2023 IMEKO TC-4 International Conference on
Metrology for Archaeology and Cultural Heritage
Rome, Italy, October 19-21, 2023

# Comparison of two technologies in 3D surveying of Real Estate Assets and Cultural Heritage

Giulia Fiorini[1,2], Maria Alessandra Tini[1], Francesco Montelli[3], Gabriele Bitelli[1]

[1] *Department of Civil, Chemical, Environmental and Materials Engineering (DICAM) – Alma Mater Studiorum University of Bologna, Viale del Risorgimento 2, 40136, Bologna, Italy,* giulia.fiorini12@unibo.it, mariaalessandra.tini@unibo.it, gabriele.bitelli@unibo.it
[2] *Department of Classics – Sapienza University of Rome, Piazzale Aldo Moro 5, 00185, Rome, Italy,* giulia.fiorini@uniroma1.it
[3] *Operai dell'Arte APS, Via Sauro Babini 80, 48124, Ghibullo (RA), Italy,* francesco@montelli.dev

***Abstract* – Accurate three-dimensional (3D) data from indoor spaces holds significant importance in various fields like real estate management, industrial archaeology and Cultural Heritage. Villa Maraffa complex, located near Ravenna (Italy), served as a case study for employing and comparing advanced technology and sensors in surveying these contexts. To acquire data, the sensors used were Matterport Pro 2 and Leica RTC360. The first one, mainly developed for real estate surveys, has been chosen because of the efficiency and cost-effectiveness in generating point clouds, although with lower precision compared to the Leica RTC360 Laser Scanner, the other sensor employed in this study. The focus of the paper is on assessing the point cloud's quality, with an analysis of the Matterport data, including global and specific evaluations. Potential issues like incomplete data and misalignment are identified by comparing coordinates from the Leica scanner. The results are examined to find an optimal solution for a prompt, precise, and well-timed survey, enabling a complete digital reconstruction of the object.**

## I. INTRODUCTION

Planning building projects, preserving Cultural Heritage, and creating virtual reality experiences are merely a few of the applications available for indoor 3D modelling. Human history artefacts, such as historic houses, excavation sites, and stone sculptures, provide complex geometries and significant information about human evolution.

To maintain their long-term survival, digital representations of Cultural Heritage assets must be documented, protected, restored or rebuilt. 3D point cloud data has emerged as a reliable tool for attaining these goals [1]. It is essential in the 3D virtual reconstruction of cultural artefacts because it provides extensive information on three-dimensional geometry and colour and material properties [2]. Since the beginning of 2000, there has been a surge in interest in using 3D point cloud data in the subject of real estate assets and Cultural Heritage, with both academic and corporate sectors actively investigating its possibilities [3].

Terrestrial laser scanners (TLSs) give comprehensive and precise geometric information, but they are expensive, need careful planning of scan locations, and can be time-consuming to use [4]. In contrast, panoramic multi-camera systems offer a lightweight and affordable alternative [5]. With the emergence of low-cost consumer-grade panorama cameras [6], users can capture a full 360-degrees view in a single shot, reducing the number of pictures required to capture a scene [7]; a widespread system of this type was developed by Matterport Inc., with the aim of operating above all in the real estate sector.

In earlier research investigations, the potential of Matterport device was investigated, including its use for developing interactive virtual worlds and determining data accuracy [8], [9]. This paper investigates the performance of the Matterport Pro2 in comparison with the Leica RTC360 laser scanner [10], in the case study of *Villa Maraffa* in Italy. The aim is to push the boundaries of the Matterport Pro2 (note: the model Pro3 is currently available) and gather both qualitative and quantitative data, considering as a reference the results of the Leica device. The last is in fact characterized by significantly higher declared values of precision and accuracy.

The primary focus is on the characteristics of these instruments, considering also the differences on the acquisition and data processing phases. The theme that was mainly analysed in this study is the comparison between the obtained point clouds, evaluating the metric quality of the one obtained using Matterport Pro2 as a survey tool and analysing the quality of the auto-alignment process. The objective is to assess the effectiveness of these technologies in specific contexts, such as the preservation and restoration of Cultural Heritage, and to conduct a comparative analysis of these instruments, considering some advantages, disadvantages, and limitations.

Villa Maraffa was chosen as the case study because the shape and the articulated internal distribution of the rooms of this built complex make it a perfect case study for testing the data collecting capabilities of the two sensors as well as cloud alignment. Furthermore, being a country home from the eighteenth century, it might be regarded as a model example for both Cultural Heritage and industrial archaeology contexts.

## II. CASE STUDY: VILLA MARAFFA

*Fig. 1. Historical Picture of Villa Maraffa, in Cortina di Russi e la sua storia, in "In Rumàgna", 1981/82, p.106.*

The Villa Maraffa complex (Fig. 1), located near Ravenna (Italy), consists of a historic villa, a washhouse, and a farmhouse whose name derives from the surname of its 19th century owners, the "Maraffi" [11]. In order to trace the historical developments and changes that have affected the Villa and its surrounding structures, it is necessary to examine the names of the owners and the modifications they made to this building, which is believed to originate from the 18th century [12]. This examination can be conducted through census documents and other sources of information. Unfortunately, the archives of Ravenna do not contain any preserved maps or records pertaining to the possessions and owners, neither for the 18th century nor the subsequent century. The earliest confirmed information, however, can be traced back to 1835, when the villa is mentioned in a census declaration under the ownership of Pasquale Maraffi himself [12]. The Villa changed proprietors and uses multiple times over nearly a century, with subsequent changes both in the shape and the internal structure of the building. After being owned by the Galletti-Abbiosi girls' orphanage until 1974, the villa was abandoned [12]. Each owner made modifications to the original structure, affecting its arrangement and relationship with the surrounding environment.

The villa is currently being restored, which will result in a change in its role. The reconstruction, based on the Operai dell'Arte restoration project, aims to renovate and replace the existing structure while retaining its historical aspects from the 18th century. This entails adapting the building to its rural surroundings and redesigning the internal spaces to meet the demands of the institution.

## III. DATA ACQUISITION

### A. *Matterport Pro2*

A completely automatic device that records the world in three dimensions is the Matterport Pro 2 3D camera, which uses PrimeSense chips [13]. As previously stated [14], the system is based on an image-based implementation of the SLAM (Simultaneous Localization and Mapping) technology. To gather the information required to produce a 3D depiction of indoor places, the Matterport Pro2 is made up of a system of three cameras, an infrared sensor, and a motor that turns it 360 degrees. The 3D sensor records depth and enables the reproduction of a location in 3D space, whereas the 2D sensor is used to take images. The shortest acquisition distance is 1 m while the maximum acquisition distance ranges between 4 m and 5 m, depending on ambient lighting and the geometry of the object being detected. This small range can be a problem for acquisition in situations where staying closer to the object is not possible or when acquiring data in large spaces. Because of this limitation, data must be collected from multiple scan positions [15]. The field of view of this instrument is 360 degrees horizontally and 300 degrees vertically, this is evidenced by the presence in the point cloud of two shadow cones, one above and one below the acquisition point. This can cause problems when acquiring ceilings characterised by the presence of, for example, exposed beams that create shaded areas. The majority of scans take 25 to 30 seconds to complete, including camera acquisition time, data transfer to the mobile device (smartphone or tablet), and an initial raw automatic alignment of the acquired data [16]. The intricacy of the geometry and the quantity of scans have an impact on processing time. After transmitting the scans to the portable device, the 3D Capture programme automatically merges them. As previously stated, this is a raw alignment that will be refined during the post-processing phase. Cortex, Matterport's patented reconstruction engine, performs this automated 3D reconstruction within a few hours after the project is uploaded to the cloud servers. Due to the online and non-analogue nature of Matterport's data processing, the entire process is automated and requires no user intervention. Matterport's 3D models combine high-dynamic-range (HDR) images with the geometric model [17]. Users can take virtual tours of surveyed buildings using the Unity multimedia plug-in, making it especially useful in the real estate industry. Users can download, in addition to point clouds, 3D models (in OBJ format) of the scanned scenes to use in virtual reality applications [17]. Matterport states that the accuracy of the measurements it makes is about 1 percent of the distance between the instrument and the point acquired under optimal conditions; this translates to an approximation of 0.05 m for a point acquired at the maximum distance of 5 m [18]. However, factors such as recalibration, unexpected temperatures, and other variables can all have an impact on measurement accuracy.

While the Matterport camera has been used successfully in outdoor environments [15], [19], sunlight interference at the wavelengths utilised by the infrared camera may impact 3D data collection and scan alignment [16]. Moreover, previous research has shown that, when compared to laser scanners, the Matterport Pro2 3D camera has restricted precision in modelling indoor spaces, and it produces an irregular point cloud that depends on the specific technique employed to generate it [14], [17]. Furthermore, its applicability is restricted by its limited range, even if rapid data acquisition and computerised processing help to overcome these shortcomings, mainly for not expert users [7].

We started our survey using the Matterport Pro2 camera from the centre of the building, at the main access (Fig.2).

Using this tool, data has been acquired in 94 positions.

*Fig. 2. Survey with Matterport Pro2.*

Considering the acquisition time of each scan, the time needed to move and position the instrumentation, and the first required data processing step, such as identifying doors and windows, the total survey duration was about 5 hours. After these were completed, the data were uploaded to the online platform for automatic post-processing.

### B. Leica RTC360

In this investigation, the reference point cloud was obtained using the Leica RTC360 terrestrial time of flight laser scanner [7], [20]. It is a suitable option for producing a reference point cloud, with a data collection rate of two million points per second, a range of 130 m, and an accuracy of 2.9 mm at 20 m [10]. Leica Register360 is used to process the measurement data. Because no targets were utilised throughout the scanning process, the point clouds had to be joined in Cyclone Register360 using automatic cloud-to-cloud matching.

*Fig. 3. Survey with RTC360.*

The survey with RTC360 began in the same place as the survey with the Matterport Pro2 camera (Fig.3). We adjusted the scan data on the RTC360 to the lowest point density before beginning the survey so that it would be realistically comparable to the findings provided by Matterport. Throughout the process, we manually improved and double-checked the scan registration on the iPad using the Leica Cyclone Field360 application. The data was collected from 24 scan positions over the course of around 2 hours. Following the completion of the RTC360 survey, the analysis and verification of the results began. We started by improving registration and links between scans on plans and sections with the Leica Cyclone Register360 programme. This was done by checking the correctness, strength, and overlaps of the scans, so it was possible to go in and improve and implement the connections so that we would get data that met the requirements in terms of precision and accuracy. Unlike data obtained from the Matterport camera, where information about the alignment of the various scans is not available, we were able to examine the overall quality of the global point cloud after concluding the post-processing elaboration using the RTC360 laser scanner, which was characterised by 30 connections with total strengths and overlaps of 82% and 53%, respectively. The final average error on the connections between point clouds is 0.002 m. This is an appropriate result because both the quality of the metric data acquired and the quality of the alignment process achieved a very high degree of accuracy, which is higher than the one that is required for the representation scales commonly used in architecture.

## IV. DATA ANALYSIS

### A. Entire point clouds comparison considering the auto-alignment of the Matterport data

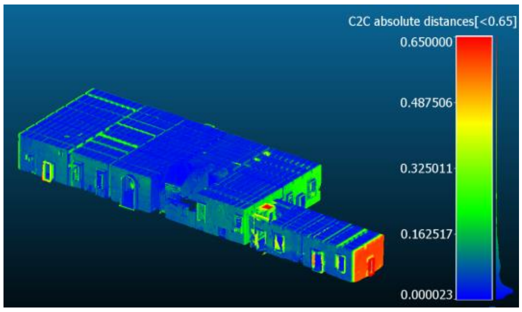


*Fig. 4. Distance analysis between the two point clouds starting the comparison from the main entrance.*

CloudCompare open source software was used to compare the two global point clouds acquired from the Matterport and RTC360 laser scanners. The initial step was to align the Matterport point cloud with the same reference system as the RTC360 one. The Iterative Closest Point (ICP) algorithm was then utilised to enhance the manual alignment procedure. Then we started analysing the distances between clouds using the "nearest neighbour distance". In this analysis, we used a distance range of 0 m to 0.65 m, that was previously identified as the true value of the maximum distance between the representation of walls and ceilings in the two point clouds. In Figure 4 are represented the different distances between the two point clouds: in red, the greater distances are indicated, and in blue, the smaller ones. Thanks to these analyses, we noticed that the vertical walls, running transverse to the main development of the building, were characterized by the greatest distance values. This investigation revealed how the distance between the two clouds, particularly in the walls, increased as one moved away from the point where the two clouds had been oriented. This prompted us to consider issues with Matterport's automatic alignment of single clouds.

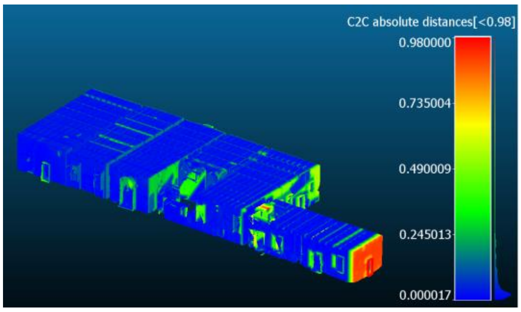


*Fig. 5. Distance analysis between the two point clouds starting the comparison from the corner on the left.*

For this reason, and in order to take in account the potential error propagation due to point cloud alignment of Matterport data, we decided to carry out the same analyses starting the alignment of the two clouds from one edge.
In this case, the maximum cloud-to-cloud distance is 0.98 metres. Figure 5 shows that the distances between the walls near the narrowest part of the building are greater. The distance between the walls in this section of the building, in particular, is between 0.70 m and 0.98 m. This result suggests that the trend of the differences increases in relation to the distance from the alignment point.

### B. *Single point cloud comparison*

After comparing point clouds referred to the entire structure and observing the distribution of distances, it was decided to examine individual point clouds. This type of analysis would allow us to determine if the substantial discrepancies in the overall clouds were caused by Matterport's data collection issues or the automated alignment procedure, about which we have no information. For this analysis, it was necessary to identify a room that could be acquired in a single scan while keeping Matterport's maximum acquisition range in mind. After considering the data provided by the manufacturer, the acquisition conditions, and analysing the point cloud, it was decided that 4.5 m would be the maximum acquisition range for this case study. We first aligned the two point clouds in the same reference system, then we removed the points that were not part of the room to avoid to include them in the distance calculation. The cloud-to-cloud absolute distance range is between 0 m to 1.947 m. The analysis of the results obtained from this comparison revealed that the distance between the clouds in the room acquired with the two instruments reaches a maximum value of 0.080 m, while the greater distance values refer to the different shaded areas beneath the two tools or to objects that have moved between the two scans. To better emphasise and determine the average value of the distance between the two clouds, we recomputed the cloud-to-cloud distance by restricting the maximum distance to the eliminable mistakes. As a result, the average distance between the two clouds was calculated to be 0.044 m (Fig.6). Given that the room's sides are respectively 5 m and 7 m long, the result achieved is consistent with what the manufacturer reported.

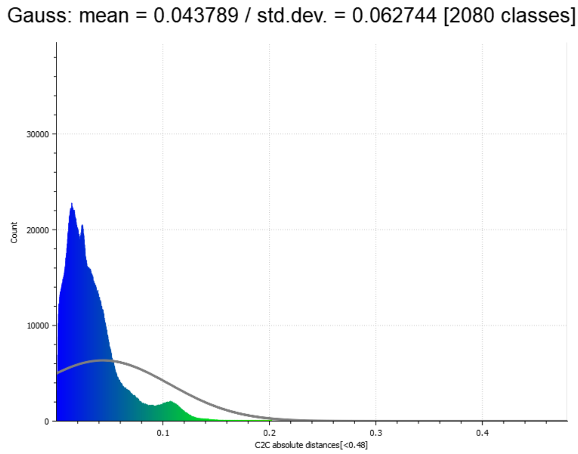


*Fig. 6. Histogram showing the distribution of distances when comparing individual clouds*

By analysing only one scan per instrument, it was also possible to perform a quick analysis of the number of points acquired. As can be seen from Table 1, and as it was possible to imagine considering the technical characteristics of the two instruments, the amount of points acquired by RTC360 is more than twice the amount of points acquired by Matterport Pro2. Furthermore, when evaluating the points that were eliminated because they did not belong in the room, an even greater difference can be seen due to the difference in the acquisition ranges of the two instruments.

*Table 1. Number of points in the two point clouds.*

| | RTC360 | Matterport Pro2 |
|---|---|---|
| Complete Point Cloud | 10.058.840 | 4.533.554 |
| Segmented Point Cloud | 9.552.633 | 4.404.387 |
| Deleted Points | 506.207 | 129.167 |

### C. *Entire point clouds comparison manually aligning all single Matterport point clouds*

Following the results of the comparison of the individual point clouds, it was decided to continue the research by performing a new comparison of the two point clouds, but this time manually aligning the individual clouds acquired by the Matterport Pro2 camera with each other. First, all point clouds were segmented by deleting all points acquired at a distance greater than 4.5 metres from the station point. As a result, all points with an excessively high degree of inherent inaccuracy have been eliminated. Following the completion of the segmentation phase, we moved on to the alignment phase, beginning with the first acquired point cloud and proceeding in the acquisition order. Already during this phase, we could see significant differences between the automatically determined position of the point clouds and the one we assigned. Furthermore, despite the fact that some station points were made precisely in correspondence with these critical passages during the acquisition, these differences were found to be especially significant in correspondence with the critical areas of passage between two different rooms. Once all 94 scans acquired with the Matterport Pro2 camera were manually aligned, the overall cloud thus obtained was compared with that obtained by merging the scans made using the RTC360 laser scanner. The ICP algorithm was used before comparing the two clouds to better align them with each other.

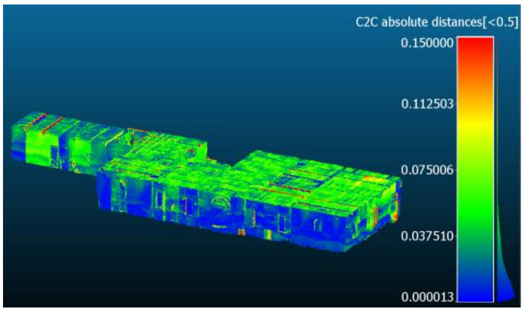


*Fig. 7. Distance analysis between the two point clouds after manually segmenting and aligning the scans*

After reviewing the preliminary results of the study on the distances that the software automatically calculates from the information it has available, it was decided to compare the distances by narrowing the range so that all values that did not represent the distance between the two point clouds at fixed features were eliminated from the calculation. By then analyzing the results in a range of 0 m to 0.15 m, it was possible to study more clearly the distance relationship between the two clouds. This analysis revealed an average distance of 0.022 m between the two clouds (Fig. 7). When viewing the data in false colours, it is clear that the distances between 0.03 m and 0.07 m, which are represented in green, are concentrated on the part depicting the ceiling. This is because, despite the fact that numerous scans were performed within each room, always approaching different walls during the acquisition, the distance between the instrument and the ceiling remained constant and was thus probably greater than in other parts of the building. There are also some areas on the ceiling that show a high distance between the two clouds, looking at these data it can be seen that these are regions, which were acquired during the survey with the RTC360, but not with the Matterport system because they were covered by the shadow cone cast by the beams.

## V. RESULTS

The more scans there are in a long chain, the more likely it is that small errors will accumulate. It was prudent to double-check this research with an RTC360, made to achieve much higher metric quality levels, as a reference point cloud. Based on the comparisons made in this study, we can conclude that Matterport is suitable for conducting real estate surveys of rooms or small buildings. Furthermore, it is useful for quick documentation of ongoing projects to record changes during work where accuracy is not critical, and it is a cost-effective tool for users. However, the speed of Matterport Pro2 is dependent on the dimensions and geometry of the objects because, unlike RTC360, which has a distance range of 0.5 to 130 metres, Matterport conducts the survey in the distance range of 1 to 5 metres, so for a large room, more stations are required, which increases the acquisition time. As a result, we cannot say which is faster than the other because it is dependent on parameters such as dimensions and required accuracy. Matterport Pro2 has some limitations that may influence a user's decision. First, Matterport can only conduct indoor surveys because it is based on an infrared light projection system that is strongly influenced by the interaction with other light sources, while RTC360 can conduct both indoor and outdoor surveys. Second, since it was designed as a tool for real estate surveys, thus more oriented to the creation of virtual tours based on panoramic images, it is not a tool designed to generate a dense point cloud, this is particularly noticeable in ceilings since it is not possible to approach them easily to acquire data from other station points. This lack of data makes it not an appropriate tool for detailed surveys of historic buildings where very often ceilings have complex geometries, such as coffers, arches and vaults. Another limitation of this tool is the inability for users to record the original raw data acquired, but the alignment result, after uploading the scans to Matterport's cloud service, is made available about 24 hours after upload, via the media player in Matterport 3D Showcase, while RTC360 allows users to align point clouds and evaluate overlaps, strengths, and cloud-to-cloud distances using Leica Cyclone Field 360 software. The final limitation is that the Matterport does not have the option to automatically remove movable objects, whereas the RTC does. As mentioned earlier, the software accompanying the RTC360 allows for immediate exploration of the three-dimensional model that has been acquired, as well as the ability to align the various clouds in real time. These features, which make it possible to verify the data acquired as early as during the campaign phase, combined with the ability to control the subsequent post-processing stages with extreme precision and the instrument's own acquisition characteristics in terms of precision and accuracy, make it an ideal tool for surveying in the field of Cultural Heritage. On the other hand, the difference in the cost of the two tools is very high and also justifies the different targets in terms of users and applications. Some of the critical issues of the Matterport Pro 2 camera highlighted in this paragraph have been solved in the new Matterport Pro3 model, whose operating system is based on the LiDAR technology. In fact, data acquisition is possible even outdoors, with a maximum distance of 100 m (the minimum distance is 0.5 m); in addition, the accuracy claimed by the company is higher, it is stated as 0.02 m at 10 m.

## VI. CONCLUSIONS

The acquisition of complete point clouds of the interior areas of buildings, particularly historic buildings, is a very complex issue, requiring a careful preliminary study and planning phase of the survey and very long acquisition times since many scans need to be made. In this process, the possibility of seeing in the field a preview of what has been acquired, as offered by the software that accompanies the two instruments that were used for this research, makes it possible to optimize the acquisition time by adapting the position of subsequent scans to areas where information has not yet been acquired. According to the research, Matterport Pro2 and RTC360 provide a different level of precision and accuracy of the acquired point clouds, so the choice of instrument must be dictated by the purpose of the survey, going by the metric quality of the point cloud and the number of scans to be made, thus the acquisition time. Another aspect that must be taken in to account concerns the user's possibility of having direct and objective control over the post-processing and quality of the data. This is an element that, for some users is of paramount importance, while for other users a closed process, performed automatically without the need for work and control by an experienced operator, is an optimal solution, especially when the quality of this process is guaranteed. The combination of these considerations leads to highlight how Matterport Pro2 turns out to be a valuable tool in the field of real estate and expeditive documentation of the different phases of work on a construction site, while to perform precise and accurate surveys it is better to rely on professional surveying laser scanners, such as RTC360.

## ACKNOWLEDGMENTS

Our acknowledgments to Anita Yousefi, who worked with us during the acquisition and data processing phases in the framework of her Master Thesis, and Agnese Franzoni, who supported historical analysis about the case study.

## REFERENCES

[1] G. Bitelli *et al.*, "The GAMHER research project for metric documentation of Cultural Heritage: current developments," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* vol. XLII-2/W11, pp. 239–246, May 2019, doi: 10.5194/isprs-archives-XLII-2-W11-239-2019.
[2] A. Arapakopoulos *et al.*, "3D Reconstruction & Modeling of the Traditional Greek Trechadiri: 'Aghia Varvara,'" *Heritage*, vol. 5, no. 2, pp. 1295–1309, 2022, doi: 10.3390/heritage5020067.
[3] G. Bitelli, M. Dellapasqua, V. A. Girelli, E. Sanchini, and M. A. Tini, "3D Geomatics techniques for an integrated approach to Cultural Heritage knowledge: the case of San Michele in Acerboli's church in Santarcangelo di Romagna," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* vol. XLII-5/W1, pp. 291–296, May 2017, doi: 10.5194/isprs-archives-XLII-5-W1-291-2017.
[4] I. Selvaggi, M. Dellapasqua, F. Franci, A. Spangher, D. Visintini, and G. Bitelli, "3D comparison towards a comprehensive analysis of a building in Cultural Heritage," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* vol. XLII–2, pp. 1061–1066, May 2018, doi: 10.5194/isprs-archives-XLII-2-1061-2018.
[5] M. B. Campos *et al.*, "A Backpack-Mounted Omnidirectional Camera with Off-the-Shelf Navigation Sensors for Mobile Terrestrial Mapping: Development and Forest Application," *Sensors*, vol. 18, no. 3, 2018, doi: 10.3390/s18030827.
[6] L. Barazzetti, M. Previtali, and F. Roncoroni, "Can we use low-cost 360 degree cameras to create accurate 3D models?," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* vol. XLII–2, pp. 69–75, 2018, doi: 10.5194/isprs-archives-XLII-2-69-2018.
[7] M. Ingman, J.-P. Virtanen, M. T. Vaaja, and H. Hyyppä, "A Comparison of Low-Cost Sensor Systems in Automatic Cloud-Based Indoor 3D Modeling," *Remote Sens (Basel)*, vol. 12, no. 16, 2020, doi: 10.3390/rs12162624.
[8] R. Shults *et al.*, "Capability of Matterport 3D camera for industrial archaeology sites inventory," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* vol. XLII-2/W11, pp. 1059–1064, 2019, doi: 10.5194/isprs-archives-XLII-2-W11-1059-2019.
[9] https://matterport.com/blog/introducing-pro2-3d-camera-my-all-one-marketing-solution," Jun. 16, 2023.
[10] https://leica-geosystems.com/products/laser-scanners/scanners/leica-rtc360, Jun. 16, 2023.
[11] https://www.ediltecnica.com/project/villa-maraffa/, Jun. 16, 2023.
[12] F. Fabbi, "Villa 'La Maraffa' Vicende storico-architettoniche," vol. 5. 2007.
[13] K. Khoshelham and S. O. Elberink, "Accuracy and Resolution of Kinect Depth Data for Indoor Mapping Applications," *Sensors*, vol. 12, no. 2, pp. 1437–1454, 2012, doi: 10.3390/s120201437.
[14] M. Pulcrano, S. Scandurra, G. Minin, and A. di Luggo, "3D cameras acquisitions for the documentation of Cultural Heritage," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,*vol. XLII-2/W9, pp. 639–646, 2019, doi: 10.5194/isprs-archives-XLII-2-W9-639-2019.
[15] D. Gärdin and A. Jimenez, "Optical methods for 3D-reconstruction of railway bridges Infrared scanning, Close range photogrammetry and Terrestrial laser scanning," University of Technology, Luleå, 2018.
[16] https://support.matterport.com/s/article/How-Sunlight-Affects-MatterportScans?language=en_US&ardId=kA05d000001DX1g, Jun. 16, 2023.
[17] V. V Lehtola *et al.*, "Comparison of the Selected State-Of-The-Art 3D Indoor Scanning and Point Cloud Generation Methods," *Remote Sens (Basel)*, vol. 9, no. 8, 2017, doi: 10.3390/rs9080796.
[18] https://support.matterport.com/s/article/Scanning-a-Job-Site-for-Construction-Documentation?language=en_US&ardId=kA05d000001DWyY, Jun. 16, 2023.
[19] C. Popescu, B. Täljsten, T. Blanksvärd, and L. Elfgren, "3D reconstruction of existing concrete bridges using optical methods," *Structure and Infrastructure Engineering*, vol. 15, no. 7, pp. 912–924, Jul. 2019, doi: 10.1080/15732479.2019.1594315.
[20] T. Ogawa and Y. Hori, "Comparison with accuracy of terrestrial laser scanner by using point cloud aligned with shape matching and best fitting methods," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* vol. XLII-2/W9, pp. 535–541, 2019, doi: 10.5194/isprs-archives-XLII-2-W9-535-20