took 3 minutes and 44 seconds, with the resulting scan size being 5120 × 2205 pixels with a total of 11.3 MPts. The point spacing was 12.272 mm at a distance of 10 meters.

The data obtained from the scanner were processed in the specialized software FARO Scene. This software ensured the registration of the data with the creation of the corresponding point cloud. During the analysis of the point cloud (Fig. 3), it was found that the glass wall with the overlay caused problems with the correct recognition of the reflections (Fig. 4). As a result, the scanner produced duplicate data reflected from the glass wall.

Fig. 3 Point cloud created by terrestrial scanner.

In spite of that, the detail of the point cloud was still high and even small details of the room can be seen in the point cloud. The scan time was relatively short, the scan itself took 3 minutes 44 seconds. However, assembling and disassembling the device required approximately 10 minutes, while data processing accounted for an additional 20 minutes of time.

The total time required for scanning, data registration and point cloud creation was approximately 30 minutes. In addition to the point cloud, the scanner also produced a detailed 360° image of the room, which can be used for visual analysis or presentation of the area.

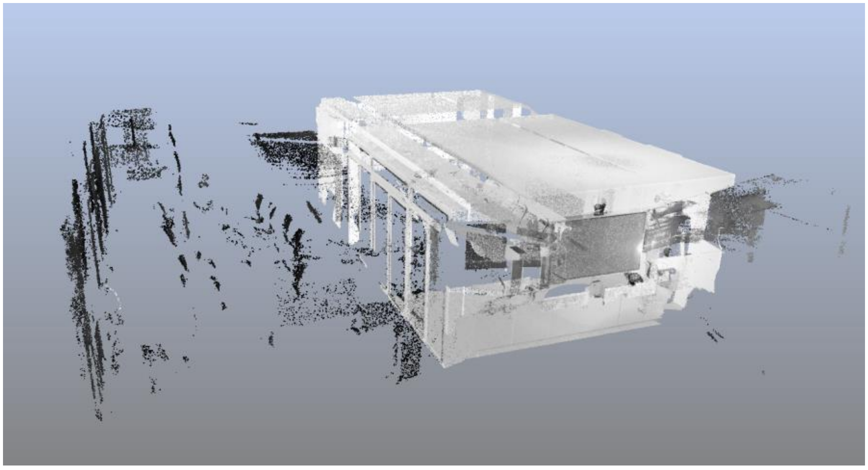

Fig. 4 Duplicate data in the point cloud.

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Scanning with a mobile phone

Scanning of buildings or spaces can also be done by using cheaper equipment, e. g. mobile devices by Apple. In 2020, the Apple company was the first to integrate the LiDAR remote sensor into mobile phones. [6].

The company considered improving photos without digital editing. Their intention was also to capture the depth of the subjects during capture. In this way, they create a depth map. A depth map is like an image; however, instead of each pixel providing colour, it indicates the distance from the camera to that part of the image (either in absolute terms or relative to other pixels in the depth map). The depth map can be used along with the photo to create image processing effects that process differently the foreground and background elements of the photo, such as the Portrait mode in the Camera app on iOS [7]. In this way, the company was able to create a blurred background effect using the LiDAR sensor.

The use of the system is interesting for other purposes as well. The data that it provides is suitable for many applications but may not meet the needs of those that require greater depth accuracy. Starting with iOS 15.4, it is possible to access LiDAR on supported hardware, which offers highly accurate depth data suitable for use cases, such as scanning and room measurement [8].

The applications use the cameras and especially the LiDAR sensor. The priority is to measure the distance from the phone to the object. At the same time, they also use the camera to create surface textures. The cameras take pictures of the elements directly as scanning takes place. Scan are transferred to the space. This also gives the textures of individual objects.

During the scanning of the selected room, a commercially available application (3D Scanner App) was selected. The app offers a wide range of scanning, settings and also a large number of export options. Using the mobile device, it is simple to turn any object or space into a 3D model. After scanning, we can measure the room dimensions, as shown in Fig. 5 in the application.

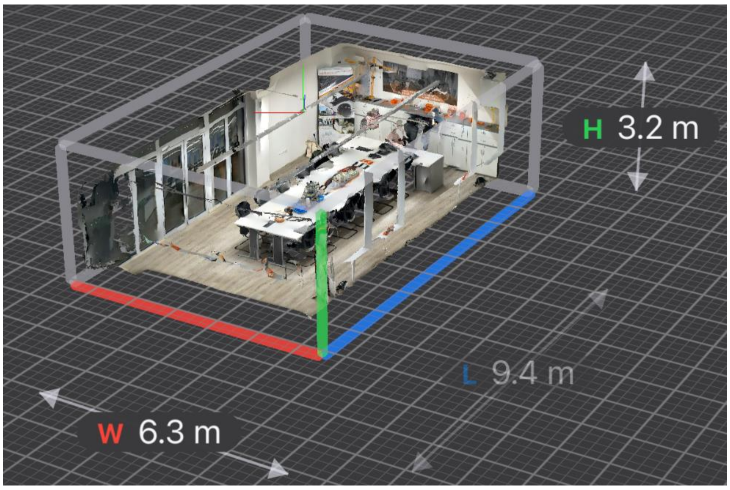

Fig. 5 3D model created by smartphone with room sizes.

Scanning with the smartphone was performed immediately after turning on the app. The scanner has to move the smartphone around the room and track the objects captured on the app. The motion trajectory during scanning is captured in Fig. 6, represented by the blue line. Uncaptured of areas, spaces are marked in red. For a complete scan, it is necessary to carefully scan every corner of the space, occasionally traversing all areas several times. The captured distance from the device is a maximum of 5.0 m.

The space capture (as shown in Fig. 7) took approximately three minutes. Subsequently, data processing is enabled on the smartphone to add the colour data captured by the camera and a model is created with the texture of the space as well.

Processing took approximately 1 minute with HD texture. The total file size is 510 MB. However, when exporting according to the type of exported file, the size is lower. For a standard file type such as .obj ~ 15 MB. The resulting scan had 372,000 × 578,000 pixels, number of images: 343. The point spacing was 15 mm at a distance of 5 meters.

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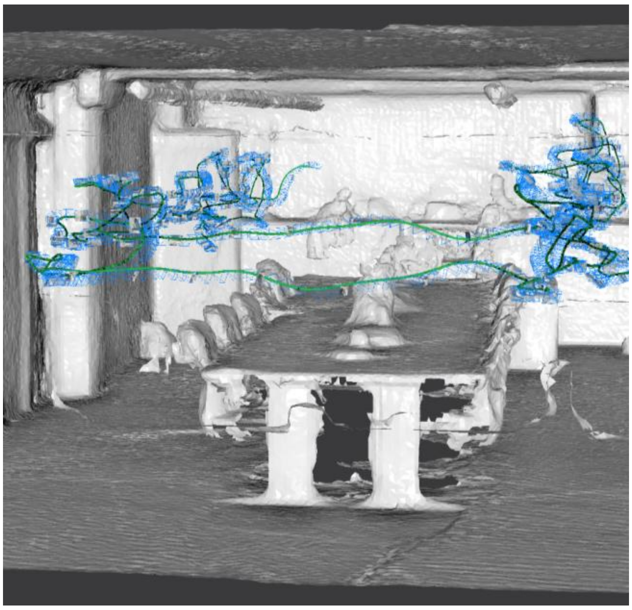

Fig. 6 Model created by a smartphone, without texture, with the scan trajectory marked.

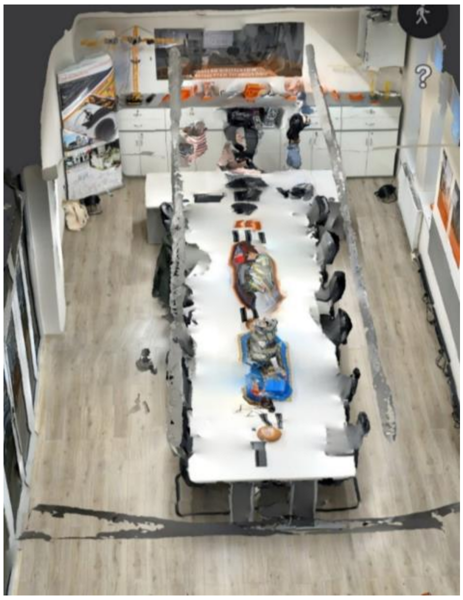

Fig. 7 Model created with smartphone and with texture.

Scanning with MR vision devices

The third method of scanning was using Microsoft HoloLens 2 mixed reality glasses. This eyewear is equipped with advanced sensors and technology that allows for real-time capture of the environment. The Mixed Reality HoloLens 2 as a scanning tool was used in order to achieve an intuitive, fast and universal experience [9]. The device works on the principle of trigonometry, where geometric relationships and angles between the sensor and the reflected point are used to calculate distances between points. This technology allows the creation of simple 3D models. The room was scanned using the glasses fitted to a real person moving around the room. The person had to turn their head to capture all the details. The glasses scanned through built-in sensors, with the scan result only visible through the connected computer.

The glasses were connected to the computer through a common network and a VPN address. An instruction was given on the computer to start the scan. Once all details were captured, the scan was completed and the resulting simple model of the room was immediately visible on the screen of the connected computer. The resulting model was able to be exported in .obj format (Fig. 8).

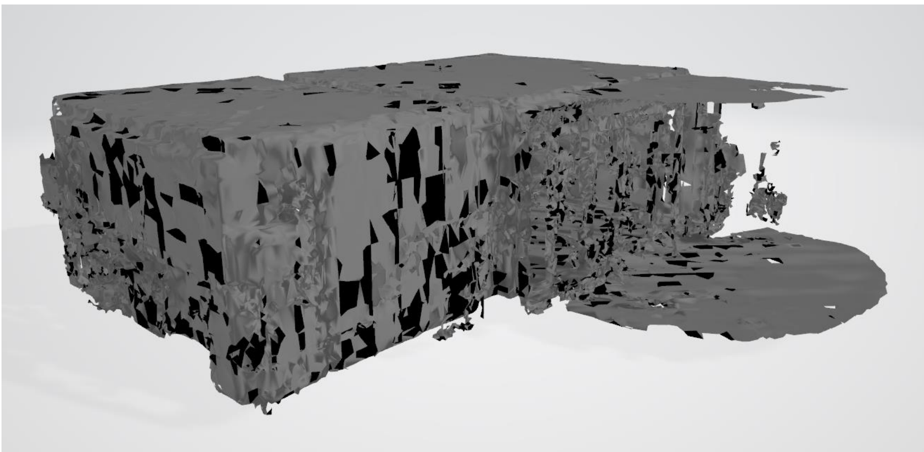

Fig. 8 3D model (data volume) created by scanning with MR glasses.

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Scan detail was generally low, due to limitations of the technology and the relatively simple method of data capture. Nevertheless, the shape of the room and larger details such as doors, windows and furniture were recognisable. The scan was black and white, which provided a basic visualisation of the space only. In the point cloud analysis (Fig. 9), it was possible to observe empty spaces in places where the glasses could not adequately capture data, such as in the corners of the room or on small surfaces. Even scanning through the augmented reality glasses had trouble to correctly discern the reflection in the glass wall. They did not define the glass and recorded data outside the scanned room.

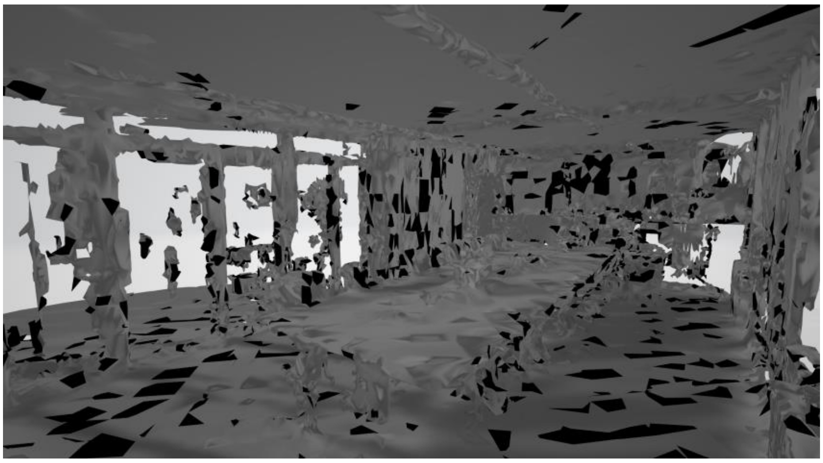

Fig. 9 3D model of the interior created by scanning with MR glasses.

The scanning process was very quick and took about 10 minutes. During this time, the glasses captured all the essential parts of the room. The data processing time was almost negligible, with the creation of the basic 3D model taking approximately 5 minutes. The total time required for scanning, data processing and model creation was thus only 15 minutes, making this method efficient for fast capturing the basic geometric data of a room.

4 DISCUSSION

Scanning the room produced recognizable results for the research (Tab. 1). All scanned data were applicable for possible visualization of the room or for further modelling in a 3D environment.

Tab. 1 Result comparison table from measured spatial scans.

Device	Total scan time (minutes)	Precision (mm)	Measured range (m)	Captured texture	File size (MB)	File size in .RCP format (MB)	Equipment price (EUR)
Static 3D scanner FARO	**34**	12.3	10	YES	251.43	323	9000~40000
Mobile phone	**4**	15	5	YES	510	40.2	1000
Virtual glasses	**15**	80	3	NO	19.68	10	4000 ~7700

The professional scanner achieved a high level of precision, with minimal distance between points within the point cloud. The processing time was slightly longer than for the other scans. The main reason for the prolonged scan was the tripod layout and the positioning of the scanner on the tripod. A large amount of data had to be processed through paid software. This factor in the analysis may discourage potential users. The high precision professional scanner produced an accurate scan even with additional pictures. The disadvantages of the scanner include the high purchase price, the paid software and the need of using a tripod.

Mobile phone scanning is not a widely used method. Very few smartphones have these scanning features. It is necessary to have a LiDAR sensor in the mobile, which is only found in Pro versions of iPhones. These smartphones are in a more expensive price range compared to other smartphones. Nevertheless, compared to scanning devices, their price is still very affordable. In fact, it is much lower than the price of other scanners. The

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accuracy between the measured points is very similar to that of a professional scanner. Thus, in terms of both precision and price, this device surpasses the other ones. The distance between points in the point cloud is low and the model appears to be of high quality. However, this does not mean that the recorded points are in the correct location. Therefore, as the table shows, its accuracy is comparable to that of a professional scanner. Moreover, the software is freely available. The disadvantage of the device is that the scanning can only be conducted up to a distance of 5.0 meters. Also, it is necessary to walk around with the scanner while scanning and capture every corner, angle or other features. Therefore, the quality of the data acquired largely depends on the skills of the person operating the device. The most advantageous parameter is that the device is easy to carry because of its small size and the possibility of wide use in addition to scanning. Furthermore, scanning with a mobile device has another advantage. When GPS is enabled, the scan is georeferenced. The model then contains data from the coordinate system.

Virtual glasses offer virtual tour possibilities. Thanks to sensors for distance resolution in space, the glasses can also scan the space itself. The glasses were able to process the space data quite quickly. However, their accuracy was not completely precise, it was rather indicative. The polygons that made up the model were 10 × 10 cm in size. They were not very attractive in terms of their price either. But if the owner of this device needs to perform scanning, it can still be considered an option.

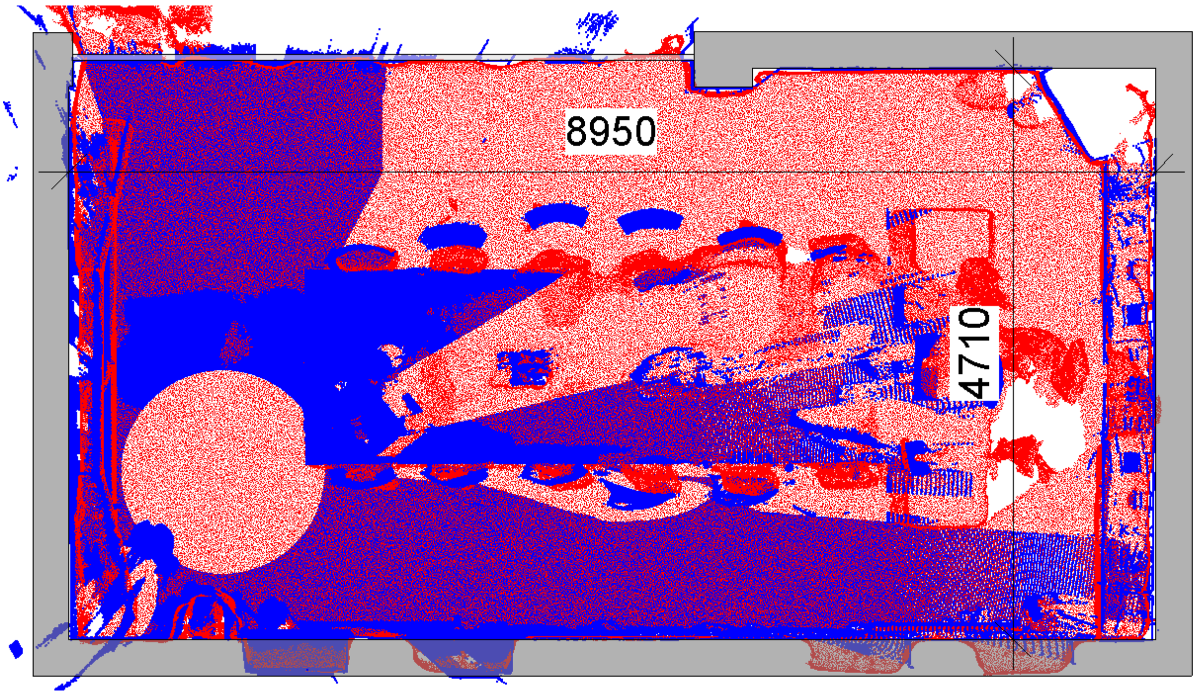

Fig. 10 Comparison of point clouds, displayed in view.

The point clouds from the FARO scanners and the mobile phone were exported to Autodesk Recap, where they were saved in RCP format. They were then compared in REVIT. This is shown in Fig. 10 as a floor plan of the measured room. The blue colour indicates the point cloud from the professional FARO scanner. This scan showed almost zero deviation and can be used to correctly and accurately draw the room or object. On the other hand, the red colour indicates the point cloud from the mobile phone. This scan has significant deviations, especially in the corners. However, even this scan can be used to draw the space, as the main dimensions of the room, windows and other objects in the space are captured. Problems are visible on flat surfaces or in a few corners only. This scan is created by the gradual movement of the person working with the mobile phone, which is why it depends on the person rather than on the device.

Scanning with a mobile phone is suitable for lower-cost scanning, yet it is not accurate. The point cloud from the virtual glasses was not exported or compared since it is only possible to export the mesh and also due to the large deviations between the scanned points.

5 CONCLUSION

All devices were evaluated in terms of scanning, price, precision and quality. The devices are also designed for scanning, but there are two multi-purpose devices being compared. The advantage of the multi-purpose devices is that the owners do not primarily use them for scanning only. The most affordable is namely a mobile phone with a scanning feature. In terms of precision, it is the professional tester static scanner. In terms of accurate and detailed scanning of historical or other detailed objects, it is advisable to use a professional static scanner. In terms of scanning space as a proportional model and dimensions, it is possible to use virtual glasses or a mobile phone. From a practical - more multi-purpose and cost point of view, it is advantageous to use a mobile phone as a scanning tool. To improve the scanning quality, it would perhaps be worth considering to purchase a paid application with enhanced capabilities.

This research has enriched the understanding of digital technologies. In the description, it highlights possible cheaper and quite accurate scanning options. Scanning of large buildings is different from scanning of small objects. The purpose of use is the most important factor. Depending on the desired result of the scanned point cloud, it is necessary to use the selected device designed for this purpose. If it is necessary to perform a precise measurement to digitize the space for the purpose of distorting the actual situation, it is necessary to use precise measurement. In this case, a static scanner or, for small rooms, a mobile device can also be used. If the purpose of use is to visualize a space, it is also possible to use cheaper, less-precise scanning devices.

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