XXVII FIG CONGRESS
11–15 SEPTEMBER 2022
Warsaw, Poland

Volunteering for the future – Geospatial excellence for a better living

Presented at the FIG Congress 2022,
11-15 September 2022 in Warsaw, Poland

Evaluation of the LiDAR in the Apple iPhone 13 Pro for use in Inventory Works

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PLAN

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Study areas

Colored point cloud view of the section of an office room scanned by the iPhone 13 Pro

Colored point cloud of a fragment of the main hall of Warsaw University of Technology scanned by the iPhone 13 Pro

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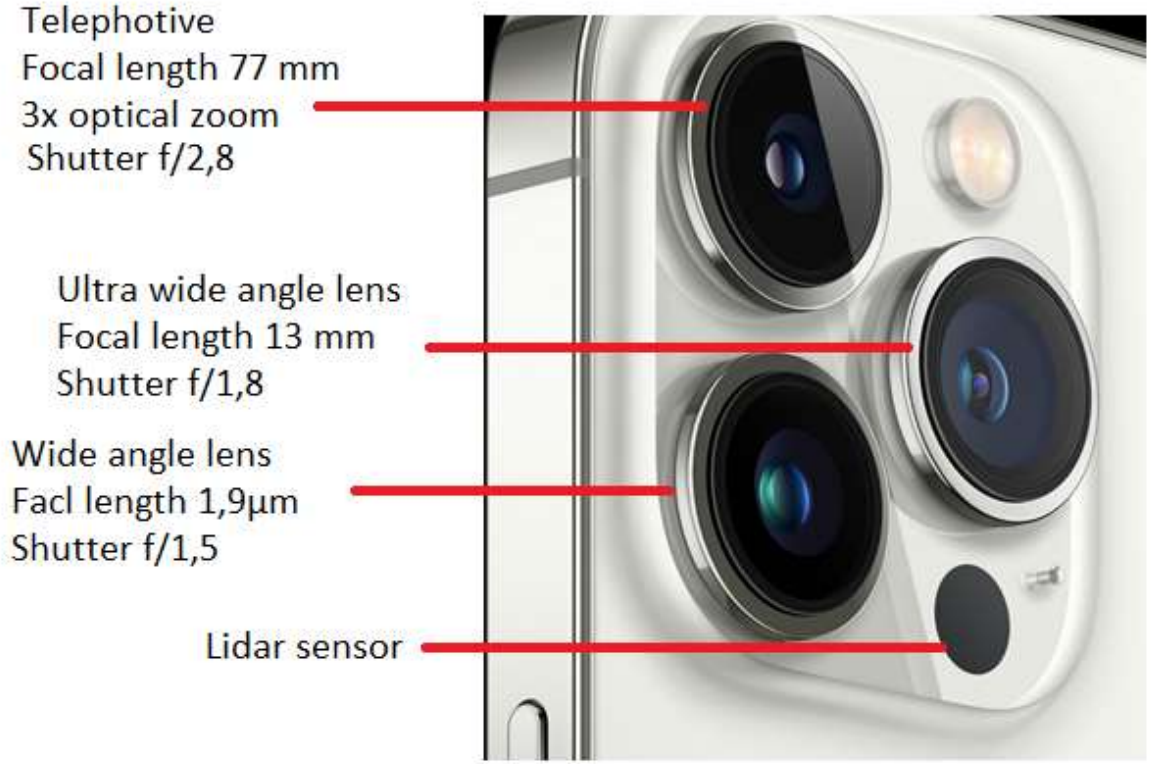
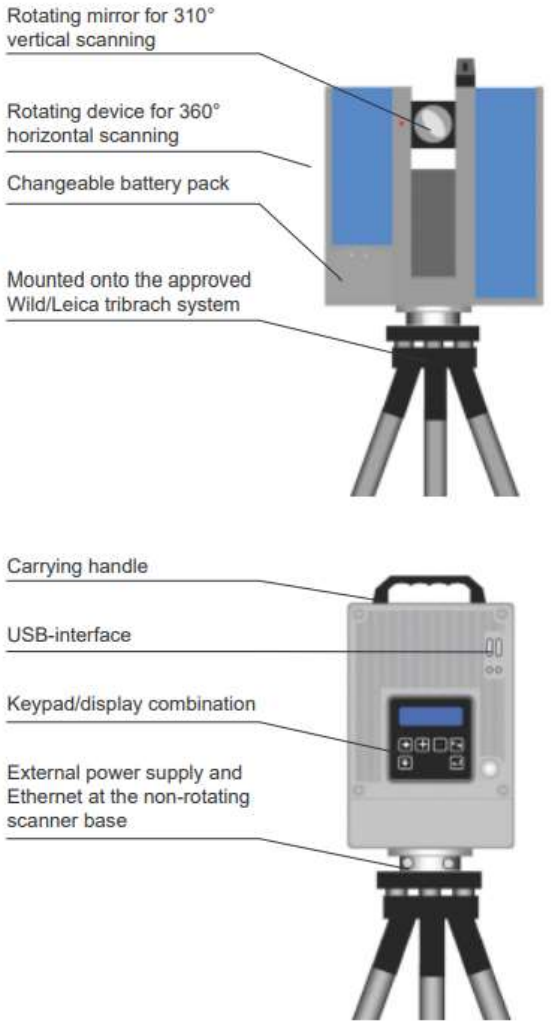
Instrumentation and data collection - Apple's iPhone 13 Pro - device under test



Basic data	
Display	6.1", 2532 x 1170px, OLED, Super Retina XDR
Built-in memory [GB]	128
Camera LED lamp	Rear 3 x 12 Mpx, Front 12 Mpx Yes
Processor model Number of processor cores Operating System System version	Apple A15 Bionic Six-core iOS iOS 15
Camera functions	Bokeh effect, Geolocation, HDR with Dolby Vision support, Optical Image Stabilization, Panorama, Red-eye reduction, LiDAR, Wide angle lens, Telephoto lens, Night mode, Portrait mode, Ultra wide angle lens, Continuous shooting
Physical Specifications	
Thickness [mm] Width [mm] Height [mm] Weight [g]	7.65 71.5 146.7 203

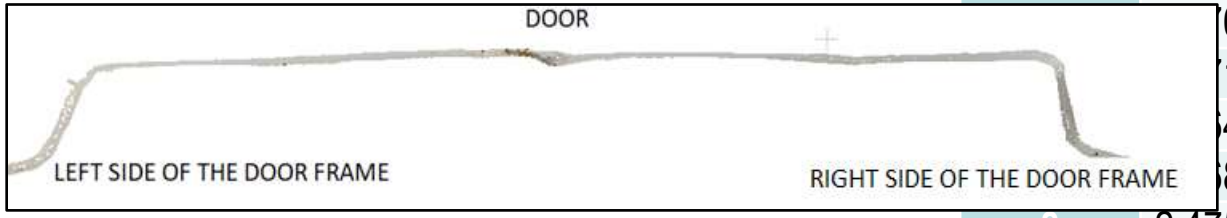
Instrumentation and data collection - Z+F 5006h terrestrial laser scanner - reference device



Ambiguity interval:	79 m
Min. range:	0.4 m
Resolution range:	0.1 mm
Max. data acquisition rate:	1,016,727 pixel/sec
Linearity error up to 50 m:	≤ 1 mm
Range noise at 10 m: - Reflectivity 10% (black): - Reflectivity 20% (dark grey): - Reflectivity 100% (white):	 1.2 mm rms 0.7 mm rms 0.4 mm rms
Resolutions: - Preview - Middle - High - Super high - Ultra high	Scanning time: - 25 sec - 1 min 40 sec - 3 min 22 sec - 6 min 44 sec - 26 min 44 sec
Illumination:	All conditions from darkness to daylight
Dimensions and weights Scanner (w x d x h)/weight:	286 mm x 190 mm x 412 mm/14 kg

Accuracy of selected object dimensions in the point clouds

Horizontal section of a door frame scanned with iPhone 13 Pro



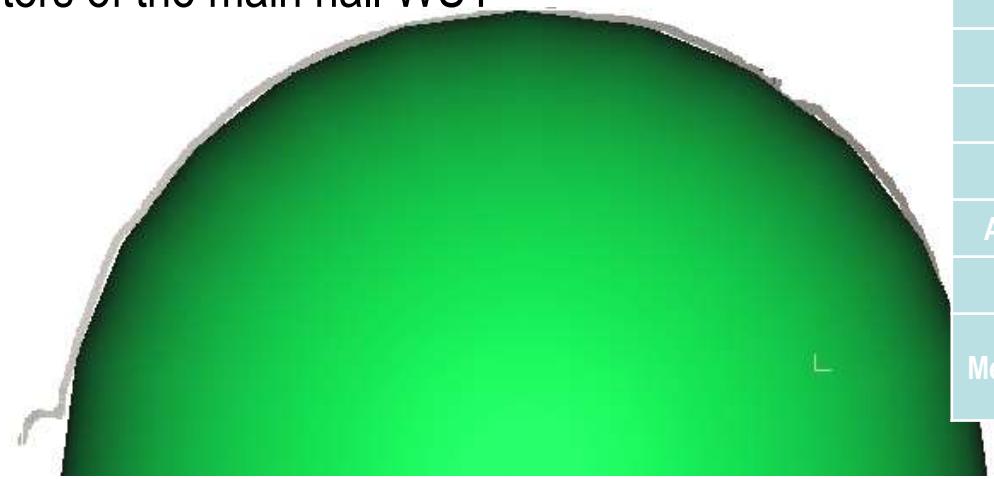
From an office space, the height and width of the room and the doorway were selected as typical dimensions

Element to be measured	Dimensions of entrance door frame interior opening				Basic room dimensions			
	Height [m].		Width [m].		Height [m].		Width [m].	
	iPhone 13 Pro	Z+F 5006h	iPhone 13 Pro	Z+F 5006h	iPhone 13 Pro	Z+F 5006h	iPhone 13 Pro	Z+F 5006h
1	2.476	2.486	1.291	1.305	4.339	4.396	3.376	3.347
2	2.474	2.475	1.266	1.307	4.396	4.395	3.389	3.344
3	2.475	2.477	1.286	1.305	4.332	4.391	3.376	3.349
	0	2.482	1.267	1.305	4.352	4.392	3.377	3.356
	1	2.475	1.272	1.307	4.349	4.394	3.360	3.341
	4	2.480	1.258	1.306	4.342	4.392	3.359	3.350
	8	2.481	1.286	1.305	4.355	4.407	3.351	3.355
8	2.475	2.477	1.257	1.306	4.352	4.406	3.364	3.345
9	2.478	2.477	1.283	1.307	4.358	4.398	3.353	3.358
10	2.472	2.480	1.292	1.304	4.338	4.382	3.361	3.349
Average	2.472	2.479	1.276	1.306	4.351	4.395	3.367	3.349
SD	0.001	0.001	0.004	0.000	0.006	0.002	0.004	0.002
Mean error	0.004	0.003	0.013	0.001	0.018	0.007	0.012	0.005

Accuracy of selected object dimensions in the point clouds

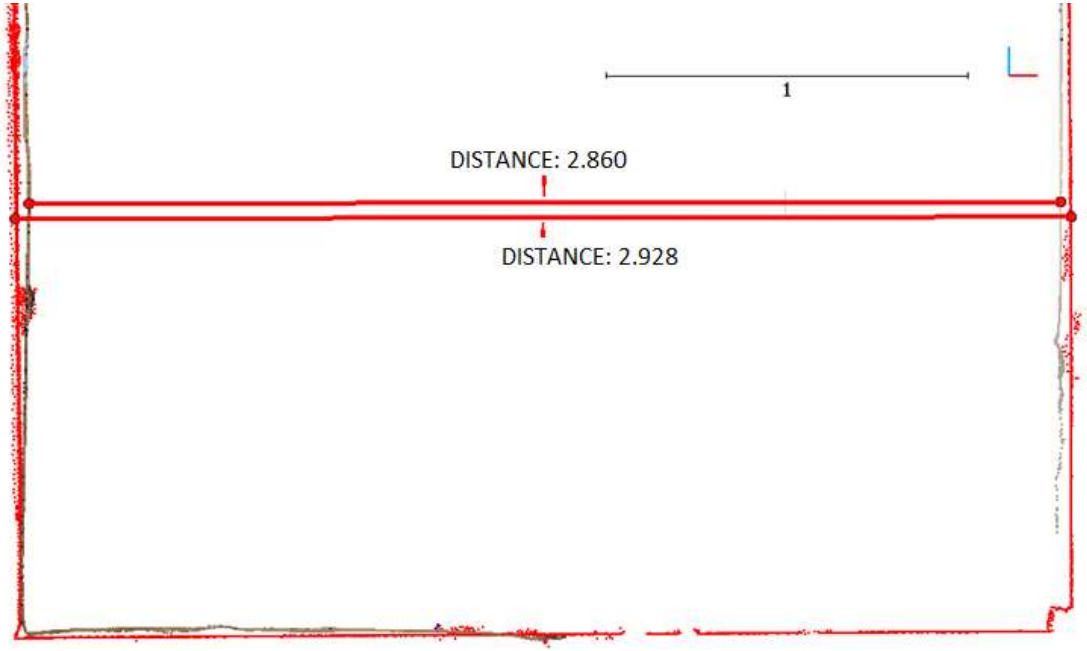
From a main hall architectural details such: the chord length between the start and end points of the arch, the height of the arch, and the radius of the arch were measured.

View of a fragment of the circle fitted into a cross-section of the point cloud from the iPhone 13 Pro representing an arch in the lintel of the cloisters of the main hall WUT

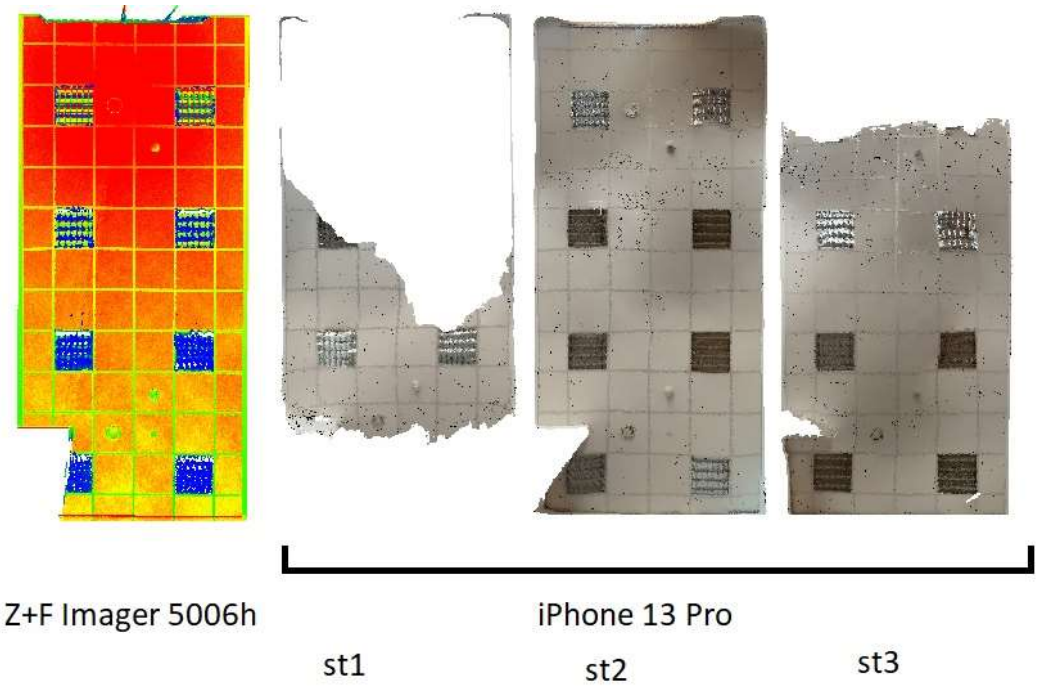


Element to be measured	Length of the chord between the start and end points of the arc		Arch height		Curve radius	
	iPhone 13 Pro	Z+F 5006h	iPhone 13 Pro	Z+F 5006h	iPhone 13 Pro	Z+F 5006h
1	1.921	1.943	0.868	0.878	1.011	0.972
2	1.901	1.940	0.874	0.876	0.985	0.971
3	1.922	1.929	0.868	0.876	0.930	0.971
4	1.923	1.929	0.870	0.878	1.000	0.971
5	1.939	1.919	0.873	0.870	0.987	0.971
6	1.924	1.912	0.871	0.876	1.013	0.971
7	1.944	1.932	0.867	0.876	0.992	0.973
8	1.929	1.922	0.879	0.871	0.975	0.976
9	1.919	1.914	0.872	0.887	0.987	0.973
10	1.935	1.931	0.877	0.880	0.990	0.974
Average	1.927	1.927	0.871	0.877	0.988	0.972
SD	0.004	0.003	0.001	0.001	0.007	0.001
Mean error	0.012	0.010	0.004	0.004	0.023	0.002

Direct comparison of two points clouds



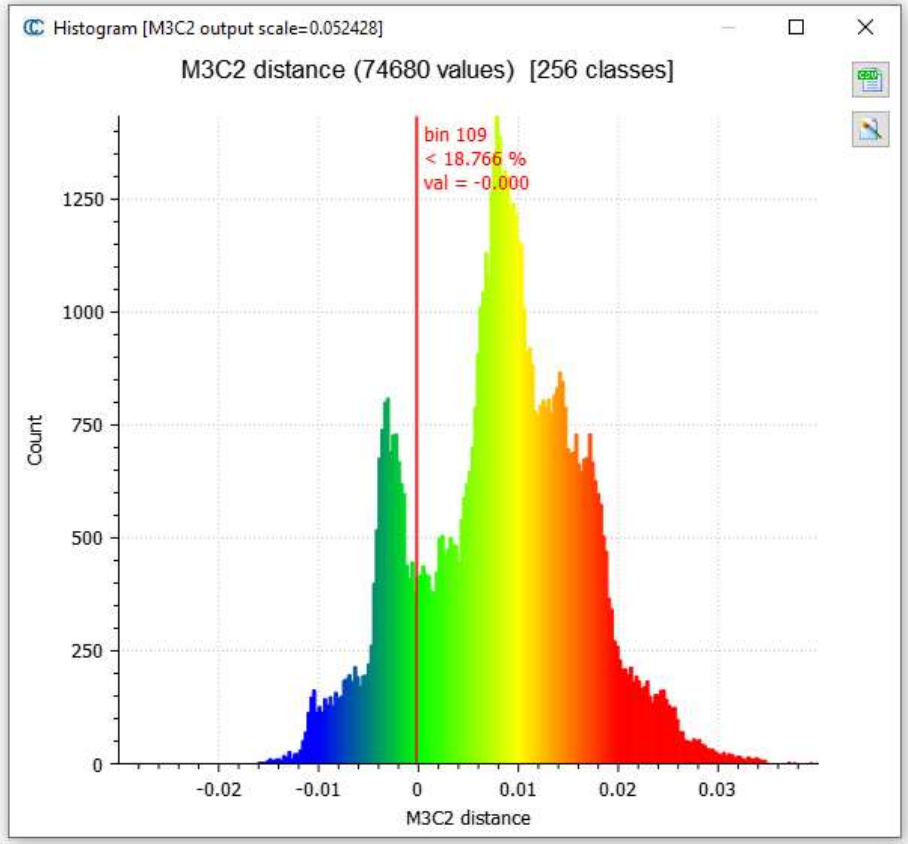
Example cross-section through the point clouds of an office room showing the differences in registered points. The point cloud from the Z+F 5006h is in red and the one from the iPhone 13 Pro in real color

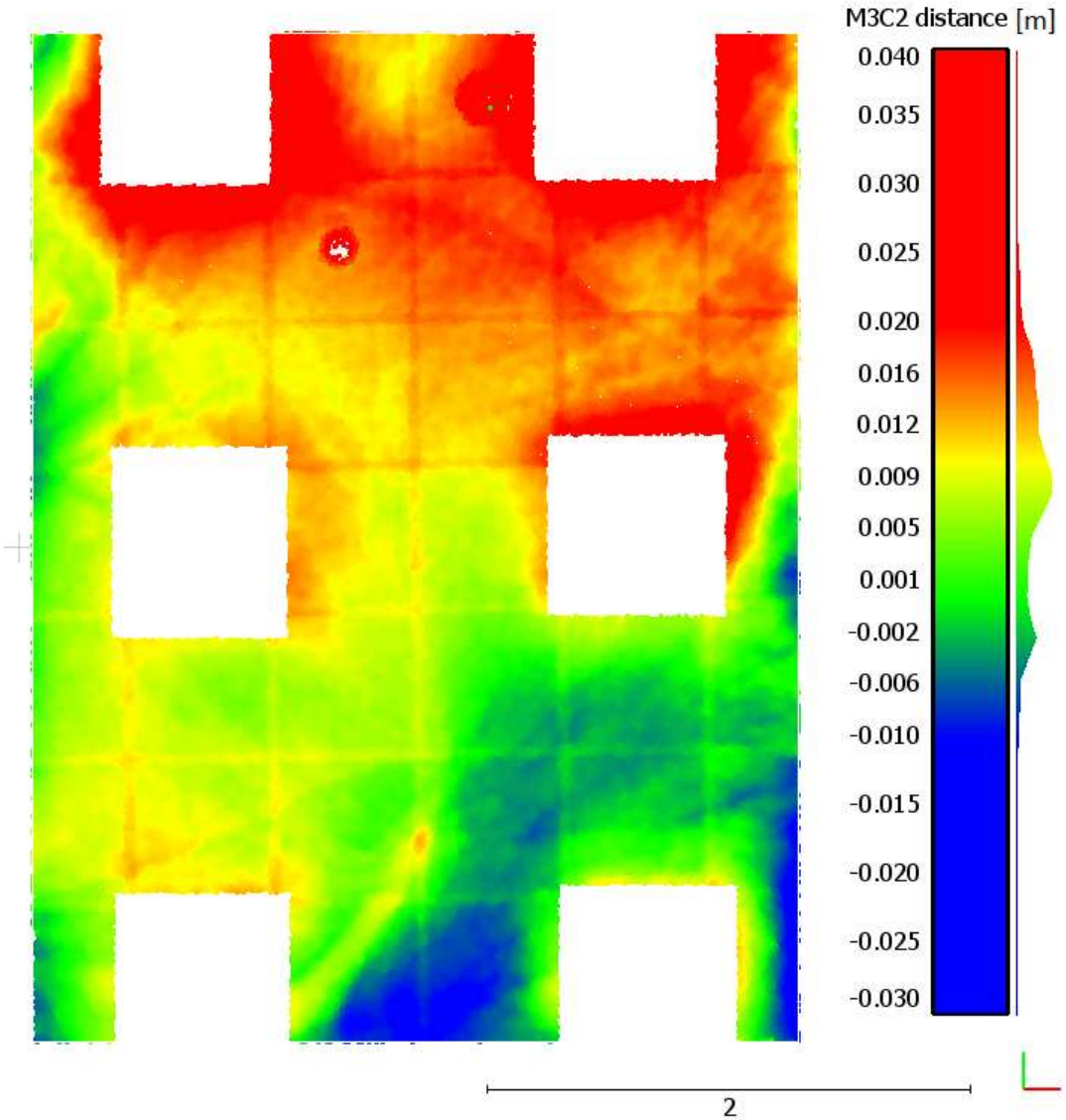


Ceiling view of the office room: point cloud from the Z+F 5006h and from three stations registered with the iPhone 13 Pro

Direct comparison of two points clouds

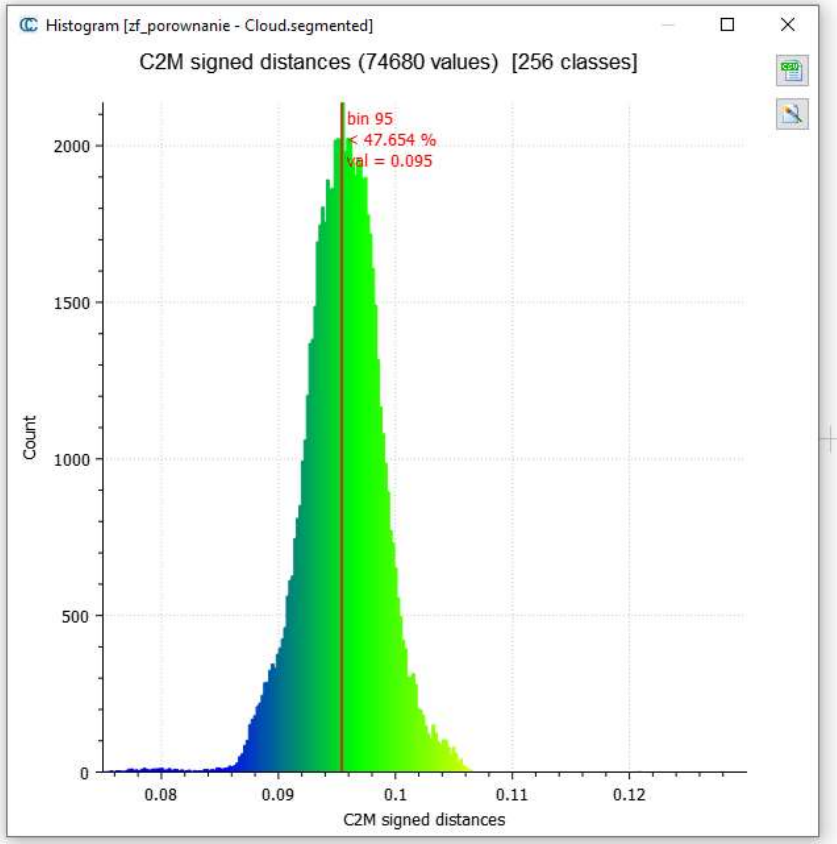
M3C2 algorithm comparison of point clouds for a section of the office room ceiling. The reference cloud was acquired with the Z+F 5006h, the study cloud was from the iPhone 13 Pro

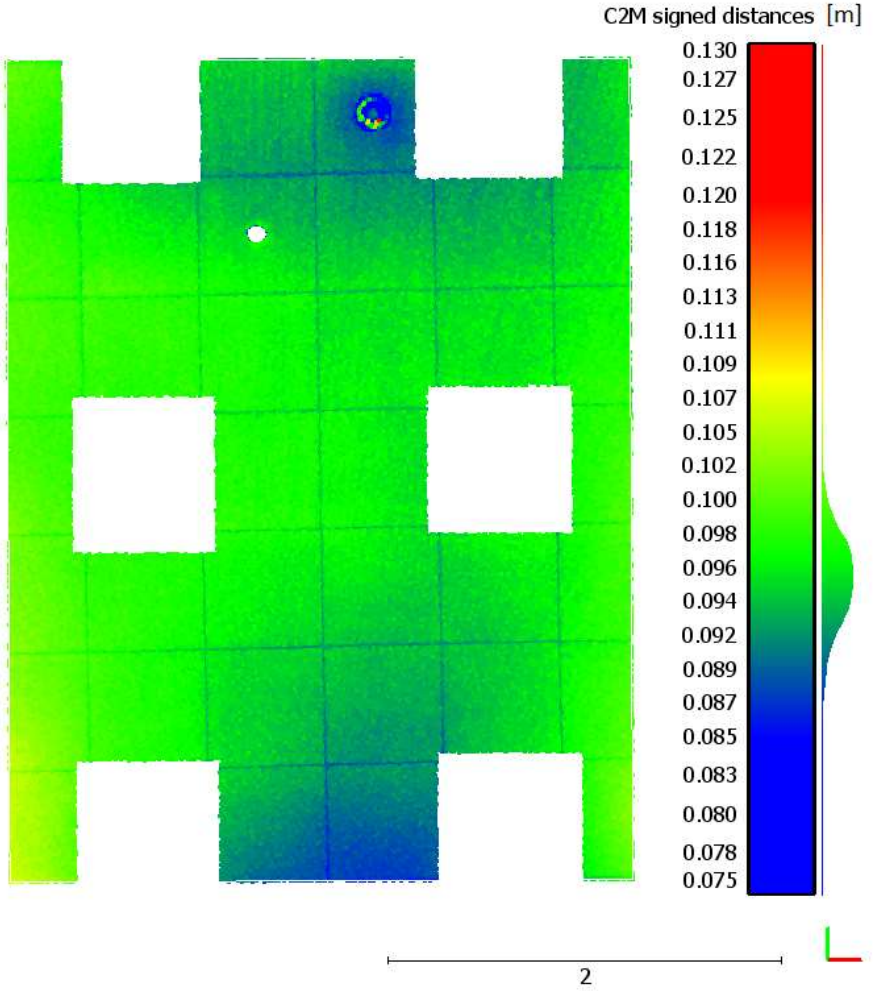




Direct comparison of two points clouds

Distances from the reference plane for **Z+F 5006h**

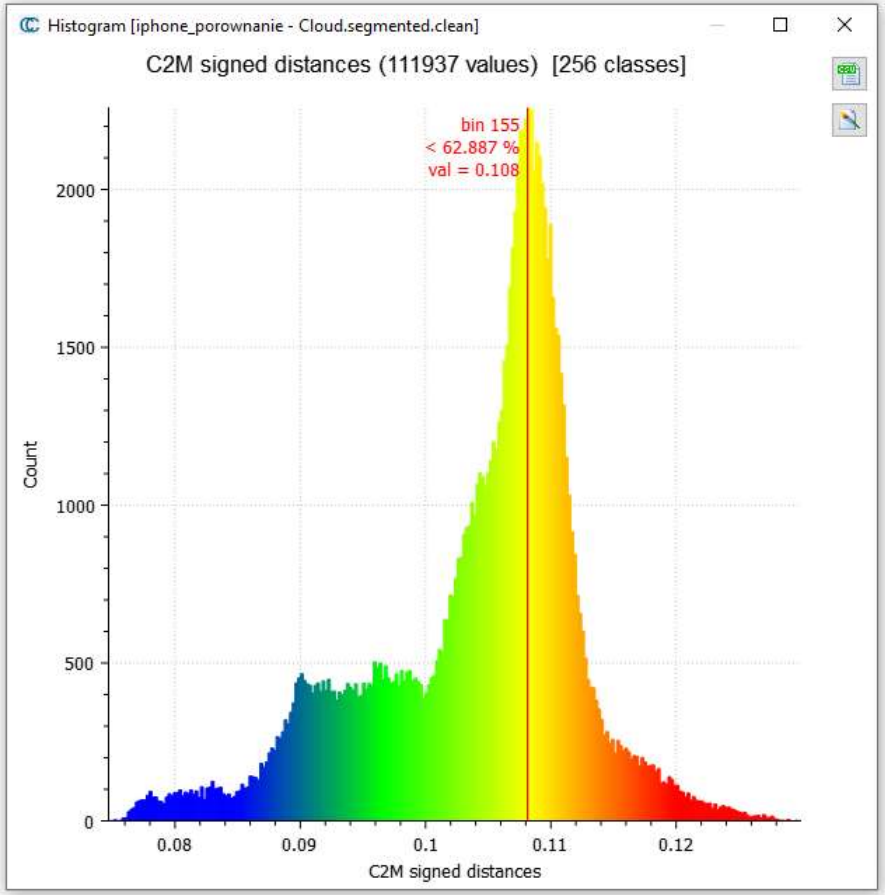


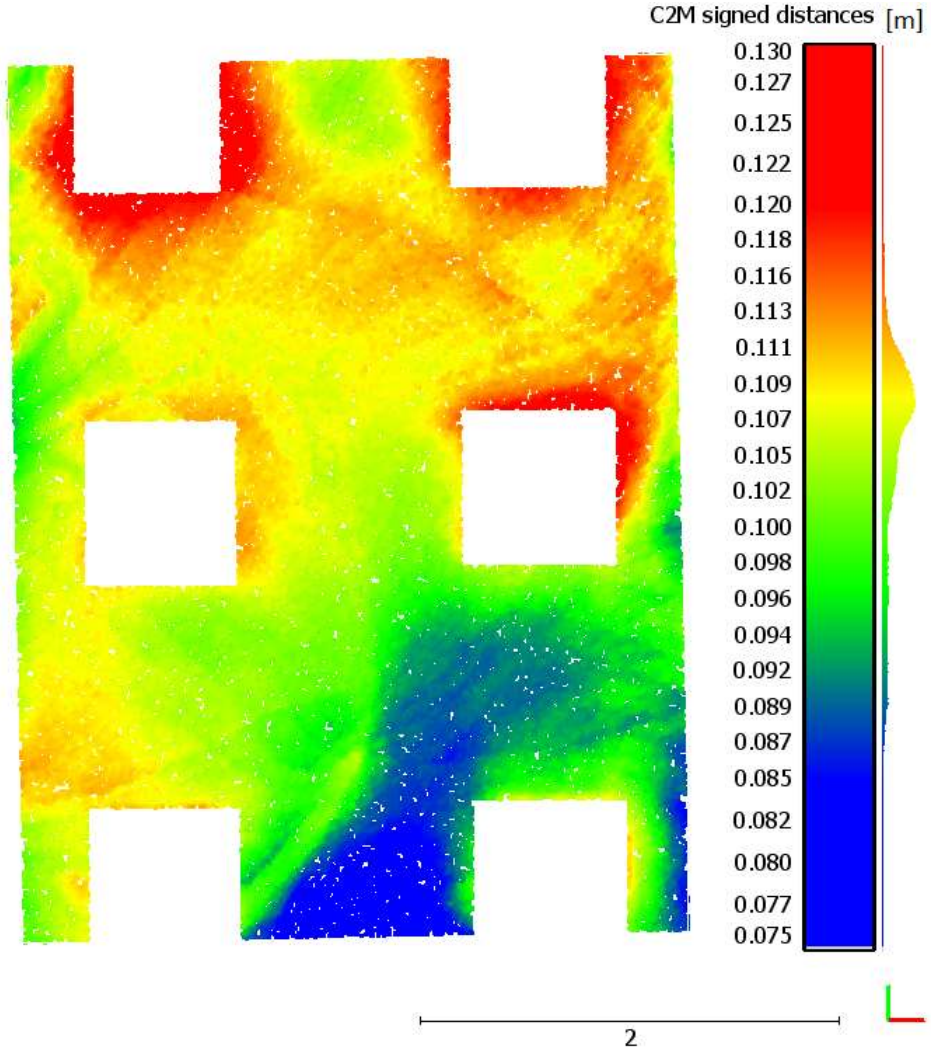


Map of point distances from a horizontal plane at a height of 2.4 m for a fragment of the office room ceiling scanned with a Z+F 5006h

Direct comparison of two points clouds

Distances from the reference plane for **iPhone 13 Pro**





Map of point distances from a horizontal plane at a height of 2.4 m for the office ceiling fragment scanned with the iPhone 13 Pro

CONCLUSIONS

The presented research indicate a great potential of the Apple iPhone 13 Pro with the built-in LiDAR function to inventory buildings.

It is necessary to remember about the necessity of using an appropriate methodology of performing measurements (acquiring spatial data) and about technological limitations.

The scanning performed with a smartphone will not replace precise solutions based on terrestrial laser scanning or classical surveying. This is mainly due to the fact that the accuracy achieved with the iPhone 13 Pro is reliable to a single centimeter, and thus this type of device can be used for work of limited accuracy, such as visualization or reconstruction concepts of an object, rather than precise tasks.

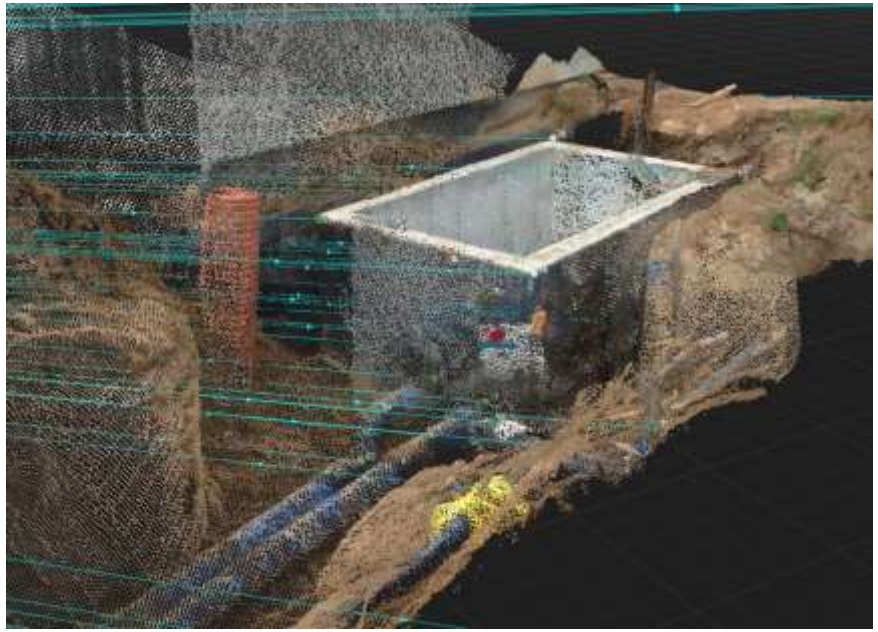
The cost of scanning with an iPhone is low enough to certainly have a positive impact on the popularity of using point clouds and their derivative products in construction and other fields.

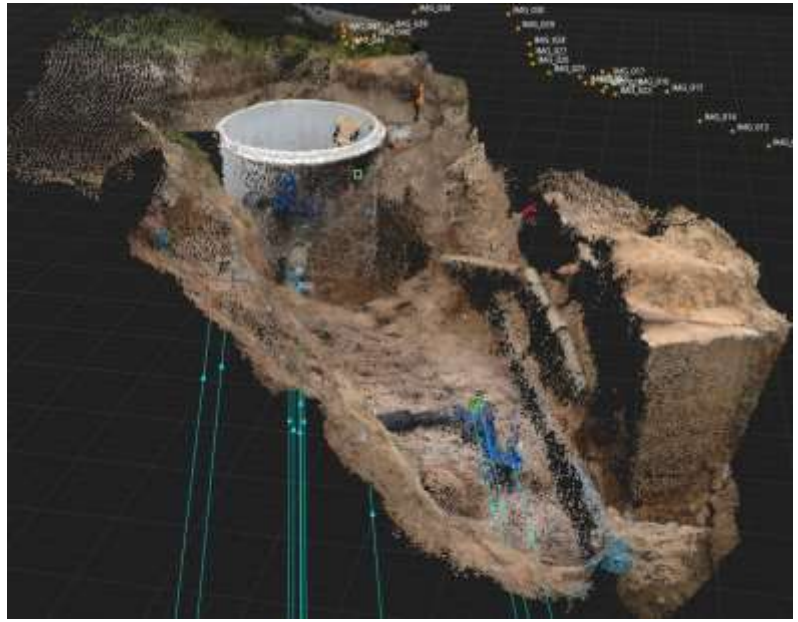
References…

With the use of LiDAR technology in Apple devices, a number of publications have appeared in world literature evaluating the possibility of using this solution for different tasks.

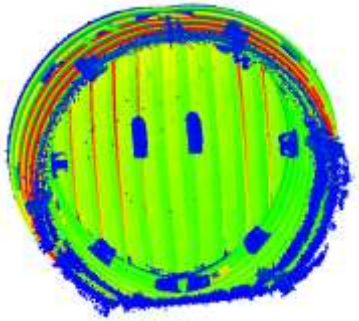
- iPad Pro LiDAR technology is impractical for scanning such small objects. - Vogt et al., (2021)
- iPad Pro is a solution that provides a point cloud immediately oriented in the field so operators can get results in real time. (Mokroš et al., 2021)
- data acquisition must be done skillfully to avoid rescanning previously scanned areas, making it less practical in the field, especially in dense diverse forests. (Mokroš et al., 2021).
- The iPad Pro with LiDAR sensor possessed DBH estimation accuracy and tree detection rate close to TLS results, which is a very good result (Mokroš et al., 2021).
- In the case of scanning geomorphological forms, the authors point that a key factor affecting the completeness of the data is the way it is collected. During scanning with the Apple devices, the distance between the surface and the device was less than 3 m (the allowable distance is 5 m), which, compared to terrestrial laser scanners that can reach a distance of up to 200 m, is quite a limitation to the use of this technology. (Riquelme et al., 2021).
- the results of scanning geomorphological forms led to the conclusion that smartphones and iPads equipped with LiDAR functionality may soon become widely used for these tasks (Riquelme et al., 2021).

New trend: LiDAR everywhere!





Leica GS18I GNSS RTK rover



Thank you for your attention,
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