Article

Assessing the quality of static Terrestrial and Mobile Laser Scanning for a preliminary study of garden digital surveying.

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Abstract: Gardens play a key role in the definition of the cultural landscape since they reflect the culture, identity and history of a people. They also contribute to the ecological balance of the city. Despite gardens have an historic and social value, they are not protected as much as the rest of the existing heritage, like architecture and archaeological sites. While methods of built-heritage mapping and monitoring are increasing and constantly improving to reduce built-heritage loss and the severe impact of natural disasters, the documentation and survey techniques for gardens are often antiquated, inventories are typically made by non-updated/updatable reports, and rarely they are on digital format and in 3D.
This paper presents the preliminary results of a study on latest technology for gardens laser scanning. We compared static Terrestrial Laser Scanning and Mobile Laser Scanning point clouds, to evaluate their quality for documentation and the estimation of the tree attributes. The evaluation is based on visual observation and graphic comparison of the two point clouds acquired in different instances. Both methods produced useful outcomes for the research scope within their limitations. Terrestrial Laser Scanning is still the method that offers more accurate point clouds with a higher point density and less noise level. However, the more recent Mobile Laser Scanning is able to survey in less time, significantly reducing the costs for site activities, data post-production and registration. Both methods have their own restrictions that are amplified by site features, mainly the lack of plans for the geometric alignment of scans and for the Simultaneous Location and Mapping (SLAM) process. We also offer the results of a comparison of the functional range of the two machines, as well as for a comparison of their terrain information extraction capabilities.

Keywords: Terrestrial Laser Scanning; LiDAR; Mobile Laser Scanning; SLAM, Forest inventory, Garden documentation; Garden digital surveying.

1. Introduction

The number of disasters around the world increases every year [1]. To a great extent this is due to growing exposure in terms of people and assets, combined with decline of ecosystems and poor governance [1]. Disasters may result from various kinds of hazard, either natural in origin such as earthquakes and cyclones, or human-induced such as fire caused by arson, vandalism or armed conflicts [2]. Saving structures of heritage value from natural catastrophes and manmade hazard is the biggest challenge of our days.

Various categories of cultural heritage property will have their own specific needs for disaster risk management. These are determined by the specific nature of each heritage type based on its scale and character [2] but, in any case, the precise documentation and mapping of the existing state is an essential part of the site management system. It represents the primary data on which set up any kind of maintenance plan or define risk prevention actions.

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Historic gardens are mainly prone to fires, floods, environmental degradation, vandalism, dereliction and other manmade hazards, which can cause damage or even destruct the aesthetics and the natural balance of a garden.

Garden documentation and survey is often made by hand drawings, photographs, and topographic survey. These traditional survey techniques sometimes cannot organically put together the complex structure of a garden, made by vegetation, decorations as statues and unique fountains, scenographic views, geometric and non-geometric paths, complex hydric systems, caves, pavilions etc. The use of laser scanners today makes possible to overcome the difficulties linked to garden surveying, which are mainly having to measure large areas with reduced visibility - due to the presence of dense foliage - on uneven terrain, where geometric references are scarce. 3D scanners automatically detect and measure the surrounding space in few minutes. Point cloud density is incomparably greater than that obtainable with any traditional technique, so that the real space can be accurately reconstructed digitally.

The results presented in this article are a preliminary part of a wider research project that intends to analyse the applicability of laser scanning and digital photogrammetry in the production of graphic documentation and representation of historic gardens within the theme of digital technologies applied to heritage preservation. There is some research already developed in this area, among them studies that use the static Terrestrial Laser Scanning (TLS) method to register plants in historic gardens [3], studies that evaluate the applicability of Mobile Laser Scanning (MLS) in gardens [4][5] for the comparison of algorithms that extract tree information from the point cloud, and works that present the combination of laser scanning with digital photographs for the digitisation of these spaces [6][7][8]. This scientific production, which has been developing and improving since mid-2010, points to a promising path, in which there is still information to seek and knowledge to produce. Within this field of knowledge, the study prepared in this article focuses on the analysis of the data acquisition of green areas through laser scanning. More specifically, the article intends to compare data that has been captured with static TLS and MLS of the same wooded area.

Briefly, TLS and MLS are two types of 3D scanning technologies for data capture and point cloud generation. Both use terrestrial scanners and differ in that one has static and the other moving captures. Terrestrial Laser Scanning consists of a static capture method. The scanner is positioned at a fixed point on the ground (with a tripod or other accessory) and it typically acquires a single scan per station. The scanner is then positioned at another station and a new scan is performed. The process is repeated over the entire site, within the area intended to be surveyed. Scan accuracy and point cloud density is defined on the control panel of the scanner before data acquisition. For Mobile Laser Scanning, one or several captures are made while the scanner, fixed on non-stationary platforms, is moved in the area to be scanned. These platforms can be vehicles, backpacks or handheld systems [9]. MLS systems can use the Global Navigation Satellite System (GNSS) to calculate the positioning and orientation of the scanned area in space. Nowadays, most MLS systems are able to reconstruct the scanned virtual environment due to the use of Simultaneous Location and Mapping (SLAM) technology [9]. Through this technology, the scanner uses its own data acquisition process to estimate its positioning in space and to generate the point clouds [2].

Diverse studies - in terms of tools and methods - have been undertaken in recent years on both forest surveying and on historic gardens surveying [2] [5] [9] [10] [11]. In recent decades, the fields of cultural heritage and environmental sciences have seen their relations with digital technologies growing, including the use of sophisticated equipment to achieve more accurate field survey information. The analysis of this research will embrace these two universes, discovering and pointing out tools already developed within the field of environmental sciences that, applied to the context of the conservation of historic gardens, can contribute positively to the preservation of green areas.

Evaluations will be based on visual comparisons and measurements.

The chosen area for this study is located in the south border of Monsanto Forest Park. The park is part of the Lisbon municipality and it has a global area of 1,045.3 ha. It occupies most of the hill and works as a green space for the Lisbonites' recreation. The analysed area is about 3,000m2 and is near the Faculty of Architecture of the University of Lisbon. The area is part of what is identified as "Parque de Merenda Europa" and it consists of a natural terrain, shaded by a set of oak trees with trunks spaced at an average distance of 7m. The area also features wooden furniture and bins fixed to the ground, to support the recreational activities.

The remainder of this study is organized as follows: in Section II, we describe the method used for the analysis of the data, while the results are provided in Section III. Section IV presents our discussion on what we faced during the research activities and Section V conclusions and suggests some possible avenues to improve future research or works with the two scanners here presented.

2. Materials and Methods

2.1. Data acquisition

2.1.1. Scanners characteristics

Laser Scanner FARO Focus 3D 120 S was used for static TLS capture. The scanner operates with a laser wavelength of 905 nm, 360° field of view in the horizontal axis and 300° in the vertical axis. The minimum range is 0.6 m and it can reach a maximum distance of 120 m. The scanner has an integrated camera for captures with colour, but this feature was not utilised for this research.

Handheld Imaging Laser Scanner Leica BLK2GO was used for MLS capture. The scanner operates with a laser wavelength of 830 nm, field of view of 360° on the horizontal axis and 270° on the vertical axis. It has a minimum range of 0.5 m and maximum of only 25 m and point measurement rate of 420,000 pts/sec. The system includes a high resolution 12 Mpixel camera and rolling shutter for image capture along with scans and point cloud colouring, and three 4.8 Mpixel cameras and global shutter for visual navigation via SLAM.

2.1.2. Site activities

Data acquisition for this research was limited to scanning the site area (Figure 1) from ground level only. The surveys were conducted on two consecutive days and a single scanner was used on each day. On the first day, the area was surveyed with the FARO Focus by the researchers. On the second day, the same area was scanned by a surveyor from *Leica Geosystems* with the BLK2GO.

Figure 1. Site localization (1). The studied area is located in Monsanto Park (2), near by the Faculty of Architecture (4) of Lisbon (3).

The TLS survey required two people in the field, plus support equipment such as tripods, spheres and targets. The scanner was positioned along 27 stations with a maximum distance of 12 m between them to ensure good overlap between the scans and good visibility of the targets. The scanning process required the use of five reusable spheres, ten black-and-white fixed targets, and took about 3.5 hours to be finalised.

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The BLK2GO survey required only one person in the field holding the device and walking at a continuous pace around the trees. The scanning started and ended at the same point in one "walk". BLK2GO initialization – the communication between scanner and base station for the transmission of information related to the scanner localization – was never lost, which means that SLAM and VIS (Visual Inertial System) technology behaviour have been good for the entire scanning process. The survey took about 20 minutes.

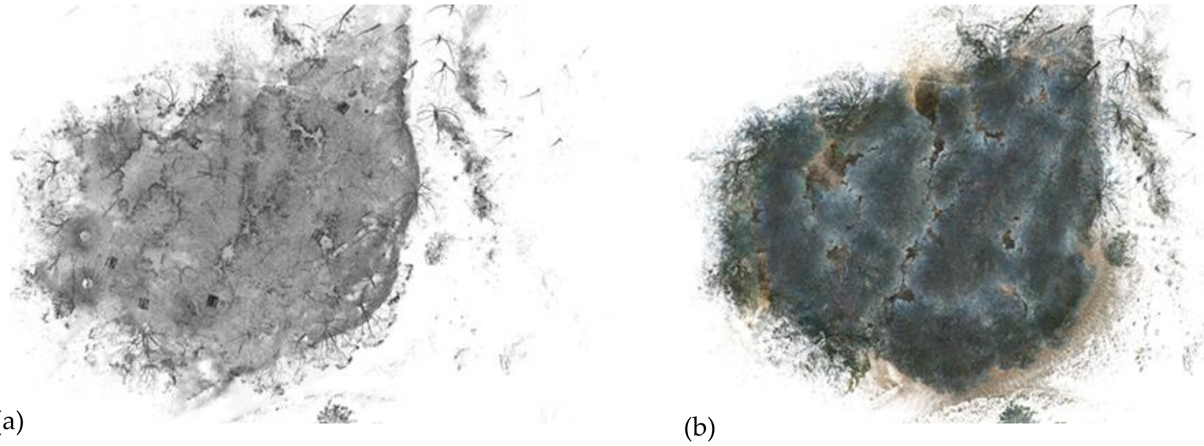
Both surveys covered a common area of about 2400 m^2.

The density of the point clouds generated by the FARO Focus was chosen before each capture from the machine control panel. Further, point accuracy and density was adjustable according to the requirements of the project. In this research, different resolutions were used depending on the conditions in which the scanner was positioned, and its distance from the targets and the scene elements. The selected values for both point cloud density and accuracy directly affect the speed of scanning. Increasing scanning time usually generates higher quality scans and decreases the level of noise in the captured data.

The density of the BLK2GO cloud depends on how fast the surveyor that operates the scanning walks; the slower the path is walked; the more details are obtained.

2.1.3. Point clouds processing and registration

The Leica Geosystems' operator, with our request to not apply cleaning filters to data, performed the first processing of the MLS point cloud. The result was a point cloud delivered in .e57 format with 139,787,408 points and a size of 4.25 Gigabytes. The scans made with TLS were processed and registered with FARO® SCENE software without the application of cleaning filters. The objective was to perceive the quality of the raw data produced by each piece of equipment; the application of cleaning filters could have inserted uncontrollable variables that would have affected the reliability of the point clouds and compromised the quality evaluation. Finally, both clouds were subsampled in the free software CloudCompare and the density values set at 1 point every 5mm. The densities were equalized with the objective of creating a controlled parameter of comparison between both, besides contributing to the reduction of the file sizes. The total areas scanned with each scanner can be seen in Figure 2.



(a) (b)

Figure 2. Surveyed areas with TLS (a) and MLS (b).

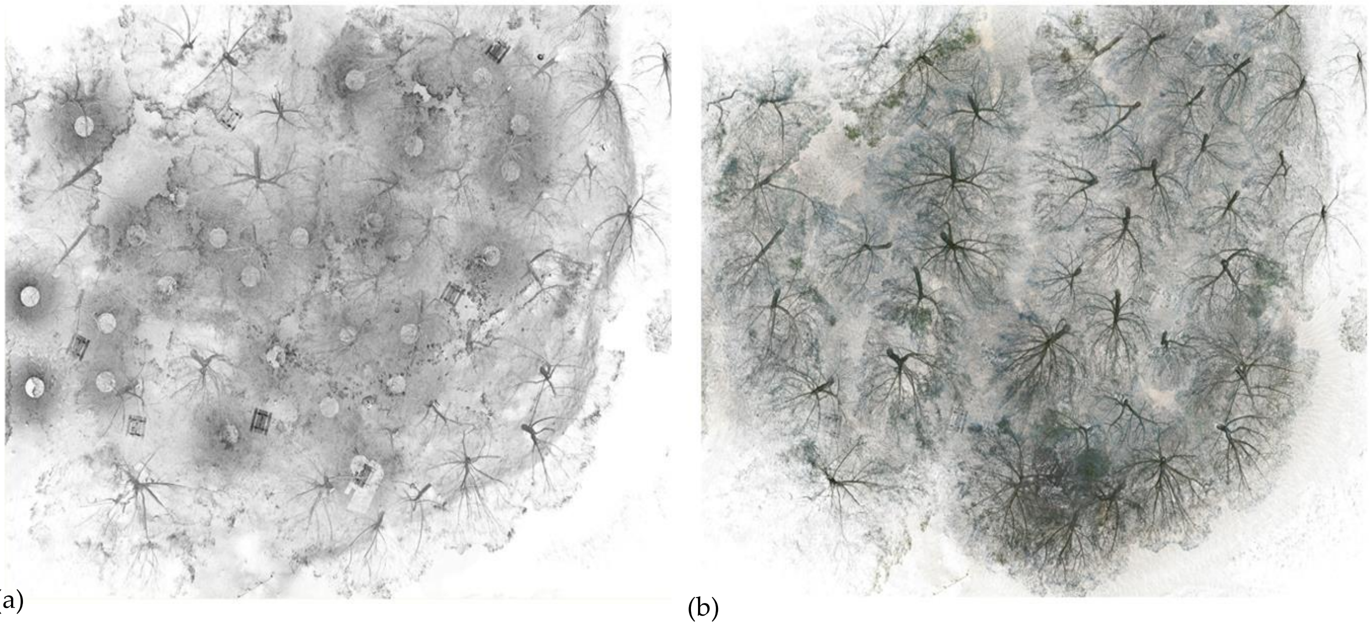
2.2. Analysis set up

2.2.1. Scans coordinate systems

The first step before data manipulation and analysis was the definition of operations to be performed in an identical manner in both clouds using CloudCompare. Before starting the comparison of the data, it was necessary to set the two clouds in the same position and orientation. We registered them together, as two different clusters, and then exported them to CloudCompare using a common local coordinate system. The mean registration error was 7 mm and the maximum error value was 10.19 mm.

2.2.2. Scope area

For the comparative analyses, we chose an area with good data coverage in both scans. Distant points were excluded from the research scope – they were significantly present in the TLS data, as scan rage was bigger and cloud cleaning was not performed. A cutting-out box was defined for the point clouds with the dimensions of 60 m x 49 m. After this operation, the TLS point cloud was reduced to 54,296,119 points and 798.8 MB; the MLS point cloud was reduced to 94,179,774 points and 2.86 GB. The result of the cut area in each point cloud can be seen in the orthoimages of Figure 3.



(a) (b)

Figure 3. Point clouds of the scope area obtained with the TLS (a) and MLS (b). Difference in density, detail accuracy and level of noise is already noticeable from this top view.

2.2.3. Point clouds information

For the acquisition of the point cloud via TLS, we decided not to acquire colour because it would have significantly increased the data acquisition time in the field. Regarding the quality of the cloud information, the TLS data shows more clearly the definition of the boundaries of the objects in the scene, such as the tables, the benches and, mainly, the tree trunks. The points on the trees are uniform in the Faro Focus scan. The MLS generates more noise throughout the scene, which contributes to more inaccuracy in the definition of the surfaces and the boundaries of the scanned objects. This characteristic of MLS is already known and is pointed out in other research [5] [9] [10].

2.2.3. Clouds deviation

We wanted to analyse the position of the trees between the two cloud for a primary validation of the acquired data. If the deviation of the two scans is lower than 40 mm we would consider the point clouds good enough to be used for further analysis, if not we would probably exclude future possibility to use SLAM technology for scanning wooded areas. Note that the clouds were not georeferenced nor inserted in a control network, so we are not evaluating the error related to control points in real space. We want to evaluate any significant differences between the two clouds obtained by TLS and MLS. Mainly because MLS uses SLAM technology and we want to analyse to what extent this technology can produce errors in a natural environment compared to TLS.

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A 10 cm thick slice of the two clouds, made 2 meters above the ground from the centre of the observation area, is shown in Figure 4: in red the Faro Focus' point cloud and in green the BLK2GO's. The two clouds coincide over the entire extent of the survey area.

Figure 4. The two point clouds are overlayed in a horizontal slice having a height of 10 cm: in red that of Faro Focus and in green that of BLK2GO.

The absence of major deviations between the two point clouds indicates that the SLAM system of MSL works well in sites with morphological characteristics similar to the ones analysed. It is important to keep in mind that scans made by MLS with very long duration or traversing very long paths are subject to larger cumulative errors that can generate significant distortions in the positioning of elements in space, but these data can be controlled before the scan as already demonstrated [2][5]. Therefore, under the conditions of the presented case study, the accuracy of the two point clouds is similar. The SLAM system was able to reconstruct the space of the forestry, even working in a densely wooded area with big canopies on slightly rough terrain, and without any regular geometry to use as landmarks.

3. Results

3.1. Data comparison

3.1.1. Tree canopy

For the first analysis, the point clouds were dissected along longitudinal and transversal planes, intersecting each other at the centre of the clouds. The visualization was adjusted to the cross-sections of the planes, and the information beyond the planes was retained. The objective was to visually verify the quality of the two clouds in the zones with better data capture (centralized area of the study object) and with greater canopy coverage. One of the first features that stands out is the more realistic appearance of the BLk2GO cloud, mainly due to the application of colour.

The point clouds comparison started with the check quality of the representation of the canopy. MLS seems to be able to construct better the total crown than TLS. However, a more careful evaluation is needed in this respect, since it is not clear if it is a better representation of the canopies or just a "filling" effect due to the higher level of noise. With a higher transparency of the crowns, and in a similar way to the trunks, branches seem to be better defined by TLS.

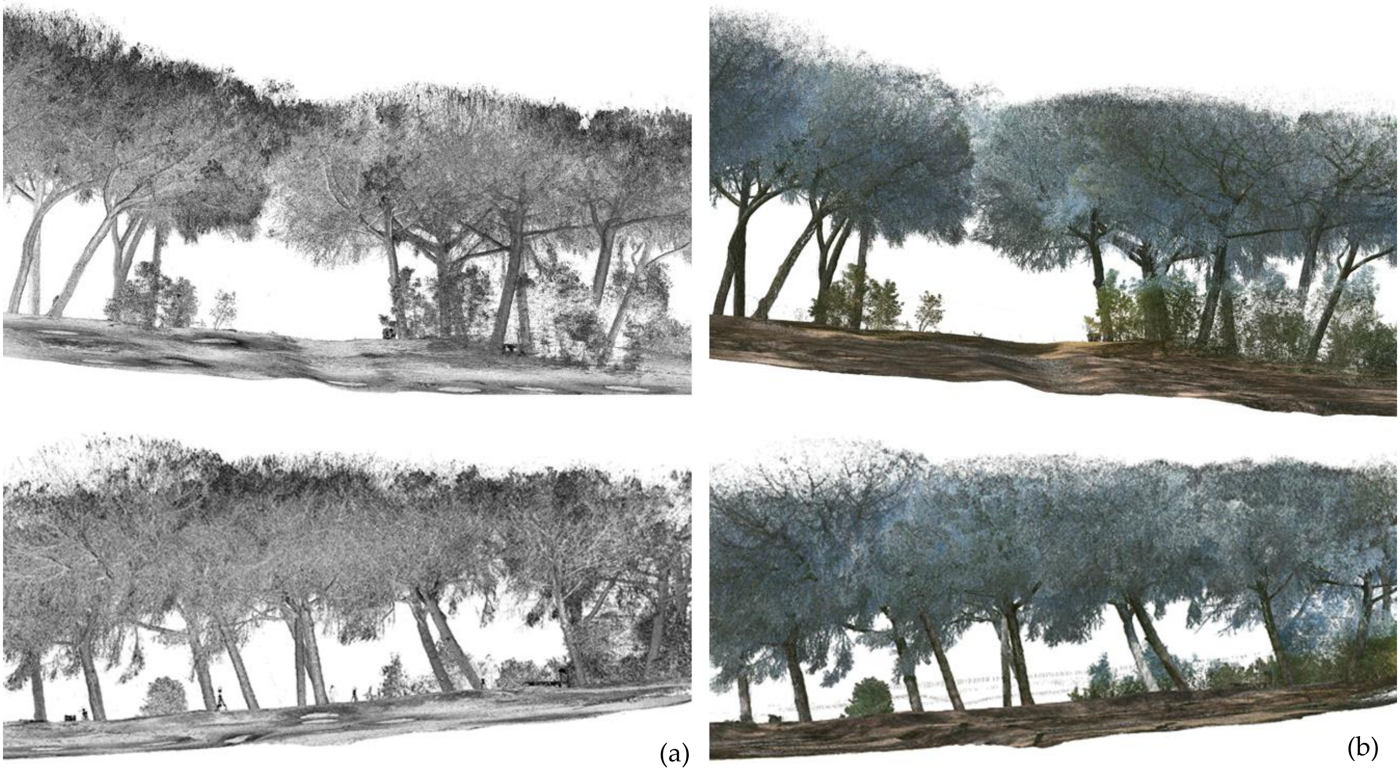

Figure 5. Point clouds of the scope area obtained with the TLS (a) and MLS (b), respectively.

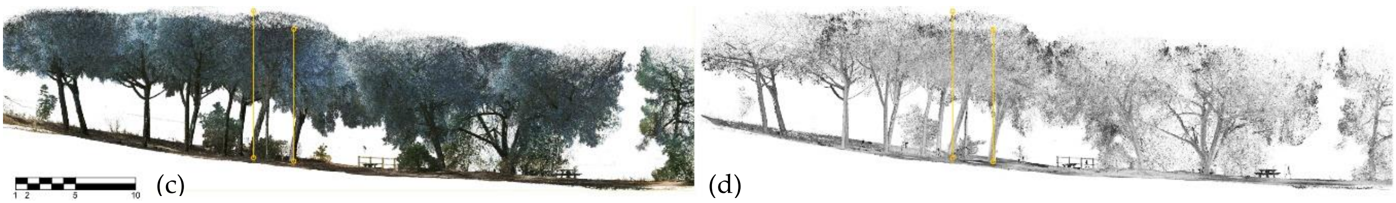

Figure 6. The tree crown profile is complete in both MLS (c) and TLS (d) scans. The value of tree heights resulted the same in both clouds, between 11 m and 12 m.

We then evaluated the maximum crown height of the trees as captured by the two scanners. A group of trees with a high crown density was chosen for the analysis. A cross section was generated to measure the total height of the crowns. Although the two scanners operate with different technologies and have differing degrees of operative limitations related to maximum range, light/shadow conditions and canopy movement, the results were similar. Both MLS and TLS measured the same crown heights with maximum points between 11 m and 12 m (Figure 6). The heights of the trees scanned for this research were within the operational range of both scanners.

3.1.2. Terrain and contour lines

The analysis of the quality of the terrain information was needed to subsequently create contour lines and evaluate the quality of this output. First, we had to separate the points on the ground from the other points in the cloud, for each cloud. To do this the

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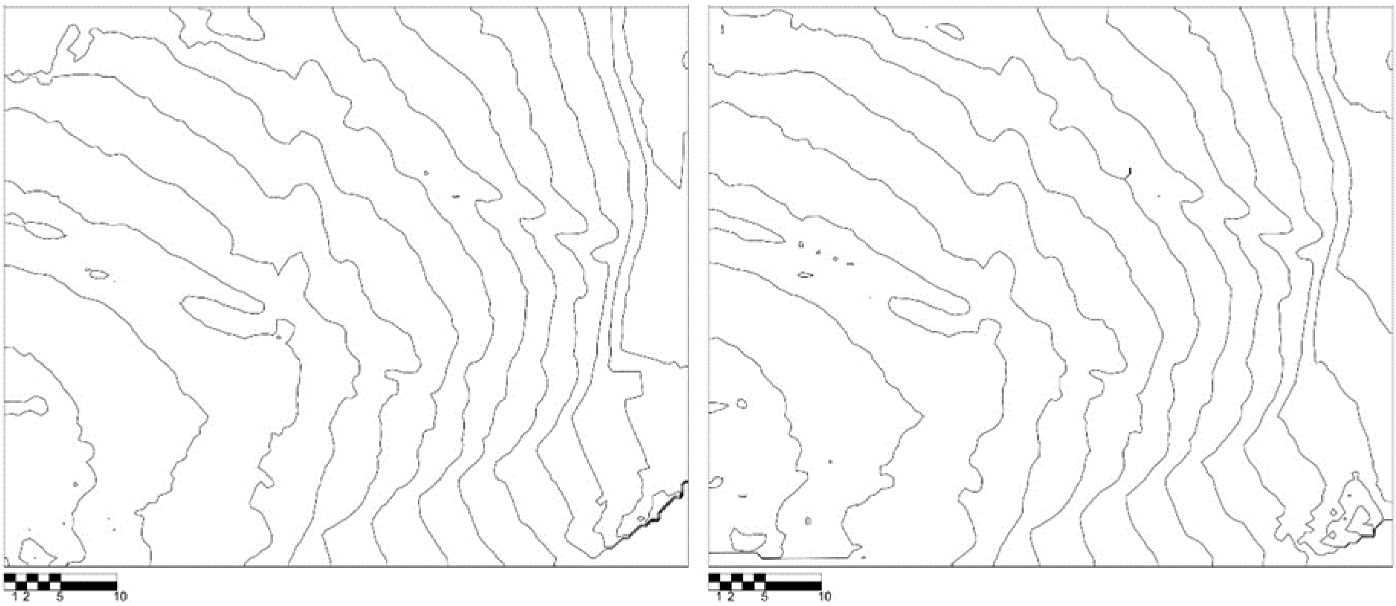
clouds were submitted to the CSF Filter Plugin [12] available in the CloudCompare software. Relief mode was used with Cloth Resolution and Classification Threshold set to 0.1 and Max Iterations set to 500. After segmentation, it was necessary to proceed to a visual inspection and manual cleaning of some remaining points (base of tree trunks and rest of shrubs close to the ground).

The Rasterize tool was used to construct contour lines. A grid of 0.5 was established, in Z direction, and with interpolation of empty cells. The contour lines were then made from the lowest point of each cloud, every 0.50m. The result, in Figure 7, shows similar contour lines, with both TLS and MLS able to provide a general morphology of the terrain. In some small area, the two images look slightly different. This is because both clouds still kept the points of the tripods and other working tools used on the ground during the scanning, and of the operators that executed the scans. When evaluated in detail, the curves produced by MLS show slightly more "oscillations" than the ones produced automatically from the Faro Focus scanner.



(a) (b)

Figure 7. Contour lines each 50 cm obtained from the Faro Focus's point cloud (a) and BLK2GO's (b).

It can be concluded that the contour lines obtained with TLS seem more accurate and reliable; however, MLS has proven to be a good tool for producing terrain profiles with relatively good information in a short time. With a few minutes scanning and some simple data processing it was possible to get extensive terrain information.

3.1.3. Trunk Diameter at Breast Height

Another important piece of information to be analysed is the quality of the definition of the trunks' boundaries in the horizontal cross sections. Laser scanning used for both forest mapping and historical gardens should produce good trunk cross sections at a height of 1.30 m, so that the Diameter at Breast Height (DBH) can be established. There are several studies [5][9][10] analysing this factor. One of the main causes mentioned as hindering trunk measurement was the level of noise in the sections of clouds generated by the MLS. High noise on the trunks' surface is usually corrected with cleaning filters that decrease the amount of points in the cloud. Thus, automatic detection and measurement of trunks by means of algorithms can be compromised [5]. Comparing the point cloud sections obtained with the two machines, a difference in the definition level of the points on the trunk perimeters is visible (Figure 8).

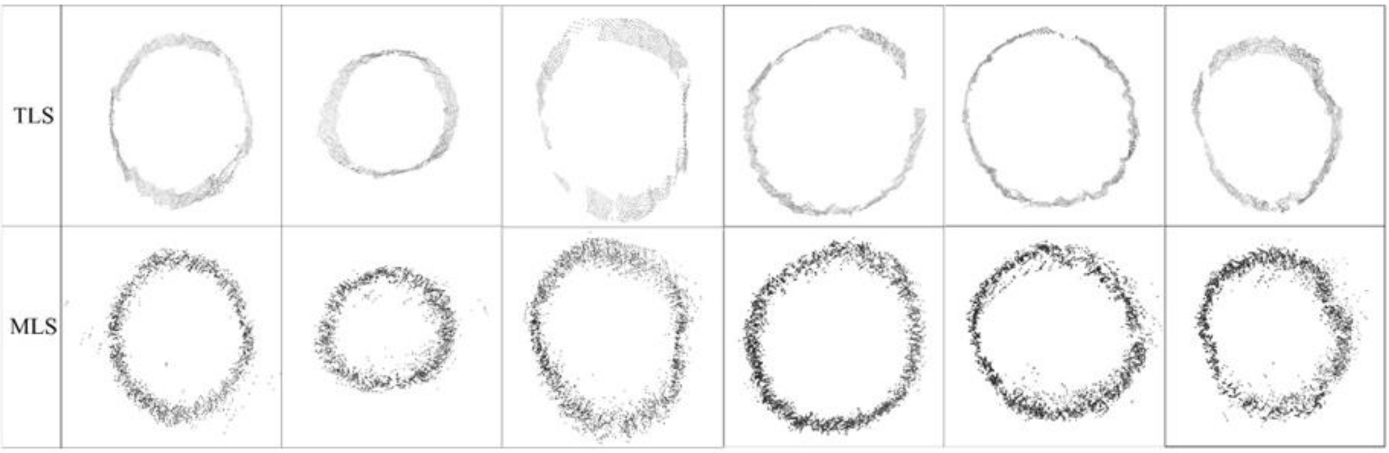


Figure 8. Horizontal sections of trunks obtained at a height of 2m from the ground.

Horizontal portions of clouds 10 cm thick and positioned 2 m above the ground were used for this comparison. The trunk sections, produced by BLK2GO and analysed without previous cleaning procedures, appear to have a good amount of points. Despite this, the points are scattered around what should be the surface of the trunk, which would hinder both manual and automatic construction of the trunk perimeter. The sections produced by Faro Focus present a greater density and uniformity of points and, consequently, a better geometric definition of the trunks. The characteristics observed in these two clouds repeat those already observed in other studies [5] [9] [10].

Although the MLS point cloud has a higher noise level, it is important to emphasise that MLS is able to detect more trees in a shorter scan time than TLS and, in doing so, is able to determine the complete shape of their trunks (Figure 9). Time is a factor considered important in this analysis. With a scan of about 20 minutes, MLS was able to provide a general mapping of the area and to represent the trees and their trunk totally. TLS, in a scanning process of about 3.5 hours, showed some difficulty in identifying complete sections of trunks and presented data with different levels of detail - detailing areas closest to the scanner positions and gradually reducing the information for more distant areas. Overall, the MLS took a more homogeneous reading and provided a better view of the site in less time.

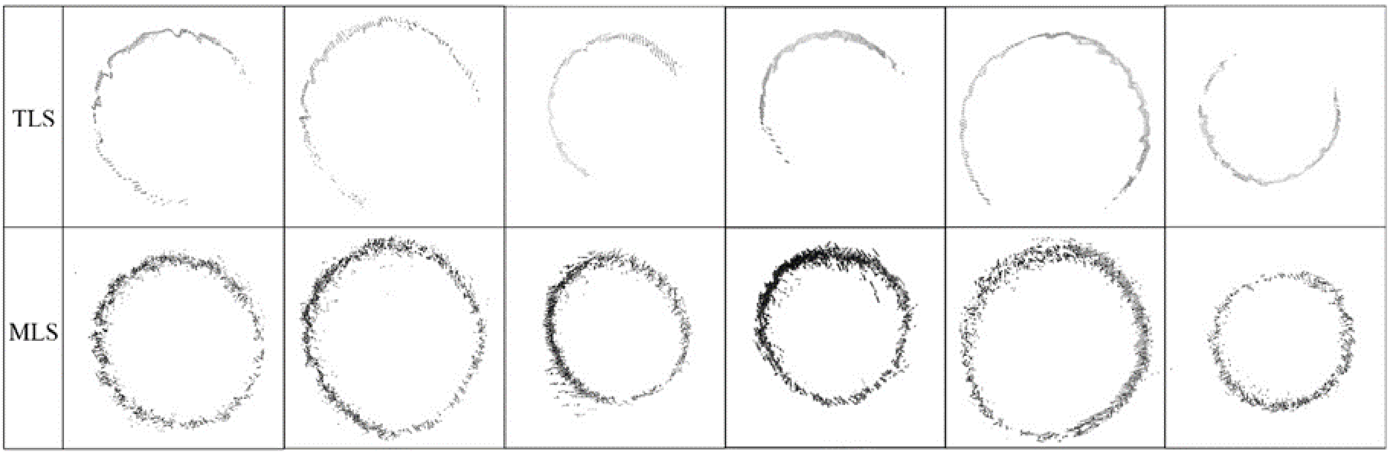


Figure 9. Horizontal sections of the trees on the periphery area obtained by TLS and MLS. Although with more noise, MLS is able to better define the sections in less scanning time.

4. Discussion

The main objective of the results presented above is to provide adequate information on the quality of point clouds generated for the creation of graphic documentation used by professionals for garden conservation projects. From this point of view, it is therefore important to give priority to scans that achieve greater precision in terms of measurements and spatial positioning of trees and furniture elements. On the other hand, when valuate the range of actions involved in heritage conservation, it is important to consider the use of survey data of historic gardens for the creation of other outputs - mostly visual - like web platforms and media, which sometimes do not require total precision. 3D reconstructions and the creation of virtual reality environments, for example, are two ways of using this data where sometimes a high accuracy is not required.

Despite the considerable advances in MLS technology in recent years, the TLS still produces information that is more accurate. Even with a lower quantity of points and a significantly smaller file size – also because the scans were not coloured – the quality of the points on the surface of the objects obtained with TLS is superior. The MLS point cloud used in this analysis has about 40,000,000 more points than the TLS point cloud, but the cloud shows more noise (Figure 10).

However, MLS was able to produce, in a very shorter time, a similar result that may prove satisfactory for garden documentation. In general, the TLS fieldwork and office work is considerably longer - in relation to the time required to complete the on-site scanning, the amount of equipment that must be loaded and moved during the process, and the additional time required to register the numerous scans acquired.

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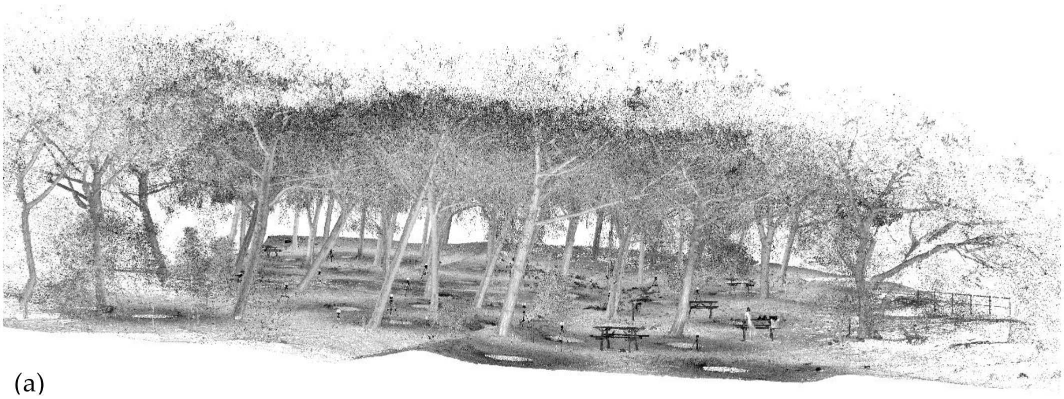
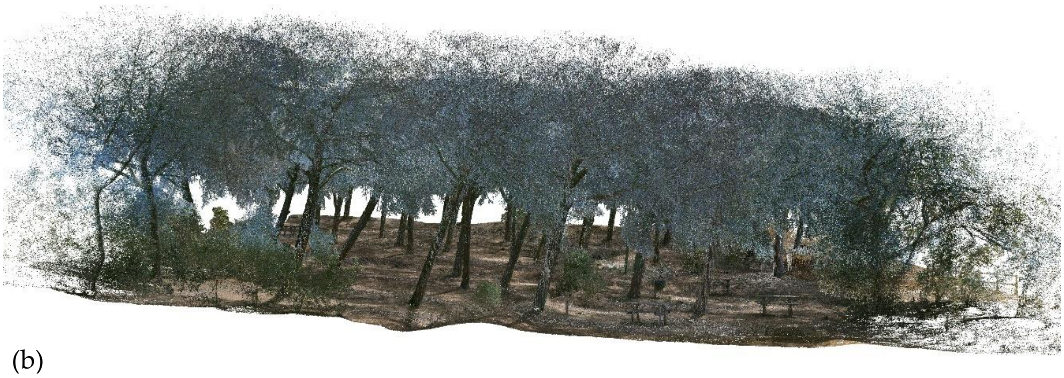


(a)



(b)

Figure10. Perspectivel view of the total surveyed area: TLS (a) and MLS (b).

MLS has been proven to be able, even with a lower precision, to produce similar results to TLS in many of the analyses conducted. The SLAM technology was able to scan a wooded area, with fast and good results despite the uneven terrain and the dense foliage. Another factor to emphasise in relation to MLS was its ease of handling on site in slightly rough terrain and its practicality compared to TLS in these same conditions.

Also, we did not test or discuss, in the analysis section, about the existing software for the manipulation of data acquired by BLK2GO, namely Cyclone 3DR by Leica Geosystems, that would enable semi-automatic extraction of tree diameters from point cloud. The work-flow consists in few steps and they are listed below. We marked with the letter (A) the ones that can be run automatically in order to give an idea of the easy process for the information extraction of trunk diameter:

- creating a digital terrain model (DTM) from the point cloud (A); shifting the created DTM of a certain Z value correspondent to the level – distance from the ground – on which the trunks will be cut and the trunks diameter will be extracted;
- splitting the point cloud to get a point cloud slice with a defined thickness – suggested value of 0.25 m – on the shifted DTM (A);
- isolating the created slice representing the trunk cuts and dividing the point cloud into portions corresponding to each trunk – it is used "split by distance" for this process with value set at 0.25 m (A). Trunks too close to each other must be separated manually;
- running the automatic extraction of "circle" selecting all the point clouds that correspondent to all the trunks (A); and sending directly the "circles" to Autodesk AutoCAD.

This feature available on Cyclone 3DR would save time for the operation related to the extraction of trees attribute, and also for the DTM automatic extraction.

Despite Cyclone 3DR would decrease the time for the operations described above, it must be taken into account the fact that the software is not open source and require a purchase of a license for product activation that could impact on the project budgeting.

In light of what has been said and the data collected in this research, the choice between TLS or MLS for surveying historic gardens is still hard to take. It falls under the following considerations: it depends on what the site conditions are (site extension, presence of a good level of light, accessibility, etc.), the information to produce and, above all, the time available for the survey.

To evaluate more clearly our experience with the two machines, we listed in Table 1 the main issues we faced during the surveying activities. We attributed to each of the issues an impact factor, from 1 to 5, for both scanners. The complexity of the operations, on site and in the office, increase for higher value of impact index and it takes into account costs, time, and health and safety procedures to take into account to complete the survey. This table should help comparing the operative differences between the Faro Focus 3D and the BLK2GO. The list of the "issues" is ordered in the real sequence they appeared, so the ones connected to site activities came first, and then the ones linked to evaluating raw data characteristics, clouds pre-processing, clouds processing and data extraction.

Table 1. Impact of the two scanners on land surveying work. The impact index, with value from 1 to 5, represents the level of complexity of the operations, costs, time, and health and safety procedures to take into account to complete the survey.

Issue N.	**Issue related to surveying historic gardens**	**Impact if used Faro Focus 3D** from 1 to 5 [1 low, 5 high]	**Impact if used BLK2GO** from 1 to 5 [1 low, 5 high]
1	Operators and equipment needed for site activities	5	1
2	Machine operating range	1	5
3	Lack of geometric references on site	5	5
4	Site reduced visibility (due to plants and other obstacles)	4	1
5	Site access (uneven or steep terrain, caves, etc.)	3	1
6	Need of using targets, spheres or ground control points	5	3
7	Scans time set up	5	1
8	Scanning time	5	2
9	Light dependency	1	5
10	Scanner battery consumption	2	5
11	Scans with colour	5	1
12	File size	1	3
13	Point cloud noise	1	3
14	Scans cleaning and filtering	3	4
15	Registration complexity	5	1
16	Tree attributes extraction and DTM creation	5	2
	Totale	**56**	**43**
	Avarage	**3.5**	**2.7**

The characteristics of gardens and wooded areas in general is the lack of geometric elements on site to be used as reference for connecting the scans between them. For this reason, choosing the static scanner Faro Focus 3D implied the indispensable use of fixed targets (in our case black and with targets and spheres), which dramatically increased data acquisition and registration time, and complexity; that is why issue n. 1, 3, 6, 8, and 14 got a high impact score.

The BLK2GO did not needed any target but it got anyway a 3 impact score for issue n. 6 because there was a risk that the scanner would lose its "initialisation" during our experiment and consequently required the help of ground references for completing correctly the data acquisition. The "initialisation" is the communication between the scanner and its base station for the data transmission and data reconstruction. The quality and validity of the scans produced by the BLK2GO depend on the SLAM technology and the VIS process, both working in remote connection with the scanner base station. SLAM uses resection and forward-intersection for the navigation between captures and detection of geometric feature in the field. The accuracy of the scans can be invalidated if the site does not have good geometric feature to be identified and captured by the scanner, or if the site characteristics do not permit the transmission of the stored data to the base station. The use of ground control points would increase control on the site operation and the accuracy of the scans. This process is suggested for larger sites than the one studied for this research

Regarding issue n. 2, which can also be a reference in the decision of which machine to use it is important to underline that MLS operating rage is limited to 25m distance, which forecloses the usage of the scanner for some sites, such as in urban area where buildings reach heights of more than 9 store. We measured oak trees about 12 m tall, in our experiment and the scanner offered a complete point cloud up to the treetops. But, for some historic gardens where hundred-year-old trees can be found that can exceed 25 metres in height, the MLS should be integrated with other digital survey technics or substituted by static TLS.

Also, issue n. 9 shows that MLS cannot be used in places with lack of light or by night since it works with integrated cameras that need a sufficient level of brightness to operate.

Issue n.10 impacts more on the operation with BLK2GO because one battery only lasts 40 minutes. We saw that in 20 minutes of scanning with the BLK2GO we acquired more data than with the Faro Focus. The scanner is equipped with two batteries by default. So, it is important to manage in advance this issue, finding the facilities where to charge the batteries during site activities.

5. Conclusions

The research presented in this paper compares data captured with Mobile Laser Scanning (MLS) and Terrestrial Laser Scanning (TLS) of the same forested area and analyses the efficiency of each method. The evaluations were restricted to visual observation and measurements. In general, MLS is able to survey a larger area, in less time and with greater ease of use on field than TLS. TLS, however, is still the method that produces more accurate results with a higher density of points on the surfaces of the objects present in the scanned area, which implies a better definition of the elements present in the site. Regarding the survey of historic gardens, the research concludes that the type of laser scanning to be used depends on the conditions available for the survey, its objective and the type of material one wants to produce. Both TLS and MLS present qualities to be exploited in the production of graphic documentation to support the preservation actions of green areas. The study also reinforces that MLS, when used following control parameters at the time of scanning, can be an important and efficient support to streamline the preservation actions of historic gardens by producing quality point clouds, in reduced time and with greater ease in field work.

However, there is a particularity of historic gardens, compared to other monuments or built heritage that can function as a determining factor in the choice between TLS and MLS and this factor is directly related to time. Most of the compositional elements of historic gardens are of a plant nature; therefore, they are alive, dynamic, perishable and renewable. These elements are subject to changes in time, natural cycles and climatic conditions. The practicality of MLS data acquisition, together with the relative accuracy and quality of the information obtained makes possible, for example, that a garden can be periodically scanned for plant growth according to the landscape architect's design. Furthermore, by doing so, the state of evolution of the garden is documented, as required by the Florence Charter [13].

Gardens often change shape, for example with the passing of the seasons, and MLS can be a tool that allows the frequent documentation of such changes. In general, MLS is able to represent the total scanned area more comprehensively and in less time than TLS. In just a few minutes, it is possible to reconstruct the garden spaces in a virtual environment and obtain important information from it.

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