FAST SURVEY PROCEDURES IN URBAN SCENARIOS: SOME TESTS WITH 360° CAMERAS

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ABSTRACT:

The use of spherical cameras (with a field of view of 360°) is becoming increasingly popular for photogrammetric applications characterised by the opportunity to capture entire scenes in a relatively short time.
This potential may be even more interesting for the digitisation of complex areas where, in addition to geometry, time, cost and social context play an important role.
This contribution is part of this field of investigation by describing two experiments conducted on the use of an inexpensive 360° camera, the Insta360 OneX2, for the expeditious survey of residual spaces below road junctions.
The area under investigation is a node in the city of Naples (Italy) located in the eastern area, considered particularly significant for the interaction between the geographical and infrastructural system.
Two different approaches are tested starting from the acquisition of the spherical photographic dataset: the traditional one by means of photogrammetric software and the more economical and user-friendly one by employing the Matterport Capture application. Pros and cons of the two approaches are discussed: the first experimental results are encouraged and support the validity of the approach for surveying complex urban spaces.

1. INTRODUCTION

In the last decade, the use of spherical images acquired with panoramic cameras for three-dimensional modelling in digital documentation projects has become increasingly popular.
This popularity is due to the advantage that spherical acquisitions provide in terms of speed and ease of data acquisition. A documentation project using spherical photography, in fact, is characterised by the capture of images of a specific scene from a small number of predetermined observation points. From these points, information is recorded with a field of view of 360°. In addition, the speed of documentation collection activities is further ensured by the recent diffusion on the market of digital cameras specifically dedicated to the production of panoramas. Such cameras are interfaced with photo-capture applications already prepared for an internal stitching such as to bypass the traditional image stitching operation, providing an equirectangular photograph without geometric inconsistencies (Barba et al., 2019).
It is obvious that the opportunity to use panoramic photographs for metric documentation purposes is closely linked to the codification and subsequent consolidation of the mathematical process of spherical bundle adjustment. Through this correction, it is possible to compute the external and internal orientation parameters that are indispensable for the determination of the photogrammetric point cloud. A comprehensive discussion of the theory, based on methods for adjusting geodetic networks based on angular measurements, can be found in Fangi (2007). The theorisation of spherical photogrammetry developed is based on the principles of classical photogrammetry and uses spherical panoramas without taking the perspective centre into account: the reconstruction of the spatial position of points is conducted by knowing the orientation of the spherical images and ensuring the spatial intersection between images in which the points to be reconstructed are recorded in at least two panoramas (Fangi, 2009; D'Annibale & Fangi, 2009; Fangi, 2017).
Since these first experiments, an increasing number of studies have focused on the validity of the application of panoramic images for surveying at different scales, from urban to architectural to archaeological complexes. Several authors have discussed the results that can be obtained using equirectangular images acquired with a variety of instruments ranging from more expensive sensors to the cheaper 360° cameras now widely available on the market. A few examples discussed in (Kwiatek et al., 2015; Agnello & Cannella, 2022; Herban et al., 2022), illustrate the different case studies with the relative scales of investigation as well as the refined processes of testing the metric accuracy and completeness of the obtained model comparing it with the outputs achievable with a laser scanner or traditional photogrammetry.
Undoubtedly, great impetus in this direction is given by the commercialisation of software based on the Structure from Motion (SfM) image processing workflow for 3D modelling (e.g. Agisoft Metashape, Pix4Dmapper) that can easily support various spherical camera models even without the need for a prior calibration phase.
At the same time, the development of high-resolution but low-cost panoramic cameras has led to an increasing tendency to employ such devices for digital documentation projects that are particularly critical for various reasons: when data collection is required in areas where accessibility is reduced and/or large spatial extensions are involved and/or acquisition times must necessarily be compressed (Abate et al., 2017; Mandelli et al. 2017)
In this context, there is no lack of research that differs from previous work in the direct use of spherical video instead of static images to make acquisition very rapid. On the other hand, a series of in-studio processing is required to refine the orientation of the images in space and guide the process of extracting homologous image points (Zhao, 2021; Barazzetti et al., 2022).
Finally, reinforcing the use of spherical cameras, even at low cost, for digitisation projects is the availability on the market of

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extremely simple and friendly applications for smartphones and the web, developed by companies to produce the increasingly popular 'digital twins'. Among these, the most recent and probably most popular is the Matterport Capture application linked to the web platform of the company Matterport, which also produces, among other products, instruments specifically intended for spherical photogrammetry applications (e.g., the Matterport Pro3). Using the Matterport Capture App, it is possible to take photographs using spherical cameras - among those supported by the application - or to take photographs with one's mobile phone that will then be automatically stitched. The application offers users the possibility of uploading their photographic dataset to the company's web platform, which, via a cloud system based on Artificial Intelligence algorithms, aligns and combines the photographic shots by processing a 3D model in the form of a textured mesh (Shults et al., 2019; Pulcrano et al., 2019; Ingnam et a., 2020).
This contribution is part of this field of investigation by describing two experiments conducted on the use of an inexpensive 360° camera, the Insta360 OneX2, for the expeditious survey of residual spaces below road junctions.
The purpose of the work and the motivations behind the choice of instrumentation and process are discussed in Section 2.
As will be discussed in detail in section 3, the dataset acquired with the spherical camera was processed according to two different approaches: the traditional using photogrammetric software and the more economical and user-friendly using the Matterport Capture application. Pros and cons of the two approaches are discussed in the last paragraph.

2. AIM OF THE WORK

The research presented comes from the work carried out for he B-ROAD project[1], whose acronym stands for ‘Below the Road’, aimed at developing urban design strategies for upcycling urban infrastructure residual pockets in the city of Naples (Italy), converting them from waste to resource
In particular, in order to digitise the analysed spaces, necessary for the prefiguration of possible urban regeneration intervention scenarios, data acquisition and processing methods were investigated that were expeditious, economical and at the same time adequately accurate from a metric and colorimetric point of view.
With this objective in mind, B-ROAD used rapid mapping and modelling tools capable of returning digital models derived from image-based point clouds structured from spherical photographs, exploiting Structure from Motion algorithms (Stendardo et al., 2022).
The decision to use 360° cameras responds, as previously stated, to several needs related to the project's field of investigation, which deals with architecturally complex areas such as infrastructure nodes. Surveying and digitising such contexts raised the following needs: (i) to consider expeditious acquisition methods for the documentation of very large areas in terms of extension; (ii) to consider equipment suitable for the collection of information related to contexts characterised by difficulties of access with large instruments due to the presence of physical barriers (i.e. road junctions and viaducts with significant machine flow) (iii) consider inexpensive tools for the documental survey of areas located in socio-cultural contexts that are very difficult from the point of view of safety; (iv) consider survey methods that allow a digital model to be obtained as an output that, due to the objectives of the project, balances metric accuracy - a level of precision of the metric datum on the order of a centimetre - and the photorealism of the surface texture.
Starting from these considerations, this contribution describes two solutions developed to overcome these critical issues, analysing pros and cons and possible future developments.

2.1 Case study

The geographical area on which the B-ROAD project focuses is the city of Naples (Italy), which is considered particularly significant because in it the interaction between the geographical and infrastructural systems has generated a wide range of interstitial spaces, differing in shape, position, extension and relations with contexts (Figure 1).
Within this area, project actions have been specified for the eastern part of the city located close to important logistic poles, such as the airport, the port and the central station. Their proximity determines a density and variety of infrastructural clusters (railways, motorways, oil pipeline), present in the eastern area, which is intertwined with the presence of a large industrial and hydrocarbon storage area, now being decommissioned.

Figure 1. Urban infrastructure network of the B-ROAD project. In red the road node under study. Image by Raffaele Spera and Luigi Stendardo.

For the purposes of the experimentation, the specific geographical field of interest is represented by the road junction located in the East Naples area, south of the Naples Gianturco railway axis and near the San Giovanni a Teduccio station. This is where road systems of different degrees converge and branch off: an elevated portion of via Argine that bifurcates via a roundabout, also elevated, into two branches, one of which reconnects to the flat portion, becoming via Galileo Ferraris, the other of which continues southwards, flowing into via delle Repubbliche Marinare. Parallel to this, at high altitude, is the axis of the A3 highway (Figure 2).

[1] *B-ROAD_Below the Road. Pilot scenarios for the upcycling of urban infrastructure residual space*, two-year research project selected and funded in the framework of the call Finanziamento della Ricerca di Ateneo, FRA 2020, University of Naples Federico II. Research Team: Luigi Stendardo_Architectural and Urban Design (Principal Investigator), Vittorio Marzano_Transportation Engineering, Valeria Cera_Representation of Architecture, Raffaele Spera_Research Fellow.

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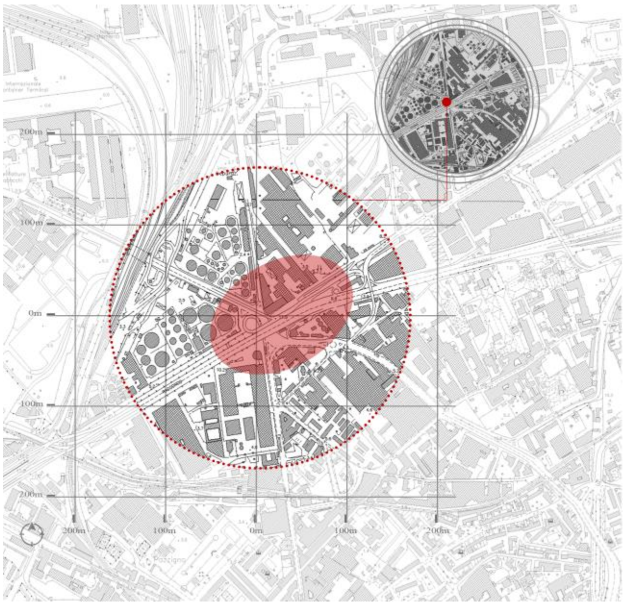

Figure 2. East Naples. Detail of the urban intersection subject to experimentation.

2.2 Materials

The use, in generic terms, of spherical cameras for surveying infrastructural constructions and, in detail, carriageway bridges is supported by a number of studies that have encouraged an initial validity of the approach (Crabtree Gärdin & Jimenez, 2018; Popescu et al., 2019).
Among the 360° cameras available today - a selection of which is shown in Table 1 as an update of the overview proposed by Garmin et al. (2022) -, a low-cost, high-resolution panoramic camera, the Insta360 OneX2, was chosen for the digitisation of the study area.

Camera	Resolution [Mpix]	Level [price range]
Ssstar	16	Entry [200€ -300€]
GoXtreme Dome 360	8	
Nikon KeyMission 360	23.9	
Xiamo Mijia Mi Sphere 360	23.9	
GoPro Max	16.6	Medium [500€ -1000€]
Ricoh Theta Z1	14.4	
Garmin VIRB 360	15	
Insta360 OneX2	18.4	
iStar Fusion 360	50	High [1000€ - …]
Insta360 Titan	55	
Weiss Ag Civetta WAM2	230	
Matterport Pro 3	20	

Table 1. Classification of some commercial 360° cameras.

This is an omnidirectional camera in which the construction of the spherical field of view is achieved by means of polydioptric sensors, i.e. 2 fisheye lenses. Specifically, the Insta360 OneX2 consists of two cameras, with one f/2 lens facing forward and another facing backward. The two sensors with fisheye lenses enable the construction of the panoramic image generally represented in equirectangular projection in which the distortion of features increases linearly from the centre to the sides of the panorama, as schematically shown in Figure 3.

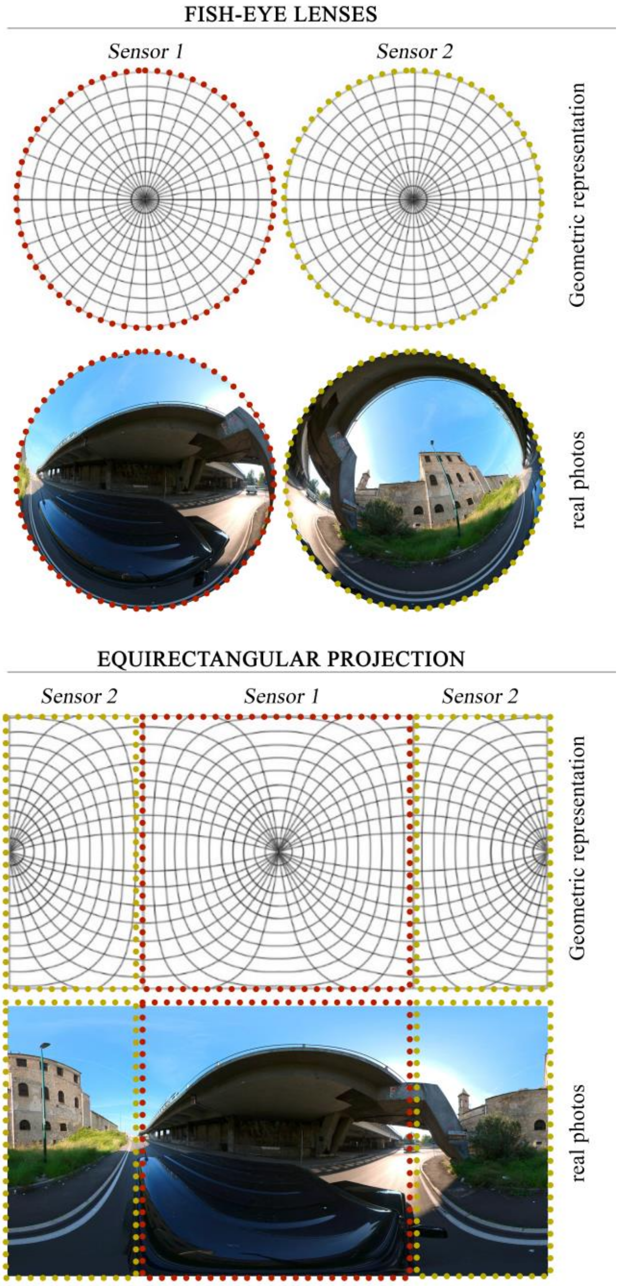

Figure 3. Geometric configuration of the equirectangular projection generated using fish-eye lenses by Insta360 OneX2.

Evidently, the selection of such instruments was the result of a compromise between price and technical performance - a summary of which is shown in Table 2 - that, as will be shown in the last section, fulfilled the starting conditions and premises. Furthermore, since two different systems were used for data acquisition and processing, the Insta360 was used in conjunction with a smartphone with an IOS operating system, connected via Wi-Fi to the camera for the control of image capture.

3. SURVEY METHODOLOGY

For the survey of the study area, two different data processing methods were tested, both based on the use of the Insta360 OneX2, for the acquisition of spherical shots.

Insta360 OneX2	
Aperture	F2.0
Dimensions (W x H x D)	4.62 x 11.30 x 2.98 cm
Video Resolution (360)	5.7K@30fps, 25fps, 24fps 4K@50fps,30fps 3 K@100fps
Photo Resolution (360)	6080x3040 (2:1)
ISO	Auto, 100-3200
Exposure Value	±4EV
Gyroscope	6-axis gyroscope
Color Profiles	Vivid, standard, LOG
Video Coding	H.264, H.265
White Balance	Auto, 2700K, 4000K, 5000K, 6500K, 7500K

Table 2. Technical features of Insta360 OneX2.

3.1 Data acquisition

In the first solution, equirectangular images were recorded with the camera using the dedicated smartphone application, the Insta360 App. The panoramas acquired on site were processed, later than the instant of acquisition, in the well-known SfM Agisoft Metashape software. The application, in fact, supports equirectangular images as input for the construction of 3D models using the collinearity equations for spherical panoramas.
In the second solution, on the other hand, the Matterport Capture application was tested for IOS systems which, supporting spherical cameras such as the Insta360, allows the display of the device used (in this case a smartphone, of the Iphone type) to show in real time the point cloud that position after position is automatically composed during the data collection phase.
The acquisition phase was similar for both procedures: approximately 200 photographic shots were taken with a distance between one station and the next of approximately 3 m and a height from the ground of approximately 1.80 m, achieved by installing the camera on a special support.
The surveyed area has a linear extension of approximately 50,000 sq. m. and is divided into a road with a cross-section of approximately 5 m. This runs, in some areas, parallel to but at an elevation 7 m lower than the carriageways of the elevated viaduct of via Argine with a North-East/South-West orientation.

3.2 Data processing

With the first method, the spherical images were imported into Metashape and processed according to the well-established photogrammetric reconstruction pipeline (Figure 4). The orientation of the images was done correctly without the need to refine the external orientation data with additional information (Figure 5).

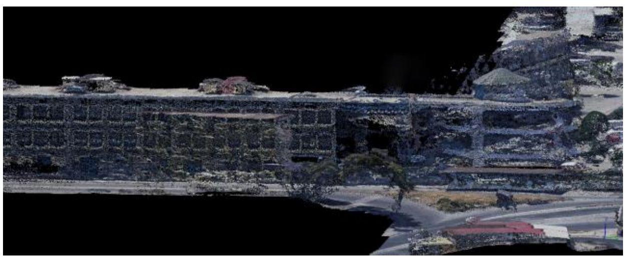

Figure 4. Point cloud obtained in Metashape with Insta360 camera. Detail.

Retracing the same trajectory and approximately the same station points, the acquisition was repeated on site using the Matterport app. Also in this second experiment, it was decided to keep the same distance between one station and the next (around 3 m) although the company recommends using a shorter acquisition radius, around 1 metre. Evidently, given the extension of the study area and the need expressed in the introduction to conduct a expeditious survey, it was unthinkable to take too many photos and thus increase the time taken to gather information.

Figure 5. Point cloud obtained with SfM algorithms applied to spherical panoramas that are correctly oriented.

The partial point clouds, relating to each station of the instrument, were progressively displayed in real time on the display of the smartphone, via the app that allows the camera to be managed using the Wi-fi connection (Figure 6).
This made it possible to verify the trajectory and adequacy of the acquisition points in order to avoid gaps in the final point cloud.

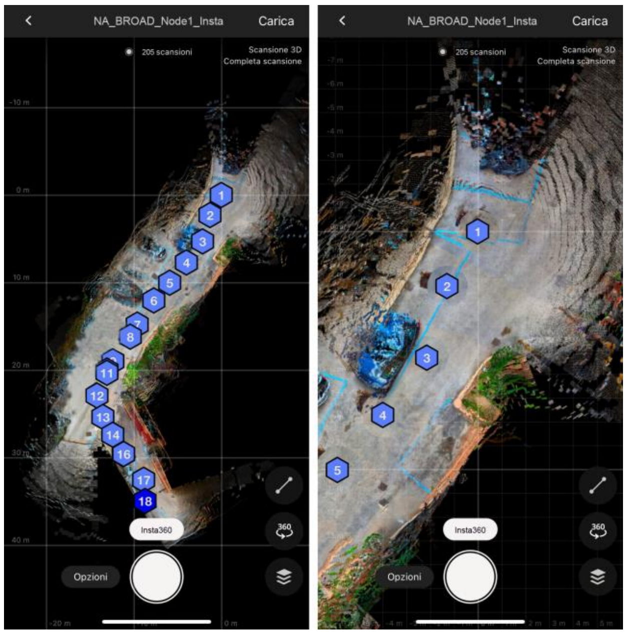

Figure 6. Station points and point cloud in the interface of the Matterport smartphone application.

Given the particular conditions stated in the introduction (need for fast surveying, impossibility of using sophisticated instrumentation due to the hostile socio-cultural context), it was decided not to use on-site reference targets. This choice, moreover, does not condition the acquisition through the Matterport application. As is known, in fact, the final reconstruction of the model is conducted by combining spatial alignment algorithms with a deep learning neural network called Cortex. Thus, elements are progressively identified on each image from which spatial and RGB colour data are extracted

and from which the next image is positioned, in an iterative process that exploits Artificial Intelligence.
Therefore, once the field data recording was completed, the overall point cloud (and mesh model) was processed in the Matterport cloud remotely - and the operator has no control over this phase - and downloaded in .e57 format (for the point cloud; in .obj format for the mesh).

4. FIRST RESULTS AND BRIEF DISCUSSION

In both processes, significantly dense point clouds were processed with discrete colour data quality.
In the first test, in order to obtain a cleaner and topologically coherent discrete model, it was necessary to mask the sky in all the images of the dataset as, in an initial processing, errors and alignment disturbances were found that were attributable to this very factor (Figure 7). In several panoramas, in fact, the sky is characterised by overexposure and/or the direct presence of the sun, in strong contrast to some areas of the same shots that are very dark.

Figure 7. Detail of the point cloud obtained in Metashape without masks (top) and with masks for the sky (bottom).

This situation was not found in the second test, where, despite the fact that the outdoor acquisition was affected by variations in the natural lighting conditions and the movement of objects within the scene, no connection or processing errors were noted. Surely, the ability of the 360° cameras to compensate for differences in lighting conditions by capturing HDR images affects the final result. However, as the first experiment showed, the transition from bright to dark spaces remains problematic.
The final model obtained through the Matterport application, however, shows some areas that are less dense and therefore lacking compared to the output of the first solution (Figure 8).
From a metric point of view, the initial results collected are encouraging and support the validity of the approach. Taking some control measurements in the surveyed area, the metric accuracy after bundle adjustment was evaluated. The RMSE values of the control points deduced from the direct measurements in a local reference system range from 1.5 cm to 3 cm, in the case of processing with Agisoft's SfM software. Slightly more than 2 or 3 decimal points those reported using Matterport application (Table 3).

Agisoft Metashape		**Matterport App**	
Control Points n.	*RMSE*	*Control Points n.*	*RMSE*
ID 1	1.7	ID 1	1.9
ID 2	2.1	ID 2	2.4
ID 3	2.1	ID 3	2.3
ID 4	1.7	ID 4	2.0
ID 5	2.7	ID 5	2.5
ID 6	2.3	ID 6	2.4
ID 7	1.7	ID 7	1.9
ID 8	2.5	ID 8	2.6
ID 9	1.5	ID 9	1.6
ID 10	2.0	ID 10	2.2
ID 11	2.7	ID 11	3.0
ID 12	2.2	ID 12	2.5

Table 3. RMSE statistics (in cm) after adding control points in the adjustment.

These statistics show metric deviations that, for the objective of digitising critical spaces for which a rapid mapping approach is required, can be considered adequate.

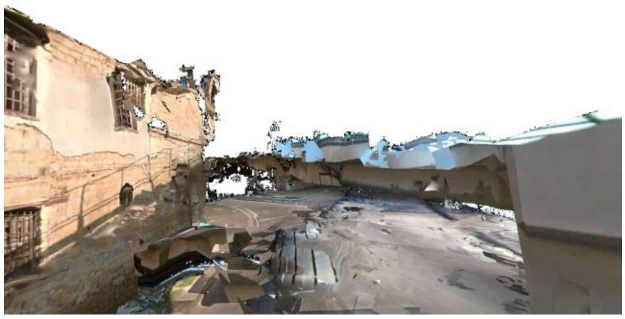

Figure 8. Detail of the Matterport model.

Further experiments will be conducted to extend the research and detail certain issues: (i) varying the acquisition step can help to assess what is the best ratio between the number of shots and the adequate density of the final point cloud to avoid gaps; (ii) varying the data capture mode (e.g. through the recording of videos from which frames are extracted instead of single photographic shots) can certainly improve acquisition times and therefore the speed of the process; (iii) the use of an adequate number of georeferenced points can optimise the entire process, making the use of spherical photogrammetry rigorous.

5. CONCLUSIONS

The employment of high-resolution but low-cost spherical cameras represents an interesting opportunity to reconstruct complex scenes in which, in addition to geometry, time and money play an important role.
This contribution presents two experiments focusing on the use of an inexpensive spherical camera, the InstaOne X2, for photogrammetric purposes. Two applications for digitising urban contexts characterised by the presence of infrastructure were tested from equirectangular images.
The two processes have pros and cons that are discussed in the paper and for which possible improvements are indicated for further testing.
The results of the first experiments demonstrate the validity of the approach: through the use of spherical images from low-cost 360° cameras, it is possible to conduct fast and inexpensive

surveying operations. These prove to be particularly useful for the collection of information necessary for the documentation of large outdoor spaces, such as narrow streets in urban centres and/or in general contexts characterised by adverse environmental conditions.

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