A COMPARISON BETWEEN TERRESTRIAL LASER SCANNING AND HAND-HELD MOBILE MAPPING FOR THE DOCUMENTATION OF BUILT HERITAGE

Alessandro Conti, Giulia Pagliaricci, Valentina Bonora, Grazia Tucci

GeCO Lab, Dept. of Civil and Environmental Engineering, University of Florence, Via di S. Marta, 3 - 50139 Firenze, Italy
(alessandro.conti, giulia.pagliaricci, valentina.bonora, grazia.tucci)@unifi.it

Commission II

KEYWORDS: Cultural Heritage, Documentation, Terrestrial Laser Scanner, Mobile Mapping, SLAM.

ABSTRACT

The increasing demand for 3D digital models has spurred the rapid evolution of technologies to acquire, process, and disseminate 3D data of physical artifacts. Current scanners meet building surveying needs, prompting the exploration of closed systems with multiple sensors, custom accessories, control systems, and varied data processing approaches. While efficient in specific conditions, these systems require careful consideration of factors like technical requirements, environmental conditions, and the intended use of the final model. This article compares a static terrestrial laser scanner (TLS) and a portable mobile mapping system (PMMS) for documenting built heritage, focusing on the City Hall of Montecatini Terme in Italy. The Leica Geosystems RTC360 scanner provides quick scanning times and pre-alignment during fieldwork, reducing post-processing efforts. The Leica BLK2GO, belonging to the PMMS family, utilizes laser SLAM, visual SLAM, and inertial IMU measurements for rapid large-area documentation. The comparison assesses accuracy, completeness, and detail recognition, revealing that both systems are suitable for heritage documentation requiring centimetre-level accuracy. However, differences in point density and roughness indicate that the RTC360 may be better for intricate details. The BLK2GO excels in efficiency but is more oriented toward general representations at the architectural scale. This study emphasizes the importance of evaluating different methodologies based on project objectives and desired levels of detail, providing insights into the strengths and limitations of each system for diverse applications in heritage documentation.

1. INTRODUCTION

Reflecting the ever-increasing demand for 3D digital models, we are witnessing a rapid evolution of technologies to meet much of the need to acquire, process and disseminate 3D data of physical artefacts. The accuracy of available scanners is already sufficient for most building surveying requirements, so the market is currently looking at different solutions to achieve faster and more efficient workflows.

Typically, these are closed systems that use multiple sensors (LIDAR, cameras, GNSS, IMU, etc.) and include customised accessories (tripods, trolleys, wearable mounts, etc.), control systems (apps on tablets or smartphones), and data processing (on proprietary software or in the cloud), so the differences are not just in the performance of the devices; but in the entire process (Elhashash et al., 2022). They are also targeted at more specialised areas, as they are very efficient in certain conditions but less suitable in others, like closed environments, rough paths, and narrow corridors (Piniotis et al., 2020). Therefore, an appropriate selection of technology and workflow is required, considering the characteristics of the building or site and parameters such as technical requirements, environmental conditions, the intended use of the final model, and the complexity of the survey object.

Among the various application areas, the digitisation of built heritage presents specific needs, including: (i) the need to document small features within large volumes, (ii) complex and inaccessible spaces, (iii) variety of materials, (iv) lighting conditions that cannot be controlled, and (v) the need to process large amounts of data (Argyridou et al., 2023).

Many papers have compared portable mobile mapping systems (PMMS) each other or with static terrestrial laser scanner (TLS) in various scenarios (Nocerino et al. 2017, Tucci et al., 2018, Ulvi & Yiğit, 2022, Tanduo et al. 2023, Trybała et al., 2023).

This article aims to compare the results of surveys done with a static TLS and a PMMS and to validate their suitability for the documentation of the built heritage (Sammartano & Spanò, 2018). After a description of the case study, the two instruments used are described taking into account the fieldwork and post-processing phases, and to try to identify, from a quantitative and qualitative point of view, the effectiveness in terms of time, cost and quality.

2. THE STUDY AREA: THE TOWN HALL OF MONTECATINI TERME

The comparison concerns data obtained in two survey sessions of the same building, the City Hall of Montecatini Terme in Tuscany, Italy. Both sets of data were collected on different occasions during educational activities. The first survey was carried out during a two-day workshop for the Restoration Laboratory of the Master of Architecture at the University of Florence (September 2022-March 2023). In this case, a Leica Geosystems RTC360 scanner was used to acquire the main public spaces inside and some areas around the building to obtain a point cloud model.

Shortly afterwards, the same venue was used for the workshop of the 8th edition of the CIPA Spring School (which preceded the 29th CIPA Symposium in Florence). During the event, entitled "3D Surveying and Modelling of Cultural Heritage", the sponsors demonstrated their latest technologies. Among others, Leica Geosystems showed its ultimate PMMS BLK2GO, recording a part of the building and providing the final point cloud.

This contribution has been peer-reviewed.
https://doi.org/10.5194/isprs-archives-XLVIII-2-W4-2024-141-2024

3. A COMPARISON BETWEEN A TLS AND A PMMS SYSTEM

3.1 Leica Geosystems RTC360 Laser Scanner

The static terrestrial laser scanning technique involves collecting 3D data around a LiDAR sensor mounted on a tripod. The scanner samples the area around it according to a pre-defined dense, regular angular grid. Since it is only possible to measure points in the line of sight, in order to obtain a complete result efficiently, it is necessary to place the instrument at positions from which the blind spots can be minimized, while maintaining sufficient overlap between the scans and the desired resolution. The registration of the various individual point clouds produced by the scans results in the overall 3D point model.

The static TLS workflow outlined above produces good results and is now a well-established standard, but the time required for fieldwork and post-processing has a significant impact on the cost of the survey.

As a result, the current trend is to increase productivity by reducing scanning times and integrating sensors and systems that facilitate post-processing.

The Leica Geosystems RTC360 laser scanner uses a combination of phase difference and time-of-flight methods, enabling very short scanning times with a speed of up to 2 million points per second.

The measurement is obtained by combining two modulated pulses of different energy to improve the simultaneous acquisition of surfaces with different reflectivity (Biasion et al 2019).

Productivity is also increased because point clouds are pre-aligned during fieldwork, simplifying post-processing. For this, Visual Simultaneous Localisation and Mapping (Visual SLAM) technology is used, integrating data from inertial and optical sensors to track relative position and orientation between successive scanner setups (Kersten & Lindstaedt, 2022).

However, the stated accuracy is lower than that of the top models from the same manufacturer, such as the P30/P40 scanners. Additionally, the absence of a biaxial compensator necessitates the use of reference points measured by a total station in all applications where accurately levelled data is required.

3.2 Leica Geosystems BLK2GO Mobile Mapping System

The Leica BLK2GO is a device that belongs to the PMMS family and combines laser SLAM, visual SLAM, and inertial IMU measurements, i.e. accelerations and angular rotations (Del Dlesk et al. 2022, Duca & Machado, 2023).

The device is small and compact, making it easy to transport with one hand. It records the trajectory's translations and rotations over time, while visual sensors capture synchronized images of the surrounding environment. These images are used to add colour to the output model and can also be viewed independently. The camera records positions using image matching algorithms, while the two-axis spinning LiDAR sensor captures distance information with a range of up to 25 meters and a stated accuracy of ± 10 mm indoors.

It is important to note that the purpose of developing PMMS using SLAM was not to achieve the highest mapping accuracy, but rather to enable rapid documentation of large areas, suitable for applications where an average accuracy of a few centimetres is acceptable (Cantoni & Vassena, 2019).

When assessing the quality of PMMS using SLAM, it is important to consider their ability to effectively correct drift errors that may result in inaccurate maps. In the case of BLK2GO, it is recommended to follow a loop route that ends in areas that have already been mapped. Additionally, the quality of the 3D model can be improved by making slow and steady movements. Post-processing involves dedicated software that evaluates the sensor trajectory and minimises the drifts typical of the SLAM approach. The software eliminates noise related to motion and generates an unstructured point model linked to spherical images.

Both systems provide high-speed laser scanning, are easy to use, lightweight and have an intuitive interface. They offer the ability to monitor the acquisition process in the field via a wireless connection with applications installed on mobile devices. The operator can visualise the acquisitions, add notes and tag interesting features or objects, and categorise some data throughout the mapping process to simplify the post-processing workflow.

Finally, to compare the two databases, the nominal differences of the tools must be considered, and they are summarised in Table 1.

	RTC360	BLK2GO
Field of view	360° (horizontal) / 300° (vertical)	360° (horizontal) / 270° (vertical)
Range	0.5 to 130 m	0.5 to 25 m
Speed	2.000.000 points/sec	420.000 points/sec
Resolution	3/6/12 mm to 10 m)	
Battery autonomy	4 h	45 – 50 minutes

Table 1. Summary of the technical characteristics of the two scanning devices.

4. THE DATASETS

To identify the application fields of two systems it is necessary to compare the database obtained for the same object, ideally acquired in the same conditions. In this case, the object is the same, but the conditions and the characteristics are different: both scanners produce point cloud models but with different structure and quality. As previously stated, the two survey campaigns were conducted at different times.

The data collected with the RTC360 is made up of 70 scans covering part of the exterior, the hall, the registry room on the ground floor, the balcony and the council room on the first floor. The point cloud of BLK2GO was acquired by a single continuous path, through the same areas acquired by the other scanner, with some extra outdoor areas like the park in the front of the palace and the rear of the building. Some areas inside were only partially accessible due to scaffolding erected for restoration work.

To enable a comparison between the two surveys, a permanent control network was established, and targets were measured from its vertices. The structure of the two datasets is clearly different. Point clouds produced by RTC360 scanner in each setup position have been pre-aligned during fieldwork with the Leica Cyclone FIELD 360 app. During post-processing, the coordinates of the measured targets were used to optimise the registration of the scans using the Iterative Closest Point (ICP) algorithm and to georeference the model (Rinaudo & Scolamiero, 2021) (Fig. 1).

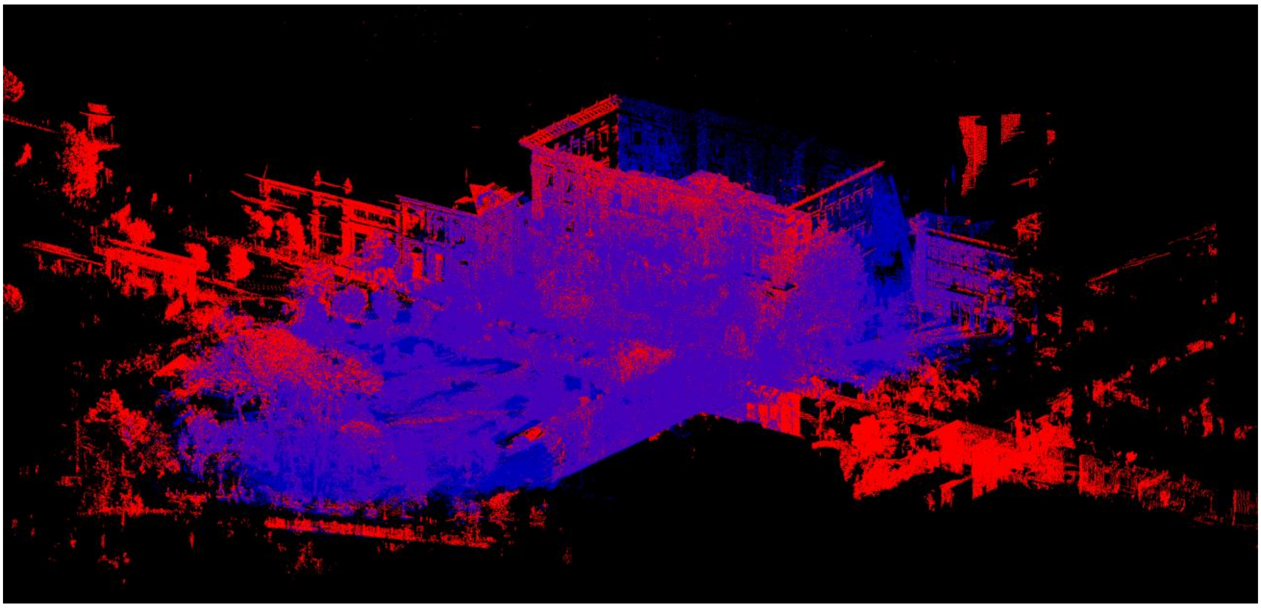

Figure 1. Overall view of the two-point clouds aligned in the same reference system: in red, the one obtained from the TLS, in blue, the one obtained from the PMMS.

On the other hand, BLK2GO produced a single, unstructured point cloud, in a local reference system. The job's completeness can be immediately verified by the operator through a decimated preview on an app in real time. It is not necessary to include targets for point cloud alignment but they were used to allow a comparison of the two datasets. For this purpose, a rigid roto translation of the BLK2GO point cloud has been done, using the coordinates of targets measured in the same reference system.
The characteristics of the two datasets vary according to the technical specifications of the hardware and software systems, specifically in terms of database size, acquisition time, and point density (Tab. 2).

BLK2GO	RTC360
385.733.652 points	2.641.175.372 points
Unique path	70 Scans
20 minutes	2 days

Table 2. Summary of database dimensional data obtained with the two tools.

In summary, BLK2GO made it possible to cover a larger area in just 20 minutes and to record approximately 15% of the points acquired with the RTC360. The comparison therefore concerns the differences between the two models in terms of accuracy, completeness, and level of detail, in relation to the needs of cultural heritage documentation.

5. COMPARISONS

An evaluation was carried out regarding the accuracy, completeness, and if the details are clearly recognizable.
Two slices of the point clouds have been extracted, one longitudinal and one transversal across the building.
The analysis of point overlap visually provides a good result, with almost identical values throughout the building, and a greater distance in the park in front of the building.
The observed drift may be attributed to the difference between the TLS setup positions and targets used for alignment, which were closer to the building, compared to the path followed with the PMMS that included areas further away and peripheral areas with lower density. Figures 2 and 3 represent the section

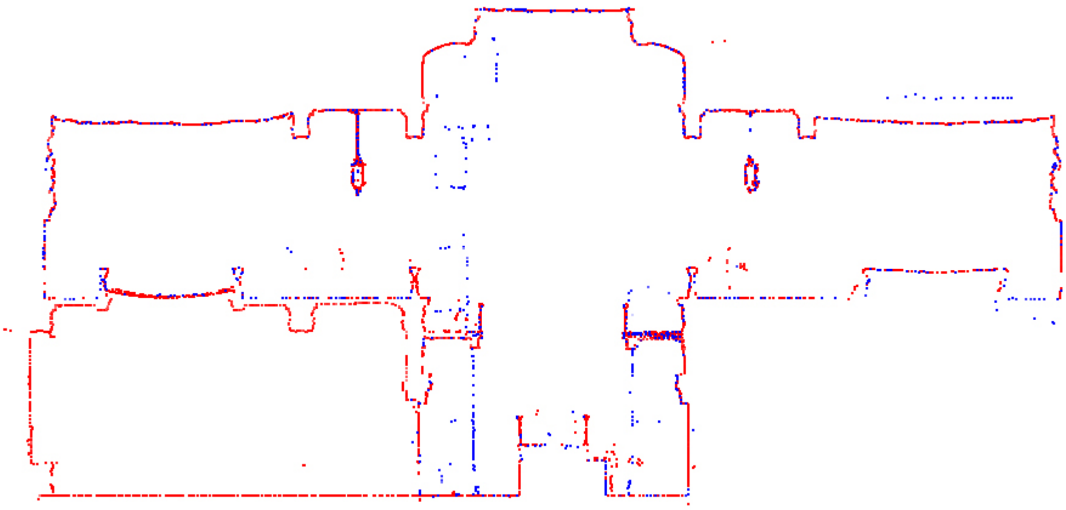

Figure 2. Transversal cross section: in red the point cloud obtained by TLS, in blue, the one obtained by PMMS.

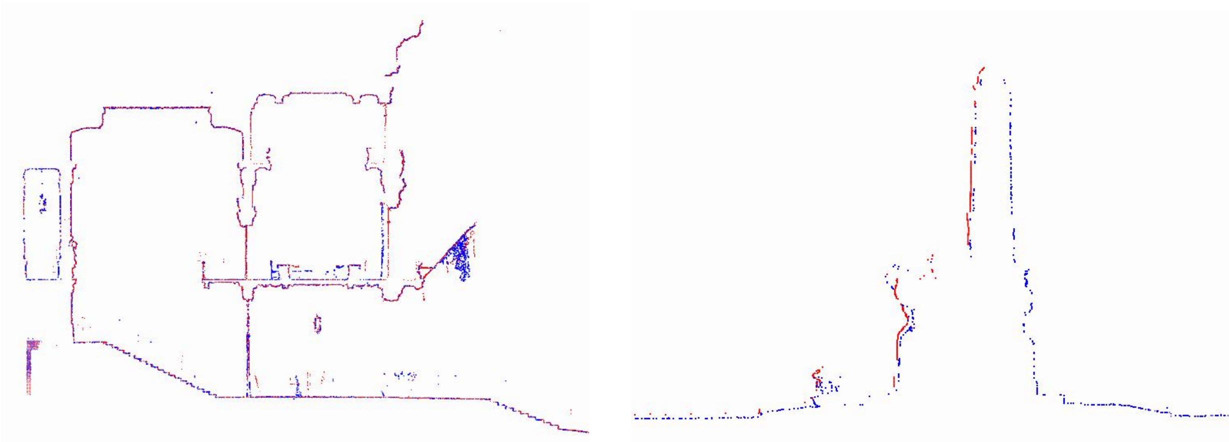

Figure 3. Longitudinal cross section (on the left, detail of the building; on the right, detail of the monument in the park): in red the point cloud obtained by TLS, in blue, the one obtained by PMMS.

analysed where the point cloud of BLK2GO is highlighted in blue and the one of RTC360 in red.

A more accurate measurement of distance has been focused on some details using the Multiscale Model to Model Cloud Comparison (M3C2) algorithm (Lague et al. 2013), as implemented in CloudCompare (CloudCompare, 2023).

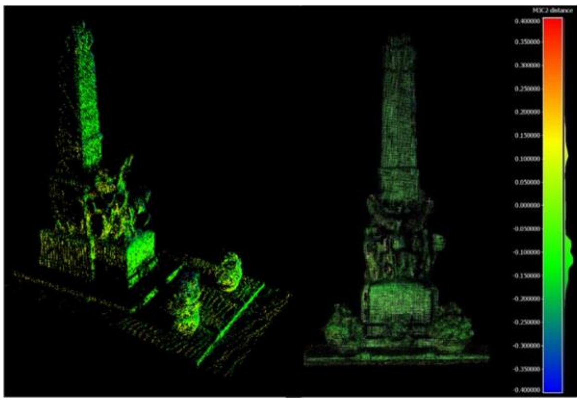

Figure 4. Distance between the point clouds of the World War I Memorial.

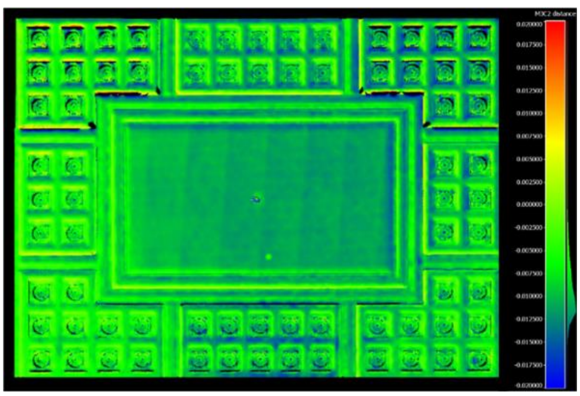

Figure 5. Distance between the point clouds of the wooden ceiling of the hall. Distances between -0.002 m and 0.015 m.

The first check was performed on the part with the highest distance, the World War I Memorial in the park in front of the building. The result highlighted a distance between the two models about ± 10 cm with a non-uniform distribution of points. This non-uniform distribution is related to the design of the PMMS route and the TLS scan positions, which did not interest the back of the monument, resulting in the acquisition of only a few points (Fig. 4).

Other comparisons dealt with architectural elements selected by material, geometric features, and relative position of the scanner. They include the wooden coffered ceiling of the hall (Fig. 5), a decorative frieze in stone representing a lion’s head (Fig. 6), and a coupled column with stone and plaster elements.

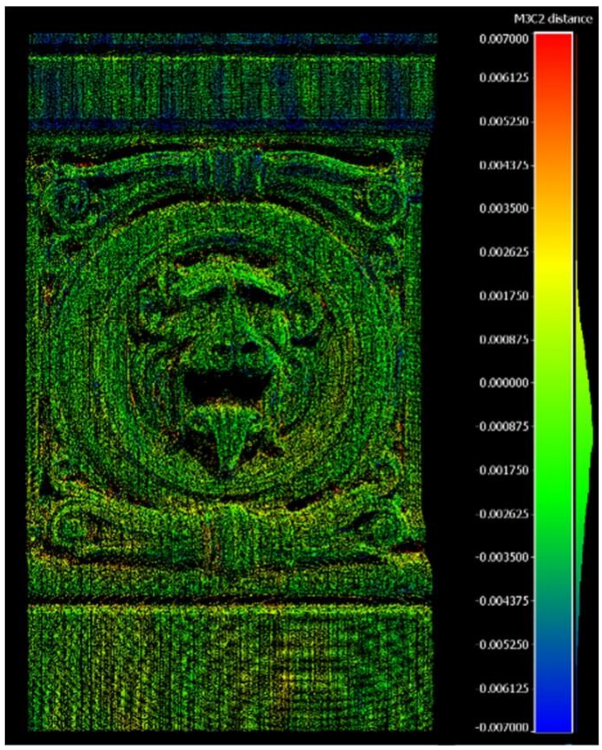

Figure 6. Distance between the point clouds of the decorative frieze. Distances between -0.005 m and 0.001 m.

https://doi.org/10.5194/isprs-archives-XLVIII-2-W4-2024-141-2024 | © Author(s) 2024. CC BY 4.0 License.

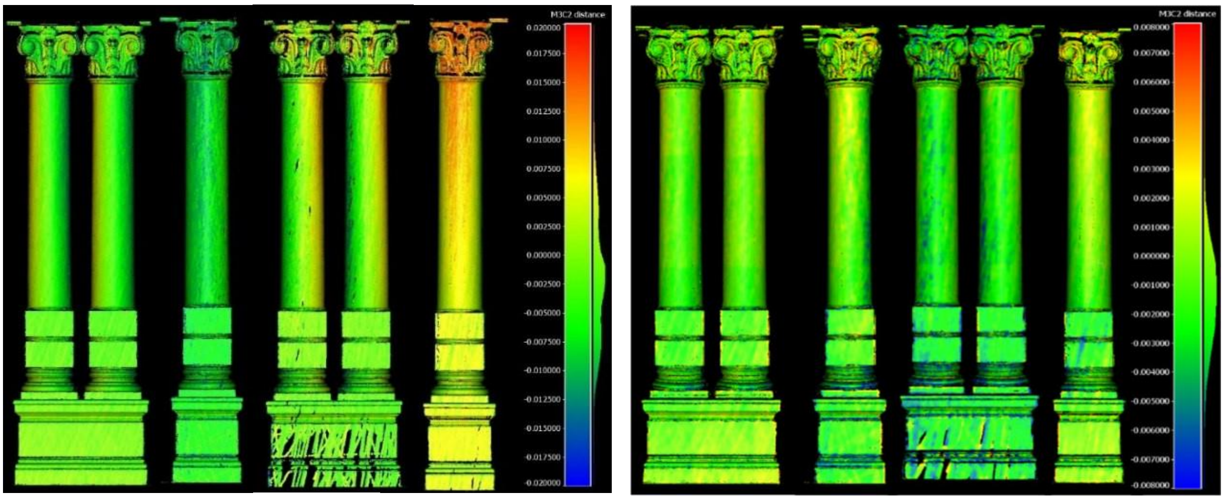

Figure 7. Distance between the point clouds of the coupled column, before (left) and after ICP optimisation (right).

The comparison of the segmented point clouds with the M3C2 algorithm in CloudCompare indicates a very small distance in all cases, regardless of the distance between the scanner and the object or material.

In the coupled column (Fig. 7) a slightly irregular distance between point clouds can be noted. The shift has been reduced after an optimisation of the alignment of the point clouds with a ICP algorithm, suggesting a non-uniform drift, although limited in a very small range. For a complex surface like the coffered ceiling, scans done with the static TLS have many holes, whereas the more manageable PMMS resulted in a more complete result, albeit with less density.

On the basis of these initial tests, it can be inferred that the accuracy and completeness of the data obtained with both systems are suitable for the documentation of built heritage for applications where an accuracy of a few centimetres is sufficient. However, it cannot be asserted that results are comparable in terms of level of detail. In the case of the decorative frieze, figure 11 and figure 12 show that the two models have significantly different point densities, as a consequence of the difference in resolution between the two laser scanners.

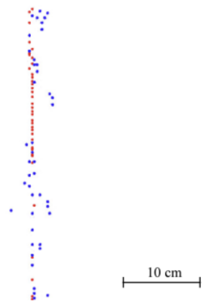

Figure 8. A detail of section of bases of columns: in red, the point cloud obtained from TLS, in blue the point cloud obtained from PMMS.

6. EVALUATION OF NOISE

In a point cloud model, roughness is defined as the differences of height between a point and the average height of its neighbours. It can be caused by the actual properties of the surface of the object or by noise and outliers due to the uncertainty of measurement and related to the instrument. When comparing two scanning systems, differences in the roughness of point models of the same surface may indicate which system is better suited for acquiring objects with complex geometries and minute details. For example, when considering a cross section of a flat surface of the basement of the column (Fig. 8), the data acquired with BLK2GO (in blue) exhibit a more irregular distribution than those obtained with RTC360 (in red).

Roughness has been estimated with the "geometric features" tool of CloudCompare. The distance between each point and the best-fitting plane computed on its neighbours within a sphere of a given radius is used to determine it. To account for the varying point densities and geometric features of the point clouds, a radius of 0.01 m was set on the test areas of both datasets. Figures 9 and 10 indicate that the roughness is

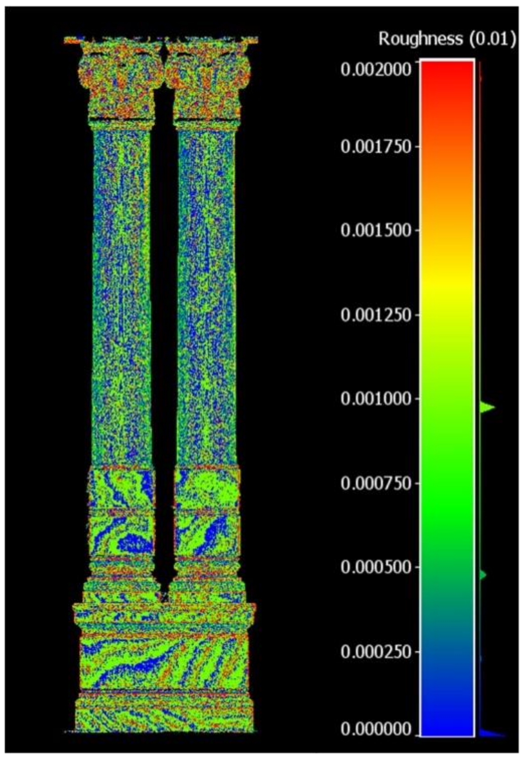

Figure 9. The roughness of the point cloud of the coupled column acquired by RTC360.

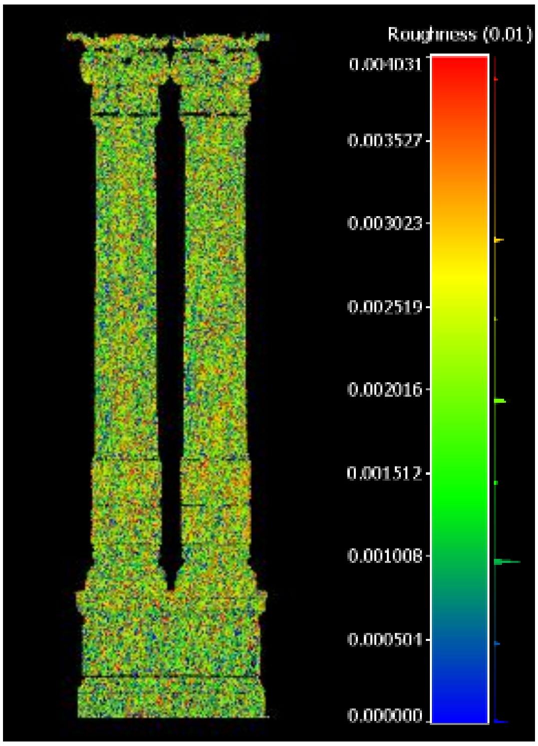

Figure 10. 3D model of columns made with BLK2GO. It shows the scalar field of the roughness.

uniformly distributed throughout the model in both cases. However, the point cloud produced by RTC360 has a roughness of less than 0.002 m, whereas the one obtained with BLK2GO is up to 0.004 m.

This is of little relevance in areas with flat and regular shapes like the coupled column, but for small elements with complex geometry a low-density, high-noise point cloud will not allow correct shape recognition or surface modelling.

To test this, the Poisson Surface Reconstruction algorithm implemented in CloudCompare software was used to generate mesh models from the two point clouds of the decorative frieze. The mesh obtained from RTC360 faithfully reproduces the object's geometry with a high level of detail (LOD) (Fig 11), instead the subject is hardly recognisable in the mesh obtained from BLK2GO (Fig 12).

7. CONCLUSIONS

The tests described show that BLK2GO produces in a short time data suitable for the documentation of heritage buildings, but if a richer level of detail is requested, e.g. for the 2D and 3D representation of small details, a higher point density is required, such as that of the range maps produced by RTC360.

BLK2GO provides an efficient workflow in all its phases, enabling high productivity, but it is more oriented towards general representations at the architectural scale. Comparing different methodologies, especially in the case of educational activities, allows for a personal understanding of the most appropriate approach for each case study and the level of detail required. The evaluation of the site, the objective of the project, and the different performances provide a clear view of the strengths and limitations of each system.

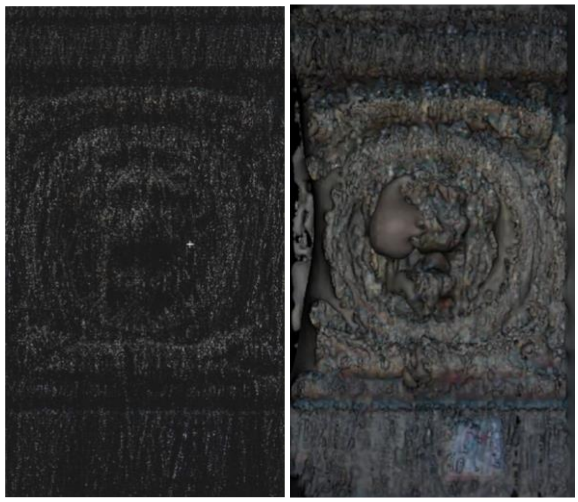

Figure 12. Point cloud of the decorative frieze acquired by BLK2GO and relative mesh model.

Figure 11. Point cloud of the decorative frieze acquired by RTC360 and relative mesh model.

ACKNOWLEDGEMENTS

The authors acknowledge Leica Geosystems for providing the BLK2GO system used in the tests.

REFERENCES

Argyridou, E., Karaoli, A., Hadjiathanasiou, M., Karittevli, E., Panagi, I., Mateou, M., ... & Efstathiou, K., 2023. The first attempt for standardisation in 3D digitisation. The EU study on quality in 3d digitisation of tangible cultural heritage, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., 48, 103-109.

Biasion, A., Moerwald, T., Walser, B., & Walsh, G., 2019. A new approach to the Terrestrial Laser Scanner workflow: The RTC360 solution. In: *Proceedings of the FIG Working Week*. Retrieved from https://www.fig.net/resources/proceedings/fig_proceedings/fig2019/papers/ts05f/TS05F_biasion_et_al_9968_abs.pdf

Cantoni, S., & Vassena, G. 2019. Fast indoor mapping to feed an indoor db for building and facility management. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., 42, 213-217.

https://doi.org/10.5194/isprs-archives-XLII-2-W9-213-2019

CloudCompare (version 2.12) [GPL software]. (2023). Retrieved from http://www.cloudcompare.org/

Del Duca, G., & Machado, C. (2023). Assessing the Quality of the Leica BLK2GO Mobile Laser Scanner versus the Focus 3D S120 Static Terrestrial Laser Scanner for a Preliminary Study of Garden Digital Surveying. *Heritage*, 6(2), 1007–1027. https://doi.org/10.3390/heritage6020057

Dlesk, A., Vach, K., Šedina, J., and Pavelka, K., 2022: Comparison of Leica BLK360 and Leica BLK2GO on chosen test objects, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVI-5/W1-2022, 77–82. https://doi.org/10.5194/isprs-archives-XLVI-5-W1-2022-77-2022

Elhashash M, Albanwan H, Qin R., 2022. A Review of Mobile Mapping Systems: From Sensors to Applications. Sensors. 2022; 22(11):4262. https://doi.org/10.3390/s22114262

Kazhdan, M. 2005. Reconstruction of solid models from oriented point sets. In: *Proceedings of the third Eurographics symposium on Geometry processing* Desbrun, M. & Helmut Pottmann H. eds. 73-82. https://doi.org/10.2312/SGP/SGP05/073-082

Kersten, T.P., Lindstaedt, M., 2022 Geometric accuracy investigations of terrestrial laser scanner systems in the laboratory and in the field. *Appl Geomat* 14, 421–434. https://doi.org/10.1007/s12518-022-00442-2

Lague, D., Brodu, N., & Leroux, J. 2013. Accurate 3D comparison of complex topography with terrestrial laser scanner: Application to the Rangitikei canyon (NZ). *ISPRS journal of photogrammetry and remote sensing*, 82, 10-26. https://doi.org/10.1016/j.isprsjprs.2013.04.009

Nocerino, E., Menna, F., Remondino, F., Toschi, I., & Rodríguez-Gonzálvez, P., 2017. Investigation of indoor and outdoor performance of two portable mobile mapping systems. *Videometrics, Range Imaging, and Applications* XIV, 10332, 125–139. https://doi.org/10.1117/12.2270761

Piniotis, G., Soile, S., Bourexis, F., Tsakiri, M., and Ioannidis, C., 2020 Experimental assessment of 3D narrow space mapping technologies, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLIII-B2-2020, 149–156. https://doi.org/10.5194/isprs-archives-XLIII-B2-2020-149-2020

Rinaudo, F., & Scolamiero, V., 2021. Comparison of multi-source data integrated survey for complex architecture documentation. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVI-M-1–2021, 625–631. https://doi.org/10.5194/isprs-archives-XLVI-M-1-2021-625-2021

Sammartano, G., & Spanò, A. 2018. Point clouds by SLAM-based mobile mapping systems: Accuracy and geometric content validation in multisensor survey and stand-alone acquisition. *Appl. Geomat.*, 10(4), 317–339.

Tanduo, B., Teppati Losè, L., & Chiabrando, F. 2023. Documentation of complex environments in cultural heritage sites. A SLAM-based survey in the Castello del Valentino basement. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XLVIII-1-W1-2023, 489–496. https://doi.org/10.5194/isprs-archives-XLVIII-1-W1-2023-489-2023

Trybała, P., Kasza, D., Wajs, J., & Remondino, F. 2023. Comparison of low-cost handheld LiDAR-based SLAM systems for mapping underground tunnels. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XLVIII-1-W1-2023, 517–524. https://doi.org/10.5194/isprs-archives-XLVIII-1-W1-2023-517-2023

Tucci, G., Visintini, D., Bonora, V., & Parisi, E. I. 2018. Examination of Indoor Mobile Mapping Systems in a Diversified Internal/External Test Field. *Appl. Sci.*, 8((3): 401). https://doi.org/10.3390/app8030401

Ulvi, A., & Yiğit, A. Y. 2022. Comparison of the Wearable Mobile Laser Scanner (WMLS) with Other Point Cloud Data Collection Methods in Cultural Heritage: A Case Study of Diokaisareia. *J. Comput. Cult. Heritage*, 15(4), 81:1-81:19. https://doi.org/10.1145/3551644