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Short Paper

Mobile laser scanning of challenging urban sites: a case study in Matera

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(a) (b) (c)

Figure 1: *The result of mobile scanner acquisition of three urban spaces in Matera: (a) Vicinato Fondazione Sassi, (b) Vicinato Rione Malve, and (c) Vittorio Veneto Square.*

Abstract

The creation of 3D models of heritage and architectural sites requires proper technologies able to capture a wide area at fine geometric and appearance detail. In this paper we address the acquisition and digitization of three challenging Points of Interest in Matera, Italy. The sites, both outdoor and indoor, are characterised by limited accessibility, complex morphology and poor lighting conditions. We describe our experience with a portable, lightweight laser scanner, describing the planning, acquisition and post-processing phases, and providing some lessons learnt in order to achieve good results in terms of quality and resolution.

1. Introduction

Cultural Heritage has always been among the core application domains for 3D digitization. With the first scanning devices being manufactured in the last century, the Michelangelo project set a milestone in the digitization of large statues [LPC*00]. The value of digital copies of works of art and archaeological findings for conservation, restoration planning and documentation purposes was clear, but the technology was still expensive and the digitization procedure required high ICT expertise [CS08]. However, the challenges posed by the applications fostered fervent research in ICT and graphics, such as acquisition of material properties, cheaper and easier reconstruction, treatment and interactive visualization of high resolution models, data protection and semantic annotation [KTL*04, KE09, CMSF11, SMS20]. Later improvements in methodology and technology made it feasible to acquire larger areas and make digital data available for heritage democratization, monitoring and conservation [BCD*06], promotion of tourism, territorial enhancement and development [FQ21]. Latest developments allow acquiring 3D data at geographic scale, with the eternal trade-off between coverage, resolution, storage and processing capacity.

In this paper, we focus on modeling 3D cities. The geometric representation of the morphology and physical features (either built or natural) of the city, which can be annotated with additional information related to specific locations (green areas, buildings, points of cultural interest, etc.), has a high potential in describing, monitoring and/or predicting urban processes [CCD*19, SCMS22]. For instance, for smart tourism management, information from the geometric model can contribute to provide a virtual visit to non accessible sites (due to overcrowding, closing hours, or visitor disabilities) or a preview for the tourist to select the must-see spots in their day visit, simulate emergency egress, plan temporary events according to the capacity and morphology of the site, etc. However, building the geometric representation of the city poses some challenges concerning the availability and quality of large-scale data.

We focus on the scanning of specific limited urban areas, describing the case study of Matera, in southern Italy. A low resolution 3D model of the city centre has already been built [SCMS22]

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from aerial data. We aim to locally enrich this macro-level representation with dense representations of Points of Interest (PoIs) having historical, artistic, architectural or social value. We report on the acquisition of three PoIs in Matera, both outdoor and indoor, carried out over two days in May 2022, describing our experience with a latest generation device. We also describe post-processing aspects, sketching some lessons learnt and next developments.

2. Background

The creation of 3D models of heritage and architectural sites requires proper technologies able to capture a wide area at the fine geometric and appearance detail of such sites. We briefly recap the most accepted optical sensor technologies for the acquisition of medium/large sites. More details can be found in [Rem11, WWD*20]. Optical recording systems are classified into *active* and *passive* approaches. Active sensors cast laser beams or light patterns on a surface; analysing the time of flight or the phase shift between the emitted and received signal, or by triangulation, they register 3D data directly, in the form of point clouds or range images. Conversely, passive sensors (e.g., digital cameras) deliver 2D images that need processing to derive the 3D information.

Active technology is characterised by high costs and weight and lack of good quality texture/color information, but high accuracy. Terrestrial sensors work at fixed positions, from a few centimetres up to a few kilometres, with accuracy from microns up to millimetres. Time-of-Flight Laser scanners can also be mounted on mobile platforms, like cars, aircrafts or drones; aerial acquisition produces airborne LiDAR data (light detection and ranging) to be post-processed to achieve gridded elevation maps, or DEMs (Digital Elevation Models). Image-based modeling techniques [REH06] are generally more affordable, since a commercial digital camera can be used for acquisition. However, they are sensitive to environmental changes (e.g. ambient light, weather, darkness) and their accuracy is lower than active systems; passive methods are therefore preferred in case of monuments or architectures with regular geometric shapes. Images can be acquired using satellite, aerial or terrestrial sensors.

Nowadays there is still open discussion on which 3D scanning technique is better in which surveying situation. The combination and integration of different sensors and techniques are typically employed to survey large and complex sites [TRC*06, HF20, SCMS22]. [Rem11] points out that one must consider the following factors when planning an acquisition session: required accuracy of the survey; portability of the device, related to the accessibility of the site of interest; cost; acquisition time: heritage sites open to visitors can offer short time for the survey; flexibility: the device should cope with different area size, manage fine details and work in different conditions.

3. The Matera case study

Matera is a city in the region of Basilicata, in Southern Italy, characterised by a complex morphology with bare highland plateaus and deep ravines, one of the most evocative landscapes of the Mediterranean. The heart of the historical centre is Piazza Vittorio Veneto and the Hypogeum located underneath, built three thousand years ago, consisting of numerous underground levels and containing a huge water reservoir, the "Palombaro lungo" (see Fig. 2). The cistern is about 18 metres high and 50 metres wide; it has a capacity of 5 million litres and has been used as a water reservoir until 1920. Today, it is a popular tourist attraction and it is accessible through hanging metallic walkways and stairs.

Figure 2: *Left: view of the Vittorio Veneto square (the hypogeum is underneath). Middle, right: view of the indoor underground cavity.*

The adjacent "Sassi district" is a complex of cave dwellings carved into the river canyon. By the late 1800s, the site became noted for poverty and poor sanitation. Renewed vision and investment led it to be a noted historic tourism destination and a vibrant arts community, UNESCO world heritage site since 1993.Due to its natural conformation, the area is difficult to navigate: it is mainly pedestrian, except for two roads encircling and cutting the district, respectively. The narrow pathways exhibit a significant gradient, uneven paving and frequent steps. The pavement is made of smooth and slippery limestone blocks. Cave dwellings are built on several levels, one on top of the other, and it is often difficult to perceive the separation between the various housing modules (see Fig. 3).

Figure 3: *View of the Sassi district in Matera and detail of the dwelling configuration and pathways.*

The morphology of the historical centre suggested the digitization of PoIs using a terrestrial mobile device, which can be hand-held while walking. Indeed, an aerial acquisition would not capture the different levels of the dwellings, while data from a previous aerial survey is already available (see Fig. 4). The white limestone is highly reflective and the hollows and overlaps produce deep shadow areas, and the indoor Palombaro Lungo has low lighting. Therefore we selected active technology versus photogrammetry.

Figure 4: *Low resolution 3D mesh model of the city reconstructed from an earlier aerial survey. The Sassi area is highlighted.*

3.1. Device description

The device used in this case study is a Leica BLK2GO [Lei22], a mobile laser scanning system (see Fig. 5). It is a lightweight one-handed device capable of acquiring 4.2×10^5 points per second in a field of view of 360° horizontal and 270° vertical. The precision range is ± 3mm and the global accuracy is ± 10mm. The acquired point cloud is colored using images acquired from 3 cameras with which the instrument captures near-spherical photographs.

Figure 5: *Our portable laser scanner: Leica BLK2Go.*

The device integrates information from the laser scans, the cameras and an inertial platform, by applying proprietary algorithms. A survey is made of several partial acquisition sessions, called *walks*, each referred to its own local coordinate system; a significant overlap among walks is needed to co-register the partial point clouds. A mobile app supports the user in evaluating the achieved coverage in real-time. The device is battery-supplied; data are saved on its internal memory to be post-processed later (see Sect. 3.3).

3.2. Acquisition sessions

Each survey campaign has been designed to balance the quality of results with the required memory, post-processing time and real-time navigation of the final model. Surveys have been divided into several walks lasting a few minutes each and having about 50% overlay two by two. Indeed, such overlap allows the different point clouds to be recorded together in a single relief. The operator's movements during a walk should be as smooth as possible while acquiring distinctive features, like sharp edges, to facilitate registration and to avoid uncovered areas. In the case of complex geometries, the survey should be divided into shorter walks.

We acquired two outdoor areas in the historic centre of Matera, the so-called "vicinati", agglomerates of a tenth of small and iconic houses facing a common courtyard, having a high anthropological interest as points of aggregation of families. The third survey focused on the Palombaro Lungo, a challenging indoor environment with poor lighting, wide spaces and a high ceiling. Being the underground site below the main square of the city center, we also acquired the exterior to locate it in its urban context. This survey was divided into two separate sessions, requiring no more than two hours of fieldwork overall. First, we acquired the underground area and a small part of the exterior, to ease indoor and outdoor registration. Then, we focused on the outdoor square, starting early in the morning to reduce the number of bystanders as much as possible.

3.3. Post-processing

Post-processing operations must be carried out with Leica's proprietary software, Cyclone Register 360 [Reg], allowing data reading, processing and exporting to open formats such as LAS or e57. Firstly, data from different walks must be registered into a single cloud. This operation involves both manual merges of walk pairs and subsequent automatic fine registration. Then, point clouds often need to be cleaned from undesired features, e.g., structures outside the area of interest but within the scanner range, or noise. Passers-by produce characteristic point patterns called tress, while reflective surfaces produce a ghost effect. Finally, georeferencing places the data into a global geographic reference system. Georeferencing can be done either within Register 360 or externally, by capturing real coordinates of a few landmarks with a portable GPS. Georeferencing was not our primary objective, so we performed it only as a test on the "Palombaro Lungo" dataset (see Fig. 6).

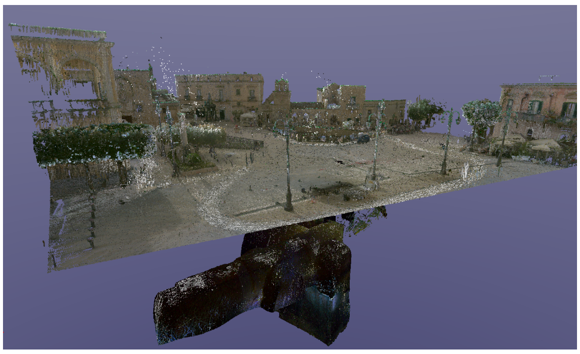

Figure 6: *View of the processed points cloud of Vittorio Veneto Square and the underground Palombaro Lungo.*

4. Discussion and conclusions

This work aimed to experiment with the use of a portable mobile scanner to build high-resolution models of urban sites of interest.

The BLK2GO scanner effectively allows PoIs with limited accessibility to be recorded in a very short time and guarantees high resolution (see Table 1), provided that the walks are properly designed and executed: movements should be smooth, to avoid losing the device calibration; characteristic features such as sharp edges should be included in the field of view since uniform landscapes or open spaces can cause the correct positioning to be lost and produce drift effects; a sufficient overlap must be guaranteed; the point cloud preview given by the app is useful to avoid finding uncovered areas after the campaign. The optimal number of walks depends on surface area, morphological complexity and presence of features.

Area	Points	Area [m^2]	Walks	PPT
Rione Malve	$\sim$ 70M	$\sim$ 650	4	$\sim$1
Fondazione Sassi	$\sim$ 80M	$\sim$ 500	3	$\sim$1
Palombaro Lungo	$\sim$ 380M	$\sim$ 4000	13	$\sim$3

Table 1: *For each site, we report ground surface area, number of walks, points of the resulting clouds and required post processing time (PPT), measured in full workdays (8 hours). The "Palombaro Lungo" refers to both the cistern and the external square.*

Despite the optimal speed of data acquisition, post-processing still requires a very long time (roughly one day for each "vicinato" and two days for the Palombaro Lungo), necessary to both align walks two by two and to remove possible noise (i.e.standing and moving pedestrians and vehicles). Post-processing timings can be reduced by properly designing the acquisition survey, planning each walk in terms of starting/ending point and path, guaranteeing good overlaps between walks, and banning or reducing the access of external agents (e.g. people) into the acquired area.

The acquisition of the underground cistern "Palombaro Lungo" allowed us to test whether and how much low lighting would influence the quality of results. As expected, low lighting did affect the data resolution but the point cloud coloring, given by on the scanner cameras. This test case also showed a positive performance of the scanning range given the very high ceiling. The acquisition survey along Vittorio Veneto square allowed to test the instrument in a wide open space, where the diametrical length was longer than the scanner range. We did several walks guaranteeing good overlaps, but not too much redundancy.

The experience gained from our case study suggests the combined use of the mobile system with a static laser scanner, for indoor and outdoor sites respectively, as the most promising setup.

Future works will address the merging of high-resolution PoI data with low-resolution models of wide urban areasas advanced level-of-detail representations of the city for smart tourism and city management. Detailed 3D modeling allows the remote visit of PoIs with poor accessibility (e.g., through VR exploration). Regular scans and documentation of sites would allow in-depth studies, such as degradation monitoring and intervention planning. Citizen engagement could determine the priority of sites for digitization while increasing the sense of belonging and the appreciation of the common legacy.

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References

[BCD*06] BRIZZI M., COURT S., D'ANDREA A., LASTRA A., SEPIO D.: 3D laser scanning as a tool for conservation: the experiences of the herculaneum conservation project. *The evolution of Information Technology in Cultural Heritage. 7th Int. Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST)* (2006), 72–78. 1

[CCD*19] CASTELLI G., CESTA A., DIEZ M., PADULA M., RAVAZZANI P., RINALDI G., SAVAZZI S., SPAGNUOLO M., STRAMBINI L., TOGNOLA G., ET AL.: Urban intelligence: a modular, fully integrated, and evolving model for cities digital twinning. In *IEEE 16th Int. Conf. on Smart Cities: Improving Quality of Life Using ICT & IoT and AI (HONET-ICT)* (2019), IEEE, pp. 033–037. 1

[CMSF11] CATALANO C., MORTARA M., SPAGNUOLO M., FALCIDIENO B.: Semantics and 3D media: Current issues and perspectives. *Computers & Graphics 35*, 4 (2011), 869–877. 1

[CS08] CIGNONI P., SCOPIGNO R.: Sampled 3D models for CH applications: A viable and enabling new medium or just a technological exercise? *JOCCH 1* (2008). 1

[FQ21] FERRETTI M., QUATTRINI R.: *Digitization and Design of Archaeological Heritage: An Interdisciplinary Research Approach to Flaminia Cultural District*. Springer International Publishing, Cham, 2021, pp. 909–930. 1

[HF20] HASSAN A., FRITSCH D.: Integration of laser scanning and photogrammetry in 3D/4D cultural heritage preservation – a review. vol. 9, pp. 76–91. 2

[KE09] KURT M., EDWARDS D.: A Survey of BRDF Models for Computer Graphics. *SIGGRAPH Comput. Graph. 43*, 2 (may 2009). 1

[KTL*04] KOLLER D., TURITZIN M., LEVOY M., TARINI M., CROCCIA G., CIGNONI P., SCOPIGNO R.: Protected Interactive 3D Graphics via Remote Rendering. *ACM Trans. Graph. 23*, 3 (2004), 695–703. 1

[Lei22] LEICA GEOSYSTEMS: Leika BLK2GO - Mobile Mapping. https://shop.leica-geosystems.com/it/it-IT/leica-blk/blk2go, 2022. 3

[LPC*00] LEVOY M., PULLI K., CURLESS B., RUSINKIEWICZ S., KOLLER D., PEREIRA L., GINZTON M., ANDERSON S., DAVIS J., GINSBERG J., SHADE J., FULK D.: The Digital Michelangelo Project: 3D Scanning of Large Statues. In *Proc. 27th Annual Conf. on Computer Graphics and Interactive Techniques* (2000), p. 131–144. 1

[Reg] Leica Cyclone Register 360. https://leica-geosystems.com/en-us/products/laser-scanners/software/leica-cyclone/leica-cyclone-register-360. 3

[REH06] REMONDINO F., EL-HAKIM S.: Image-based 3d modelling: A review. *The Photogrammetric Record 21*, 115 (2006), 269–291. 2

[Rem11] REMONDINO F.: Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning. *Remote Sensing 3*, 6 (2011), 1104–1138. 2

[SCMS22] SCALAS A., CABIDDU D., MORTARA M., SPAGNUOLO M.: Potential of the geometric layer in urban digital twins. *ISPRS International Journal of Geo-Information 11*, 6 (2022). 1, 2

[SMS20] SCALAS A., MORTARA M., SPAGNUOLO M.: A pipeline for the preparation of artefacts that provides annotations persistence. *Journal of Cultural Heritage 41* (2020), 113–124. 1

[TRC*06] TEO T.-A., RAU J.-Y., CHEN L.-C., LIU J.-K., HSU W.-C.: Reconstruction of complex buildings using LIDAR and 2D maps. In *Innovations in 3D Geo Information Systems*. 2006, pp. 345–354. 2

[WWD*20] WANG C., WEN C., DAI Y., YU S., LIU M.: Urban 3D modeling with mobile laser scanning: a review. *Virtual Reality & Intelligent Hardware 2*, 3 (2020), 175–212. 2