

SPATIAL INTEGRATION OF 3D SCAN DATA FOR A NEW BEAMLINE AT MAX IV*

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Abstract

This paper presents the integration of high-precision 3D scanned data into the MAX IV spatial metrological network during the construction of the new TomoWISE beamline. By registering point cloud data within the facility global coordinate system, the scanned data can be accurately overlaid with the beamline CAD model, providing a reliable digital representation of the installation area. This approach supports design verification by enabling the early identification of potential collisions, geometric discrepancies, and installation conflicts before physical installation begins. Detecting such issues in advance allows corrective measures, reducing technical risks, minimizing costly rework, and improving the efficiency of installation planning and execution.

INTRODUCTION

MAX IV Laboratory is the Swedish national synchrotron laboratory that has operated as a user facility since 2016. It is the successor to MAX-lab, which was in operation between 1987 and 2015. MAX IV offers access to 16 beamlines that provide modern X-ray spectroscopy, scattering/diffraction, and imaging techniques to contribute to solving scientific questions in a wide range of research fields. MAX IV employs more than 300 people and welcomes 1700+ users annually. The beamlines are open to academia, research institutes, industry, and government agencies worldwide through the user access programs. The X-ray light at MAX IV is produced by an accelerator complex comprising an underground linear accelerator of ~300 m, as well as a 1.5 GeV and a 3 GeV storage ring (96 m and 528 m circumference respectively). MAX IV is the first worldwide fourth-generation light source, which has opened opportunities to develop experimental techniques based on outstanding brightness and coherence. After several years without new beamlines, funding has been secured for the development of a new one.

TomoWISE is designed to be a state-of-the-art beamline completely dedicated to high-resolution full-field tomography of materials, exploiting the large penetration power of high energy X-rays. The beamline received funds from WISE (Wallenberg Initiative Material Science for Sustainability) and the Knut and Alice Wallenberg Foundation in June 2025. This new beamline is designed to exploit the brilliance of the beam produced at MAX IV for enhanced image contrast, fast acquisition and improved resolution in phase contrast imaging methods using parallel and divergent beams. It achieves this by the use of two separate photon sources in the same straight section, operated in alternance. One 3-Pole Wiggler to provide large beams (up to

45 mm in horizontal) and one cryo-cooled undulator based on permanent magnets, to provide highly brilliant and low divergence X-ray beams. By delivering a high photon flux between 20 keV and 65 keV, TomoWISE will dramatically expand the X-ray energy range currently available at MAX IV, thus enabling new research opportunities for the Swedish materials science community.

BACKGROUND

TomoWISE beamline will be installed at the 07 sector in the 3 GeV Storage Ring (Fig. 1). The installation area is divided into two sections by a concrete shielding wall. The first section is the experimental hall, where the optics, end station, and lead hutch will be constructed. The second section is the storage ring tunnel, where the insertion device and the front end of the beamline will be installed. The connection in between is a concrete door which is open during summer shutdowns when the alignment network is surveyed with laser tracker for alignment purposes [1][2].

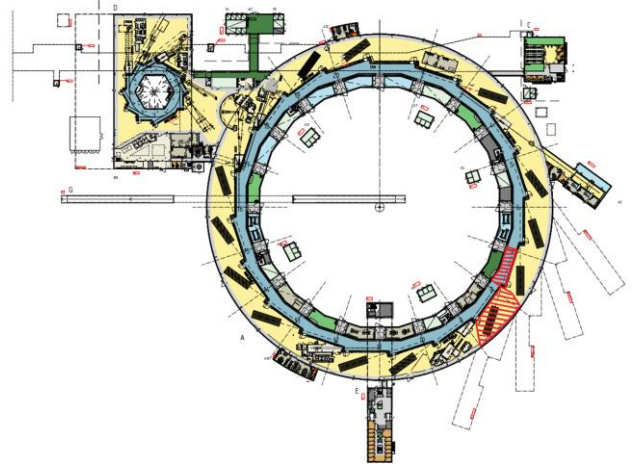


Figure 1: TomoWISE area (red grid).

As the project approached the construction phase, scheduled to begin in June 2026, both sections were scanned in advance to provide an accurate and realistic representation of the existing environment. The resulting 3D scans will serve as a reference for the design team, enabling the development and integration of all components to be installed during the construction and installation phases.

METHODOLOGY

The complete workflow followed in this project is described below, covering all steps from the acquisition and processing of the 3D scan data to its registration and integration with the corresponding CAD models.

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Data Acquisition

The scan data was captured using the Leica RTC360 [3], a high-speed terrestrial 3D laser scanner developed by Leica Geosystems, part of the Hexagon group (Fig. 2). The RTC360 combines high measurement accuracy with rapid data acquisition, making it well suited for detailed documentation of buildings, infrastructure, and other complex environments. The scanner achieves a 3D point accuracy of 1.9 mm at a 10 m distance and captures up to 2 million points per second when operating at its highest resolution. This high sampling rate enables the collection of dense and detailed point clouds while significantly reducing field-work time. In addition, the RTC360 is equipped with an integrated system of high-dynamic-range (HDR) cameras, allowing colour information to be captured simultaneously with the geometric data. The scanner also incorporates Leica's VIS (Visual Inertial System) technology, which assists with automatic scan alignment in the field by tracking the scanner's movement between scan positions. This feature streamlines the registration process and improves workflow efficiency, particularly for projects involving multiple scan locations like in this case. The scanner was mounted on a carbon-fiber tripod also supplied by Leica.



Figure 2: RTC 360 laser scanner.

All scans were acquired at the highest resolution of the instrument, as sufficient time was available to perform all the required setups. Each scan setup took slightly less than three minutes to complete. Both areas were scanned within one day of work. At the request of the technical infrastructure and power supplies team, a particular attention was given to capturing the surrounding walls of the area, ensuring that the resulting point cloud provided a comprehensive representation of the available space and its surrounding structures.

The Experimental Hall was registered by using 22 scan setups distributed across the ground and first floors. A total of 48 links were established between the setups, resulting

in a combined point cloud containing 2,693,710,487 points (Fig. 3).

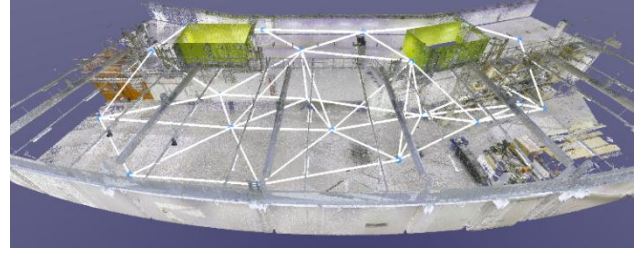


Figure 3: Experimental hall area.

The tunnel area consisted of 17 scan setups distributed along the ring section, extending from the front-end area to the inner ring area and including scanning setups on top of the magnet blocks. A total of 34 links were established between the setups, resulting in a combined point cloud containing 1,524,667,430 points (Fig. 4).

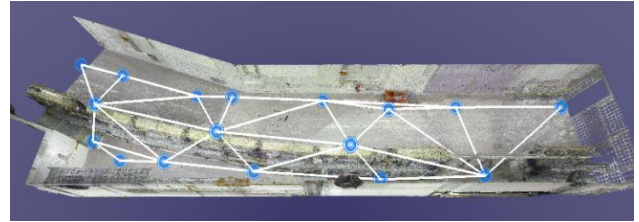


Figure 4: 3 GeV ring area.

Data acquisition and field management were carried out using Leica Cyclone FIELD 360, the companion software for the RTC360. The software enables real-time control of the set ups of the scanner, immediate visualisation of the collected point clouds, and on-site registration of individual scans. By allowing scan quality and alignment to be verified directly in the field (Fig. 5), Cyclone FIELD 360 helps identify missing coverage or registration issues before leaving the site, reducing the likelihood of costly rework. It can be used on a phone or a tablet. For smaller projects such as this one, keeping all scan setups within a single project is generally sufficient. However, when processing several hundred setups at once, performance may start to degrade, making it necessary to split the project into smaller sections.

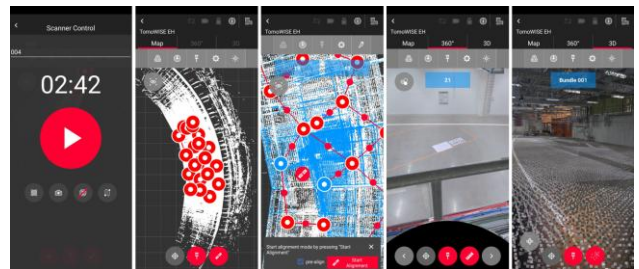


Figure 5: Cyclone FIELD 360 interface on a phone.

Data Registration

After all scan data had been acquired, the individual scans were registered together to create a unified point cloud representing the complete scanned area. Registration is the process of accurately aligning and linking the scans

from the different positions into a common coordinate system. During this stage, the point cloud was also cleaned, removing unwanted noise and artefacts caused by reflective or shiny surfaces, moving objects, and surfaces located very close to the scanner, all of which can introduce erroneous measurements. In this particular case, sections of the floor that had recently been cleaned increased reflectivity, making them more difficult to capture and register. Similar issues were observed on the painted surfaces of the magnet blocks, as well as reflective copper components and the aluminum foils used around the cooling pipes, mirrors were fully covered. These surfaces either produced incomplete point measurements or introduced additional noise into the point cloud. Object proximity was also very challenging, particularly at the front-end area, where the space around is very limited (Fig. 6).

The registration process was carried out using Leica Cyclone REGISTER 360, it's a dedicated software for point cloud registration and processing. The software supports both target-based registration, in which artificial targets placed throughout the survey area are automatically detected and matched between scans, and cloud-to-cloud (best-fit) registration, where overlapping point clouds are iteratively aligned by minimising the distances between corresponding surfaces. These registration methods, described in the following section, were combined to achieve an accurate and reliable alignment of all scan positions before further processing and analysis.

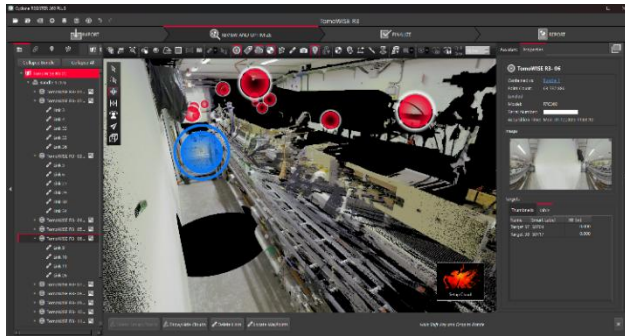


Figure 6: Cyclone REGISTER 360 (example of proximity-induced noise).

To process such a large volume of data, a high-performance workstation was required. The computer used for this project was equipped with an Intel® Xeon® W5-2545 processor (3.50 GHz), 128 GB of RAM, an NVIDIA RTX 4000 Ada Generation graphics card (20 GB), and 4.5 TB of storage capacity.

Target Recognition

To enable the scan data to be integrated into the Alignment Network, Super Precision Scan Spheres (SPSS) from Hubbs Metrology Solutions were used as reference targets. These 2.5-inch spheres are concentrically connected, via an internal magnet, to the standard 1.5-inch retroreflector sphere commonly used with laser trackers (Fig. 7), they are sufficiently large and made of non-reflective material to be reliably detected by the scanner.

During processing in REGISTER 360, the center point of each sphere was manually determined from each setup cloud. Although the software provides an automatic sphere-recognition function, it may incorrectly identify as spheres other objects in the data, such as pipe elbows, wrapped cables, cylindrical and spherical surfaces in general. Consequently, manual identification of the targets was considered more reliable and avoided the time-consuming process of checking the automatic detections throughout the entire point cloud. The resulting center points were then assigned with the same label as the corresponding points in the Alignment Network, allowing the target coordinates from the network to be directly matched with the laser scanned data [4].

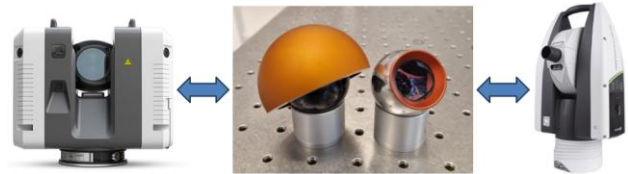


Figure 7: 3D scanner and laser tracker targets connection.

17 sphere measurements were obtained at the experimental hall, with an average of one sphere per setup. In the tunnel, a total of 41 sphere measurements were obtained, with an average of two to three spheres per setup. This difference is mainly due to the distribution of the alignment network, not all areas of the experimental hall are covered by network points since alignment requirements are not present throughout the entire areal, whereas the tunnel is fully covered by the Alignment Network points.

It was also observed that some of the spheres were not perfectly constructed, resulting in deviations from an ideal spherical geometry. However, REGISTER 360 does not provide information about the quality or accuracy of the spherical constructed geometry. The software allows only to check the quality of the constructed spheres indirectly, through their fitting into the alignment network points. Consequently, it was not possible to independently evaluate the geometry quality of each sphere measurement beyond assessing how well the center points agreed with the corresponding network points.

Best fitting with the alignment network

Next step is to link the resulting point cloud to the existing alignment network. To achieve this, the alignment network is imported to REGISTER 360 as a .txt file, allowing a best-fit transformation to be performed by using the “Apply Control” option.

For the Experimental Hall, a mean error of 3 mm was obtained, while the tunnel area achieved a mean error of 1 mm. Considering the area covered, the number of measured spheres, and the accuracy of the instrument, these results are considered reasonable in both areas.

As shown in Fig. 8, each measured sphere can be individually selected or deselected from the fitting process. In addition, a stronger or weaker weight constraint can be assigned to each sphere, allowing single adjustments on each individual measurement for the overall fit.

Applied To: [Bundle 1](#)
Mean Error: 0.001 m

Control Constraints

	Label	Setup	Error	Error Vector NEZ	Weight
☐	S0728	TomoWISE R3- 02	0.002 m	0.000 0.001 0.001 m	1
☒	S0705	TomoWISE R3- 04	0.001 m	-0.000 -0.001 -0.001 m	1
☒	S0716	TomoWISE R3- 02	0.001 m	-0.000 -0.000 0.001 m	1
☒	S0728	TomoWISE R3- 03	0.001 m	-0.000 -0.001 -0.001 m	1
☒	S0704	TomoWISE R3- 16	0.001 m	-0.000 0.001 0.000 m	1
☒	S0704	TomoWISE R3- 02	0.001 m	0.000 0.001 -0.001 m	1
☒	S0716	TomoWISE R3- 11	0.001 m	-0.000 0.000 0.001 m	1
☒	S0717	TomoWISE R3- 11	0.001 m	-0.000 -0.000 -0.001 m	1
☒	S0728	TomoWISE R3- 12	0.001 m	-0.000 0.000 -0.001 m	1
☒	S0705	TomoWISE R3- 16	0.001 m	0.000 -0.001 -0.000 m	1
☒	S0717	TomoWISE R3- 16	0.000 m	0.000 -0.000 0.000 m	1

Figure 8: Best fitting of the tunnel area to the alignment network.

Data Exporting

Once the point cloud is best fitted, it's exported as an .e57 file, which keeps the coordinates and color information of the cloud. But the software has other options for exporting like .lgs, .pts, .las, .ptg, .ptx, .rcp.

In terms of data volume, the experimental hall generated a raw data file of 158 GB, while the exported .e57 file occupied 42 GB, and the resulting mesh had a size of 716 MB. Similarly, the tunnel dataset comprised 62 GB of raw data, which was reduced to 19 GB in the exported .e57 format, while the resulting mesh occupied only 139 MB.

Visualization

There are several software solutions available for the visualization and analysis of point cloud data. Open-source software such as Cloud Compare and MeshLab can be useful for further data processing and analysis, however, they can become unstable or even crash when handling very large datasets.

Leica TruView is another commonly used visualization tool. It is a free viewer that is fully compatible with .lgs files (Leica Geosystems format), allowing direct integration with Leica Cyclone REGISTER 360. This format also provides a more lightweight way of storing and accessing the data.

One of the most widely used platforms for visualization is GeoCloud [5], a cloud-based platform developed by Hexagon for meshing, managing, visualizing, analyzing, and sharing geospatial data. Its cloud-based nature makes it particularly useful for sharing datasets with colleagues, as the data can be accessed without requiring high-performance hardware. Consequently, users with less powerful laptops can still visualize and work with large datasets without the need for extensive local computing resources.

The other main application of the software is the generation of mesh files (Figs. 9-10), which can dramatically reduce file size. This is particularly useful when importing the data into other software, as shown below.

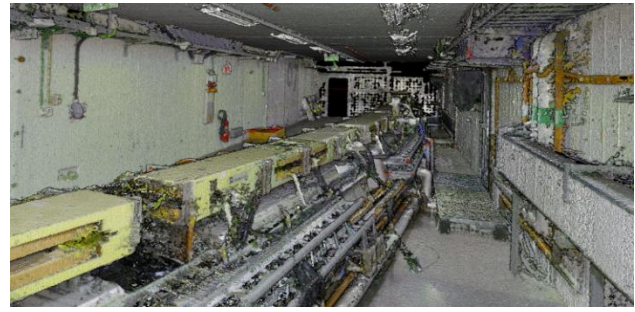


Figure 9: Point cloud in GeoCloud.

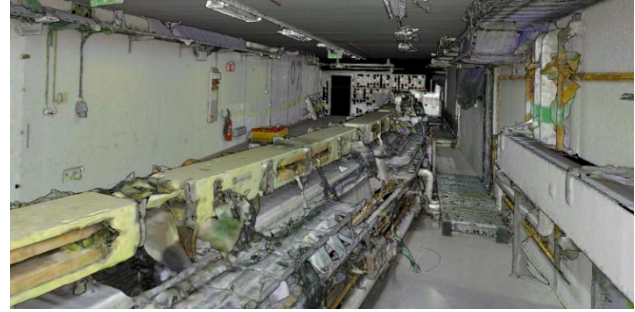


Figure 10: Generated mesh of the point cloud above.

Overlapping with CAD models

For comparison and overlay with CAD models, either a point cloud or a mesh can be used. However, mechanical designers at Max IV work with SolidWorks CAD software (Fig. 11), where point cloud data is not easily recognized or handled. Therefore, meshes are imported into the software in .obj format, generated through the GeoCloud platform. More advanced software, such as Cyclone 3DR, offers more extensive meshing capabilities and greater flexibility for this type of workflow. However, at present, the cost of a license is beyond our available budget.



Figure 11: TomoWISE CAD beamline with meshed area in SolidWorks.

RESULTS

A collision was identified between the CAD model of a vacuum pump designed for the front end, and 3D scanned data of an existing cable tray in the storage ring (Figs. 12-13). Based on this finding, it was decided to modify the cable tray in advance by cutting and adjusting it to provide sufficient space. This solution was chosen because it was quicker and less expensive than redesigning the component.

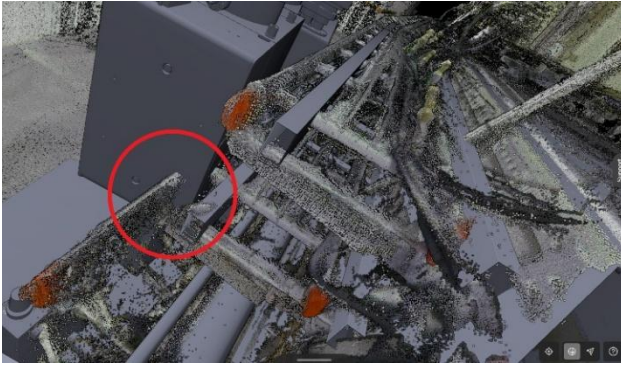


Figure 12: Cable tray collision.

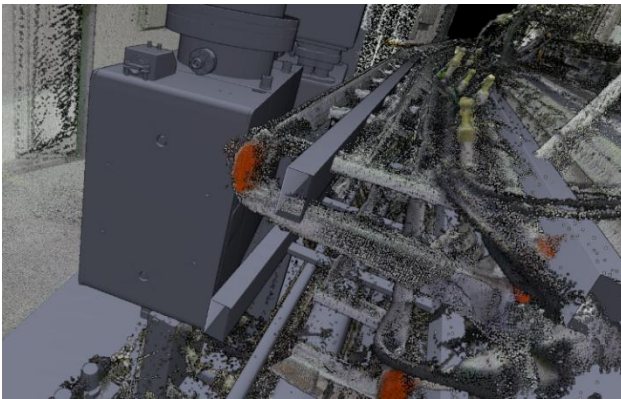


Figure 13: Cable tray scan after cut.

The installation work is currently ongoing, involving the assembly of both external and in-house-designed components within the existing facility. The scan data is already being used to support pipework connections and to determine drilling locations through walls and floors.

CONCLUSIONS

The presented approach demonstrates how integrating 3D scanning into the alignment workflow enhances spatial verification and contributes to a more efficient and reliable beamline installation process.

At present, an alignment accuracy of under 3 mm is considered sufficient for visualization purposes. However, if the scan data is to be used for alignment and positioning in the future, best-fit deviation must be significantly improved, reaching sub-millimeter accuracy.

FUTURE WORK

The aim of this project is to develop a 3D database that enables digital access to the entire installation environment in restricted areas, primarily tunnels and beamline hutches, which are inaccessible most of the time offering an additional resource for querying the spatial layout and distribution of equipment. Further analyses, such as floor height maps [6] and color mapping based on best-fit comparisons with CAD data, are also planned for the coming years.

ACKNOWLEDGMENT

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Finally, we would like to acknowledge the support of all our colleagues at MAX IV Laboratory who contributed, directly or indirectly, to this work, with special thanks to the Design Office for their valuable collaboration.

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