Evaluating the accuracy of a wearable mapping system

An assessment of NavVis VLX data quality compared to a total station and terrestrial laser scanner, including three case studies: Parking garage, narrow corridor and small offices

Introduction

The undisputed value of mobile mapping is the potential to speed up the scanning process significantly, especially indoors. But for many surveyors and laser scanning professionals who stake their reputations on data quality, there is justifiable reluctance about the level of accuracy that can be achieved using mobile mapping devices. Adding to the uncertainty is the lack of an official industry standard for assessing the accuracy of mobile mapping devices.

At NavVis, being able to assess the accuracy of mobile mapping devices is an important basis for driving innovation in the development of our hardware and software. As part of the effort to achieve the most accurate mobile mapping technology on the market, we initiated an ongoing R&D project to establish a reliable method for evaluating the accuracy of mobile laser scanning systems.

As part of this project, we have previously published an accuracy guide[1], where various benchmarks were introduced to assess the accuracy of mobile mapping systems and a test project scanned with NavVis M6 was assessed. But while NavVis M6 is perfect for large projects above 5,000 sqm, we wanted to apply the assessment criteria to our newly launched mobile mapping system, NavVis VLX, to determine what level of accuracy could be achieved by a smaller device specifically designed to scan mid-sized projects and complex environments with stairs, narrow rooms, or cluttered floors such as construction sites.

Just how accurate is the data captured with NavVis VLX?

When it comes to mobile mapping devices, absolute accuracy is dependent on the project geometry, which means we cannot make a general statement at this point. Instead, we analyzed the accuracy in three different scenarios as case studies:

- The first case is a parking garage: this type of environment is ideal for a mobile mapping system, since it is an open space where many “loop closures” are possible. It is the same garage that was previously scanned with NavVis M6[1], which allows for a side-by-side comparison of both devices.
- The second case is more of an artificial setup, but is a particularly complex scenario for mobile mapping systems: an elongated straight corridor, without loop closures.
- The third case is an intermediate scenario: an office consisting of small rooms, connected through a hallway with some additional doors between the rooms, which allow us to conduct only a few loop closures.

Accuracy benchmarks

NavVis has worked on a rigorous approach for evaluating the relative (local) and absolute (global) accuracy of a mobile laser scanner in an earlier publication[1]. The assessment criteria that were established relied on two industry standard devices as benchmarks for accuracy: a total station and terrestrial laser scanner (TLS). These devices were chosen based on the premise that to assess the accuracy of a mobile scanning system, the reference data must be of greater accuracy than the test data. Here we briefly summarize those benchmarks:

Local point to point metric based on a total station:
This metric refers to the accuracy of the distance between two points captured by a mobile scanner at a single location, e.g. within one room. This metric represents the relative accuracy of the device and is relevant because it compares a mobile solution with a highly accurate total station. People who use point clouds for drawing a CAD or BIM model need to know how close the measurements they are taking in the point cloud are to reality. If they model a room 5 meters by 5 meters based on the point cloud, for instance, how sure can they be that this represents the real conditions? This accuracy ultimately influences the certainty of the as-built documentation.

Global point to point metric based on a total station:
This metric refers to the accuracy of the distance between two points that have not been captured by a mobile scanner from a single location, e.g. the distance between opposite corners of a building. This metric represents the absolute accuracy of the device and determines how severe the so-called drift error (caused by registration of scans over a long mapping trajectory) of the SLAM technology is. Explicitly, it gives us an indication if the whole project is a little bit tilted or there is a “bend” in the overall point cloud.

This metric is relevant because it accounts for the drift error that can arise with SLAM-based technologies in elongated mappings. While the local point to point metric can provide a degree of certainty about how accurate the dimensions of a room are, the global point to point metric can give an indication about the accuracy of the whole project. In other words, how well all the rooms fit together.

Global cloud to cloud metric based on a TLS:
This most significant metric for comparing mobile and static laser scanning accuracy is one that detects deviations in a mobile point cloud by comparing it to a point cloud from a TLS. It is also a benchmark for the absolute accuracy of the system. This assessment is conducted by running a full comparison of TLS point clouds and mobile point clouds computationally. To compute the deviation between the TLS point cloud and NavVis VLX point cloud we use points and their normals to obtain an unbiased estimate of the distance between the two scanned surfaces. To account for changed conditions in the environment, such as cars or pieces of furniture which are present in only one of the scans, we include deviations up to 50 mm in the analysis, everything above that we consider as outliers. In the tests described in this document, we compared both clouds as a whole.

Because this type of comparison is fully automated, it can be based on a few million measured points. This approach therefore provides the most comprehensive insights into absolute accuracy. It should be noted that the two metrics based on the total station require manual selection of individual points in a point cloud and are therefore much more restricted and inherently more error-prone than the global cloud to cloud metric.

Two ways to increase accuracy with a mobile system: loop closures and control points

Mobile mapping is inherently prone to accumulate measurement error along the mapping path (or mapping trajectory).

There are two ways to reduce this error when using NavVis devices:

1. **Conducting "loop closures":** by returning to a point where the mapper has been before during the same scan, the error can be minimized. In such cases, NavVis Mapping Software recognizes overlapping points in the trajectory and uses these to minimize drift error.
2. **Using "control points":** control points (CPs) are surveying targets that have already been measured with high precision (e.g. using a total station). These can be used as fixed points to minimize drift error with NavVis Mapping Software.

Both NavVis M6 and NavVis VLX allow for capturing the coordinates of control points during a mapping. NavVis M6 can be used with ground control points while NavVis VLX is compatible with both ground and wall control points.

In principle, there are three available options:

1. **No control points:** Here, a point cloud in an arbitrary coordinate system is the result.
2. **Control points for registration:** Here, at least three CPs should be used per scan, to allow for registration of the point cloud in a local cartesian coordinate system.
3. **Control point-based optimization:** Here, CPs are used to both register the point cloud and to increase the absolute accuracy. The latter is achieved by doing an additional global optimization on the mapping trajectory that takes the CPs as constraints into account.

In the three case studies, we will touch upon all three approaches.

The key difference between mobile and static scanning systems

When evaluating the accuracy of mobile scanning systems, it is important to take into account a key difference in how data is captured. Terrestrial laser scanners (TLS) capture data by scanning at a single position, while mobile devices continuously capture data at multiple positions while being moved through an environment.

Therefore, when we refer to the accuracy of a TLS, we're talking about the accuracy of discrete measurements at a single position. For one position, (or set-up), the specification sheet of a TLS usually refers to certain confidence levels associated with standard deviation, often 1-sigma, which equals 68% confidence, and sometimes 2-sigma = 95%. A standard deviation of 5 mm with a confidence level of 1 sigma, or 68% means that 68% of all measurements have to be within a range of 5 mm accuracy.

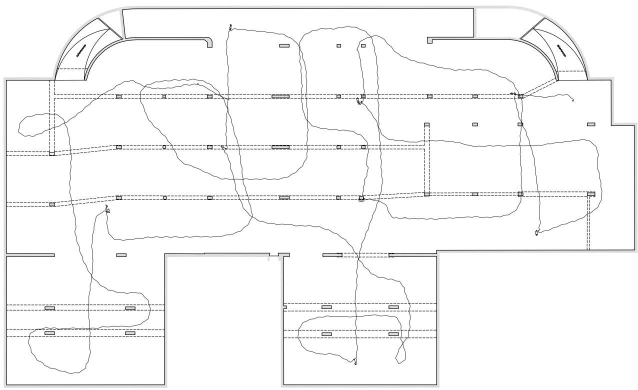
Meanwhile, the accuracy of a scan using a mobile mapping system is based on a huge number of discrete measurements taken continuously. This path of very dense scanning positions is otherwise known as the mapping trajectory.

Case 1:
Parking garage

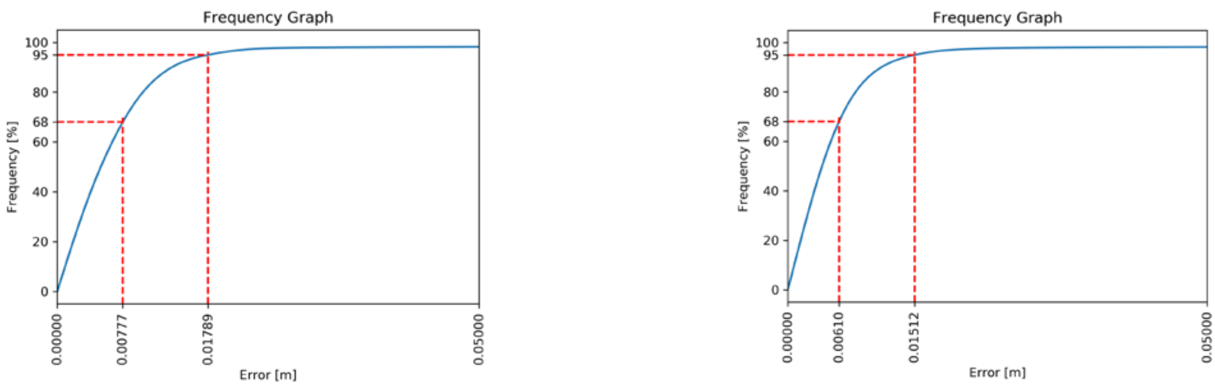
This case is well suited for mobile mapping: a parking garage with a large open space where multiple loop closures are possible (see the floor plan below). The area of this project is approximately 1,500 sqm and was scanned with NavVis VLX in 20 minutes, including capturing eight control points.

In this specific case, no panoramas were captured. The data from NavVis VLX was processed twice: a) using the CPs for registration only, without CP-based optimization, and b) using the CPs for global optimization of the point cloud geometry and for registration.

As ground truth, an external laser scanning provider was commissioned to scan the garage with a highly accurate terrestrial laser scanner. For both test scenarios a) and b) we conducted a full cloud to cloud comparison using an inhouse tool. Below, the cumulative distribution of the deviations between the TLS point cloud and the NavVis VLX point clouds is shown in two graphs. From this evidence, we can state that the absolute accuracy for test scenario a), which represents the point cloud without CP-based optimization, is 8 mm at 68% confidence and 18 mm at 95% confidence. For test scenario b), which represents the computationally optimized point cloud geometry, the absolute accuracy is 6 mm at 68% confidence and 15 mm at 95% confidence. Scenario b) is particularly interesting when compared with previous results from NavVis M6, conducted in the same test environment[1]: the NavVis M6 test resulted in an absolute accuracy of 6 mm at 68% confidence and 14 mm at 95% confidence. These results confirm the assumption that both devices achieve very similar accuracy in this type of environment, which can be explained by the same underlying SLAM algorithms in the NavVis Mapping Software. Scenario a) is particularly interesting because it represents the accuracy that can be achieved when no control points are used. In this concrete test scenario, CPs were used for registration only, and not for global optimization of the point cloud.



The parking garage test environment with mapping trajectory



Cumulative distribution of deviations resulting from the Global Cloud to Cloud comparison:
a) point cloud without CP-based optimization (left), b) point cloud with CP-based optimization (right)

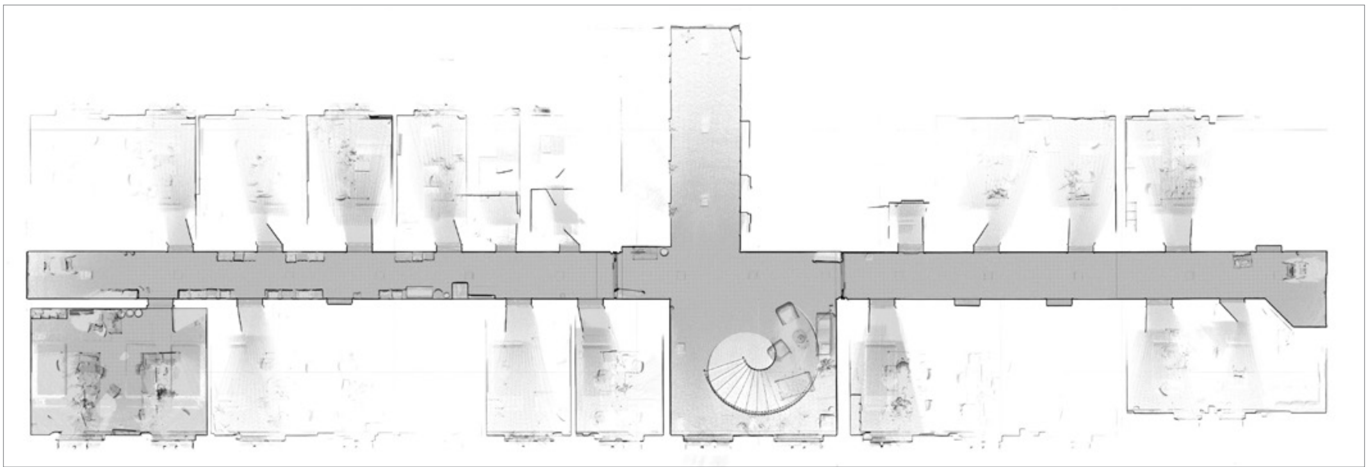
Absolute Accuracy Global Cloud to Cloud	**a) Point cloud without CP-based optimization**	**b) Point cloud with CP-based optimization**
68% of measurements are below	8 mm	6 mm
95% of measurements are below	18 mm	15 mm

Case 2:
Narrow corridor

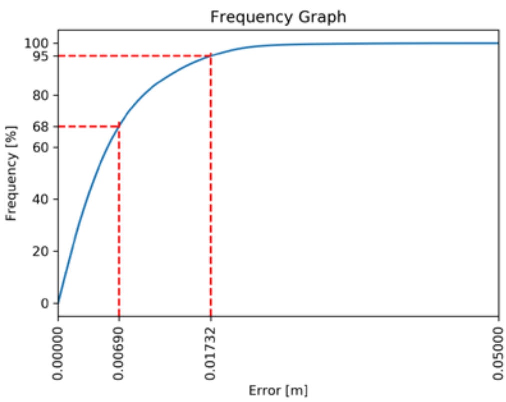
This case represents a particularly challenging environment for mobile mapping: a straight and narrow corridor (approximately 54 m × 2 m). The environment was scanned with three control points, without any loop closures and all in one go: starting at one end of the corridor, walking to the other end, without returning to the starting position.

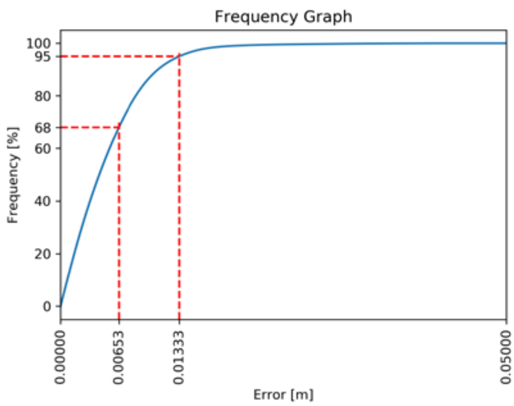
As in the first case, the data was processed twice: c) using the CPs for registration only, without CP-based optimization, and d) using the CPs for global optimization of the point cloud geometry and for registration.

As ground truth, the corridor was scanned with a highly accurate terrestrial laser scanner. For both test scenarios c) and d) we conducted a full cloud to cloud comparison. Below, the cumulative distribution of the deviations between the TLS point cloud and the NavVis VLX point clouds is represented as graphs for both tests. Especially remarkable is the fact that the absolute accuracy for scenario c) is 17 mm at 95% confidence, which is only 4 mm higher than the absolute accuracy for scenario d). For scenario c) CPs were used for registration only and the point cloud geometry was not globally optimized. Therefore, it represents the accuracy that can be achieved without using CPs at all in this particularly challenging environment.



Horizontal section through the office corridor test scan





Cumulative distribution of deviations resulting from the Global Cloud to Cloud comparison:
c) point cloud without CP-based optimization (left), d) point cloud with CP-based optimization (right)

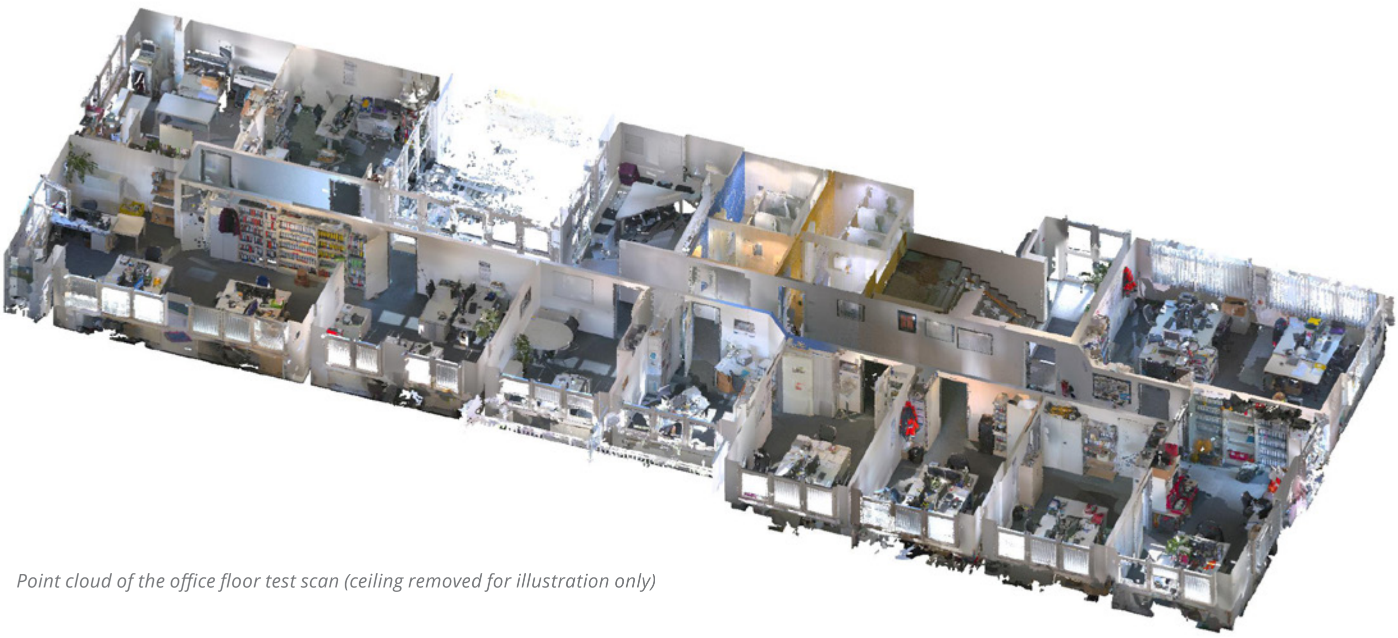
Absolute Accuracy Global Cloud to Cloud	**c) Point cloud without CP-based optimization**	**d) Point cloud with CP-based optimization**
68% of measurements are below	7 mm	7 mm
95% of measurements are below	17 mm	13 mm

Case 3:
Small offices

This case represents a typical layout for mid-size offices or residential projects – small rooms aligned along a corridor and connected with a few additional doors (see the floor plan below). The size of this project is around 460 sqm and was scanned in 30 minutes as one dataset. Control points were not used, but instead loop closures were conducted where possible. The scan includes panorama images every 1-2 m, this contributes to the highly realistic coloring of the point cloud (see the image below).

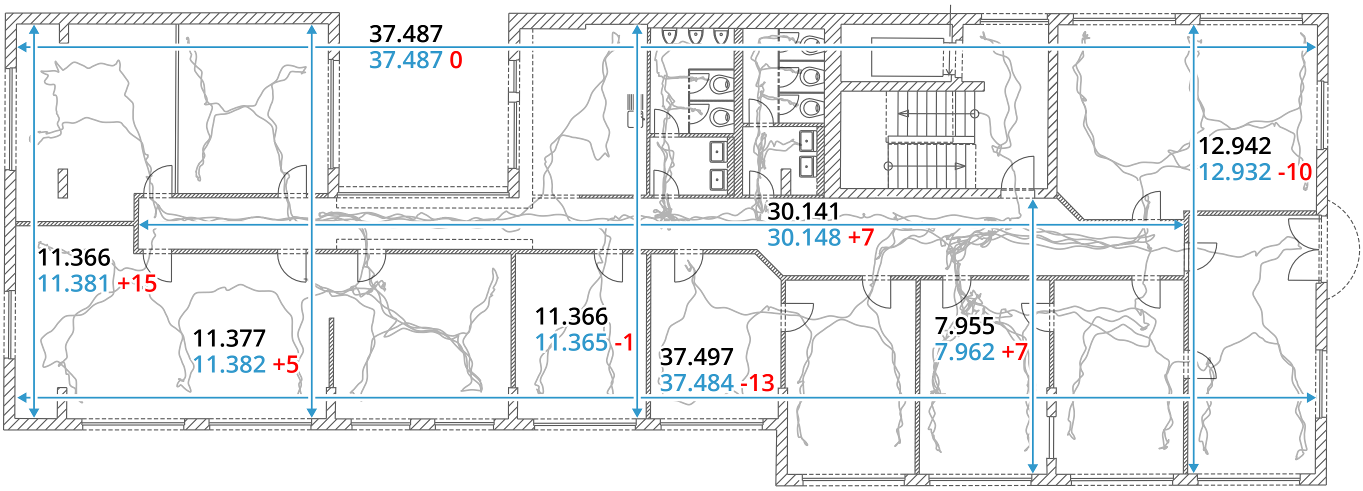
The ground truth for this case is a CAD plan created using a highly accurate total station connected to a CAD system. For the comparison, we manually measured distances from the CAD plan (numbers in black) and compared them to distances measured using the NavVis VLX point cloud (numbers in blue). We then documented the difference between those measurements, representing the error of the NavVis VLX point cloud (numbers in red). The results are summarized in the table below.

In this case, only one out of 24 measurements is above 8 mm, and none of the absolute measurements has an error above 15 mm. The measured relative accuracy seems to be higher than the number stated in the product information sheet (8 mm at 68% confidence)[3]. However, since the process of manually measuring distances in the point cloud and in the CAD plan is potentially error prone, this total station based evaluation is less reliable in comparison to the global cloud to cloud metric. Even so, this test case provides a good first impression when it comes to the accuracy range of the system in a layout consisting of small rooms.

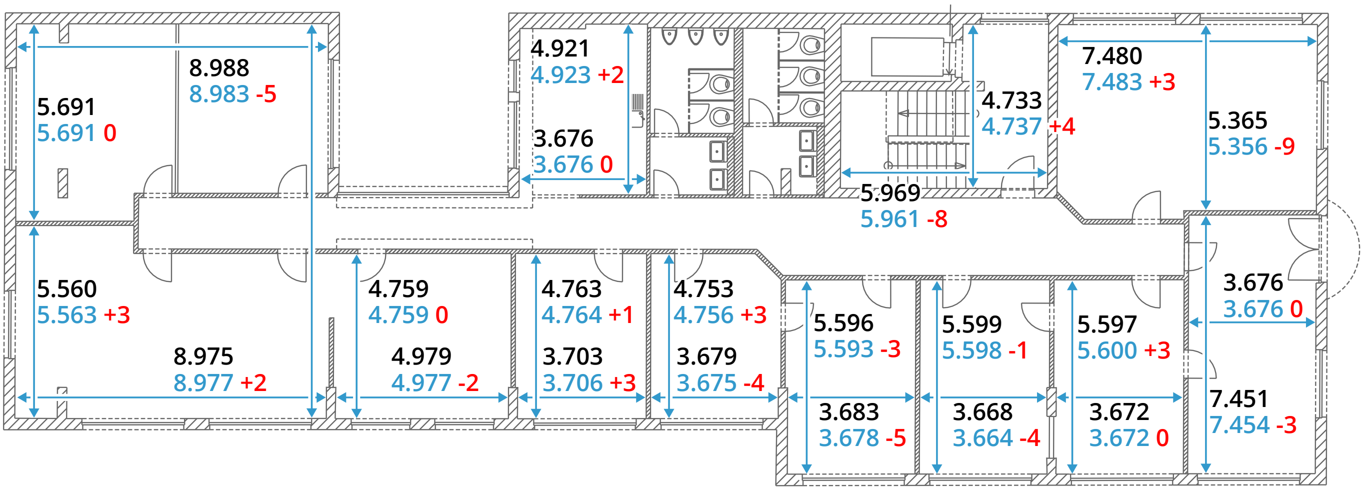


Point cloud of the office floor test scan (ceiling removed for illustration only)

Case 3:
Small offices



The office floor test environment with mapping trajectory and Global Point to Point measurements (black: total station, blue: NavVis VLX, red: deviation)



The office floor test environment with Local Point to Point measurements (black: total station, blue: NavVis VLX, red: deviation)

	Relative Accuracy Local Point to Point	**Absolute Accuracy** Global Point to Point
Number of measurements with deviation of less than 5 mm	22	3
Number of measurements with deviation between 6-10 mm	2	2
Number of measurements with deviation between 11-15 mm	0	2

Conclusion

The concrete results from the three case studies provide a good basis for laser scanning professionals to decide if NavVis VLX is suited to a project with specific accuracy requirements, and to decide if control points measured with a total stations should be used.

The most important findings from the case studies are:

An absolute accuracy within the LOA30[2], which ranges from 5-15 mm at 95% confidence, can be achieved if control points are used for global optimization, as shown in cases 1 and 2.

An absolute accuracy below 20 mm can be achieved at 95% confidence, even if no control points are used, as shown in cases 1 and 2. Case 3 most likely also belongs in this accuracy range, although we cannot derive a statistically sound 95% confidence level based on the 8 measurements. With NavVis VLX, an absolute accuracy very similar to NavVis M6 can be achieved, as shown in case 1, the parking garage.

If the required deliverable is as-built CAD or BIM documentation for construction or refurbishment, NavVis VLX is the perfect device for most indoor spaces, even without using control points. In larger projects of this type, control points might be used for registration of multiple scans.

If the required deliverable is a registered as-built survey with an accuracy level up to LOA30, NavVis VLX together with a total station to measure control points is very well suited for the majority of indoor cases.

Moving forward, we will continue to conduct research into other built environments and, in the long term, extend the scope of this accuracy evaluation towards the outdoors. Moreover, we welcome feedback and any suggestions on how to extend and standardize the evaluation of mobile mapping systems.

References:

1. **NavVis:** Indoor Mobile Mapping Accuracy Handbook, 2019, available via navvis.com/resources
2. **U.S. Institute of Building Documentation:** USIBD Level of Accuracy (LOA) Specification Guide, 2016, available via https://usibd.org/
3. **NavVis:** VLX Product information sheet, 2020, available via navvis.com/resources

NavVis Mobile Mapping Systems

NavVis has two industry-leading mobile mapping systems capable of capturing survey-grade point clouds that can be used to optimize as-built documentation workflows.

NavVis VLX

Fast capture of complex AEC projects

A first-of-its-kind, wearable mapping device that brings high-quality reality capture to the AEC industry in a versatile, compact design.

“

I was really impressed by the high quality point clouds NavVis VLX captures. The accuracy, speed and versatility of this scanning system means that we can apply mobile scanning to even more applications such as construction sites and towers, where we need to efficiently capture as-built data for BIM modeling.

Christof Rek
Managing Director, Rek & Wieck

NavVis M6

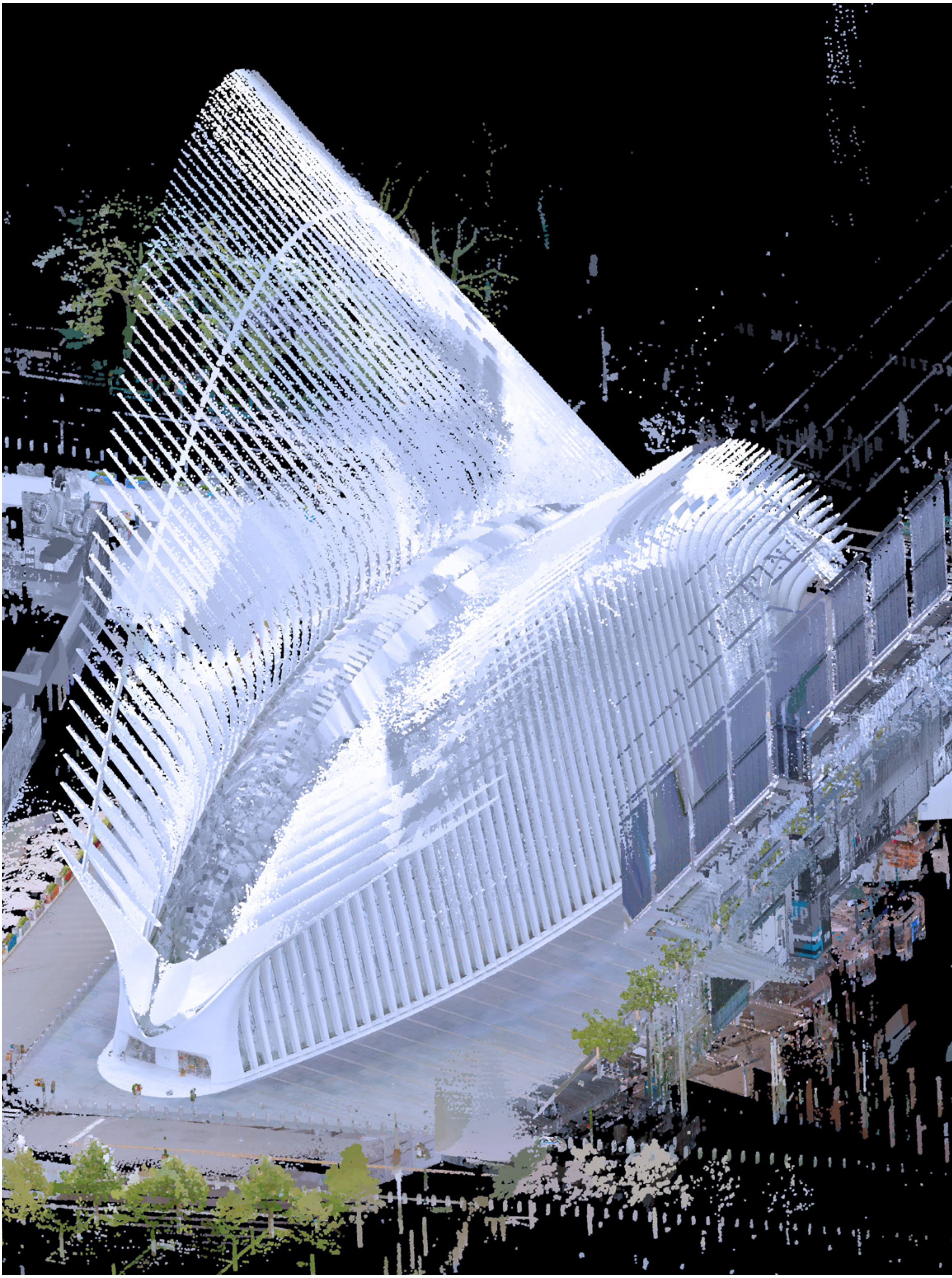
Scalable scanning of commercial and industrial properties

A fast, fully scalable mobile mapping system on wheels that captures at the speed of walking through commercial and industrial environments where every second of downtime counts.

“

NavVis M6 made it possible for us to apply 3D scanning to manufacturing facilities where both minimal disruption and high-quality data are essential.

Christoph Wintrup
Managing Director, Hemminger Ingenieurbüro GmbH & Co. KG



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Version 1.0 | June 2020 | NavVis Mapping Software 2.5.2