Geographia Technica, Vol. 19, Issue, 2, pp 78 to 90

UAV PHOTOGRAMMETRY AS A MULTIDISCIPLINARY APPROACH IN ENGINEERING DESIGN AND SUSTAINABLE LAND MANAGEMENT

Vincenzo Saverio ALFIO [1]

DOI: 10.21163/GT_2024.192.07

ABSTRACT:
The aim of the paper is to describe an integrated methodological approach of photogrammetric survey from UAVs (Unmanned Aerial Vehicles) that can be used in the field of engineering planning and design. In particular, a process is described in which the outputs from photogrammetric processing are implemented in different analysis or 3D modelling platforms to support all design activities in the field of engineering and in particular in the field of civil and environmental design. This approach was applied to an area of considerable landscape-environmental interest characterised by the presence of an estuary and a masonry bridge. The outputs of the photogrammetric processing have therefore constituted a valid support at cartographic level and for the production of two-dimensional CAD (Computer-Aided Design) drawings, as well as in the design of a cycle path, in the assessment of hydraulic risk or in the BIM (Building Information Modeling) design of the road infrastructure. The adopted methodology made it possible to obtain a high-performance and geometrically accurate dataset, characterised by high resolution, quickly and with low investment costs. In addition, by using UAV platforms, it was possible to reach inaccessible areas, limiting the risk of the operators specialised in surveying and optimising the time of operations, while still guaranteeing a complete product without loss of information necessary for BIM, GIS (Geographical Information System) and CAD procedures.

Key-words: *UAV, Dense Cloud, Photogrammetry, Engineering, 3D Model, DTM, BIM.*

1. INTRODUCTION

In recent years, aerophotogrammetric surveying using UAV has assumed a fundamental role in the planning, design and management of the territory and the structural and infrastructural works that insist on it. (Remondino et al., 2011). The result of this surveying activity generally consists of maps, 2D and 3D models of objects, as well as a series of outputs such as digital terrain or surface models, orthophotos, contour and other three-dimensional geodata; these outputs facilitate the design process in the field of engineering and architecture by reducing the workload of specialists in the field (Goncalves & Henriques, 2015). Another advantage of using UAVs is that it is possible to carry out good quality topographical surveys, taking less time to do the work than traditional measurement methods. The ability to acquire the dataset at lower altitudes than manned aircraft or satellite systems allows for high-performance and high-resolution datasets (Agueera-Vega et al., 2018; Mancini et al., 2013).

Furthermore, in classic topographic surveys, it is not possible to reach dangerous or unsafe areas or terrain unsuitable for traditional instrumentation, and in some cases, it is necessary to temporarily interrupt activities or roads, connection networks, etc.; with UAV topographic surveying, these difficulties are overcome as it is possible to carry out acquisitions in any area and at any time, without having to interrupt the operation of infrastructures and services. UAV photogrammetry, therefore, is now widely used in almost all areas of civil, environmental, and industrial engineering, and returns work that is much better than the results belonging to traditional surveys. (Jeelani & Gheisari, 2021).

Surveying from UAVs has in recent years assumed an increasingly fundamental role in the collection, interpretation and harmonisation of data (Tmušić et al., 2020). In fact, this surveying technique is applicable in different environmental contexts, such as in multi-platform and multi-scale environmental monitoring of a lake for the creation of Digital Surface Models (DSM) and orthophotos (Medvedev et al., 2020) or, in the identification of a suitable methodology for calculating the optimal

---

[1] *Polytechnic University of Bari - Department of Civil, Environmental, Land, Building Engineering and Chemistry (DICATECh), 70125, Bari, Italy, vincenzosaverio.alfio@poliba.it*

volume of waste by integrating Terrestrial Laser Scanning (TLS) and Unmanned Aerial Vehicle (UAV) technologies (Son et al., 2020). In the field of vulnerability assessment of coastal areas, this surveying technique has also assumed a key role in climate change assessment (Adade et al., 2021) thanks also to the equipping of drones with the latest sensor technologies that guarantee high spatial and temporal resolution. Furthermore, in the field of environmental monitoring, the support of UAVs is of considerable importance, for example in the field of forestry (Sferlazza et al., 2022), in photogrammetric techniques for the processing of very high resolution orthophotos and coastline extrapolation (Costantino et al, 2020), in the multi-temporal survey for assessing morphological changes due to different (natural and anthropogenic) factors in coastal areas (Zanutta et al., 2020), and also for bathymetric monitoring of shallow water bodies (Lewicka et al., 2022). The possibility of generating highly accurate Digital Elevation Models (DEM) as an alternative to satellite data also makes this survey technique interesting in the field of hydraulic modelling (Mazzoleni et al., 2020) or for the validation of two-dimensional hydraulic model simulations (Masafu et al., 2022).

In the field of civil engineering and infrastructure (Greenwood et al., 2019) and particularly in the field of inspection and monitoring, UAVs can represent a non-invasive approach in rapid mapping applications (Gaspari et al., 2022) flexible and low-cost (Lattanzi & Miller, 2017) through the use of optical and LiDAR sensors, for disaster assessment after calamitous events or for transport infrastructure damage reduction strategies (Mandirola et al., 2022). The possibility of creating 3D models from UAV surveys (Pepe et al., 2022) through the algorithms of Structure from Motion (SfM) and Multi View Stereo (MVS), has also become commonplace in the monitoring of construction progress on building sites (Teizer, 2015) with a comprehensive and efficient collection of images and the possibility of generating multi-temporal BIM models (Lin et al., 2015). In fact, from a modelling perspective, the use of UAVs for three-dimensional surveying enables the definition of high-performance 3D models from point cloud datasets (Klapa, 2023) both for the realisation of BIM models of structures and infrastructures of particular geometric complexity (Shults & Annenkov, 2023) as well as in the construction of Heritage BIM models (HBIM) when dealing with cultural heritage structures (Robador González et al., 2023).

Finally, wide use and application of such devices is also to be found in the availability of increasingly efficient navigation systems that integrate inertial systems and the integration of optical or LiDAR sensors for security control operations in certain areas (Baiocchi et al., 2023) and in transport systems, road safety and road infrastructure management with a view to the development of smart cities (Outay et al., 2020).

The aim of this article is to provide a multidisciplinary approach in the field of photogrammetric survey from UAVs and to show how some of the outputs produced can easily represent a useful and indispensable support tool for all levels of design in the field of civil and environmental engineering, from the design of sustainable works to the management of infrastructures in a BIM environment. The aim of this paper is to show the reader some possible uses of a point cloud dataset, obtained by means of a UAV photogrammetric survey, and the relative use of the processing outputs in the various disciplines of civil and environmental engineering.

2. STUDY AREA

The area under study represents an ancient river that flows through the rock and is called “Lama San Giorgio”. This area has been identified by the Apulia Region as a protected natural area, due to its naturalistic, landscape, archaeological and cultural interest. In particular, the structure investigated for the application of this methodology, is an arched bridge located on the outskirts of the city of Bari (Italy) and located within the same swamp that slopes down towards the sea (**Fig.1**).

3. MATERIALS AND METHODS

In general, the main phases of a UAV photogrammetric survey can be distinguished into a first step involving the planning of the survey. In this phase, the different parameters such as overlap, sidelap, GSD (Ground Sample Distance), flight altitude, etc. are defined and set according to the area to be surveyed. Furthermore, of particular importance is the preliminary study of the area to be surveyed in order to determine the presence of any obstacles that may affect the flight mission. The next phase is the survey phase in which all the topographic measurement operations are conducted, and, at the same time, the flight mission is carried out to acquire the photogrammetric dataset. The data acquired are then processed using appropriate photogrammetric processing software in order to produce point clouds, 3D models and a series of outputs that are useful in the spatial planning and design phases. The following pipeline (**Fig. 2**) shows the main stages of the methodological approach described in this manuscript.

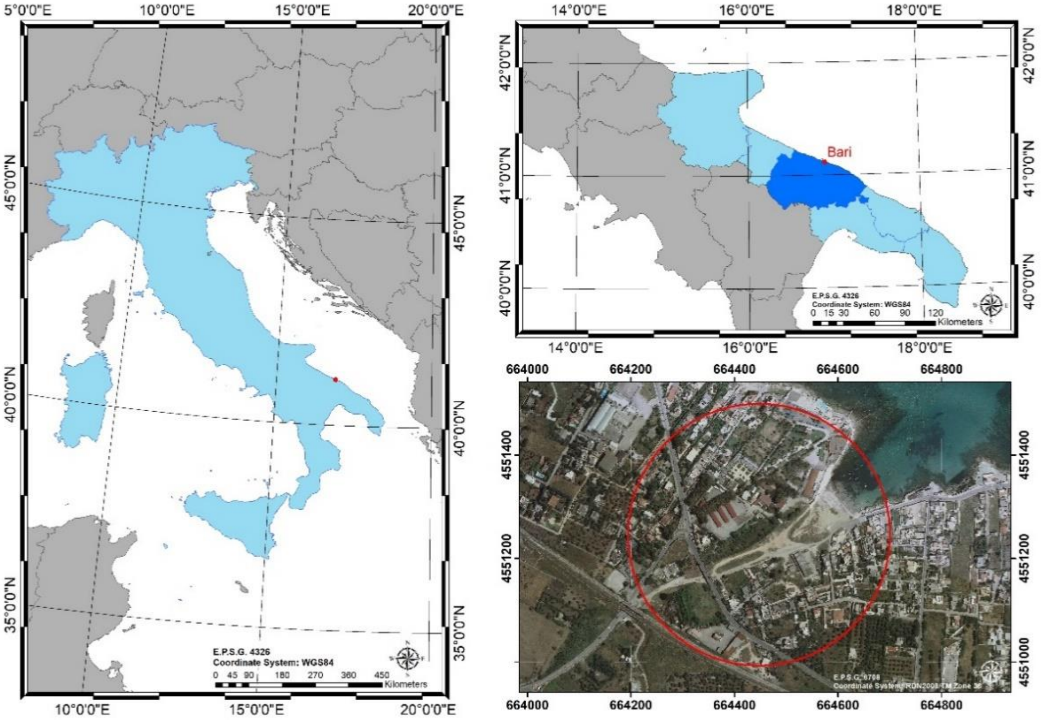


Fig.1. Cartographic overview of the study area.

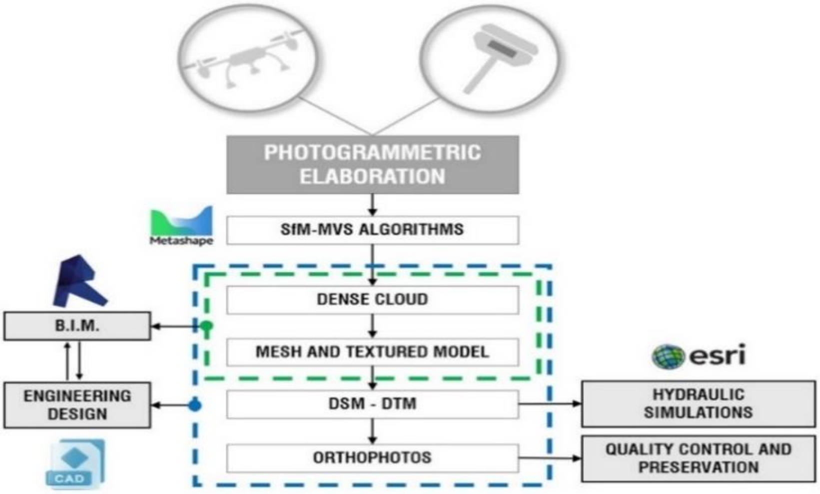


Fig. 2. Schematisation of the main stages of the methodological approach described.

3.1. UAV planning and photogrammetric survey

The methodological approach described in the following manuscript concerns the experience of an aerophotogrammetric survey from a UAV platform, for the realisation of various outputs to support engineering design in various fields of application. The survey was conducted through the use of a quadricopter for the acquisition of the photogrammetric dataset. In order to scale and georeference the final model, a GNSS (Global Navigation Satellite System) survey of GCPs (Ground Control Points) and CPs (Check Points) was also conducted, which were previously materialised homogeneously over the entire area to be surveyed.

GCPs and CPs are reference points, materialised on the area to be surveyed, which must be easily recognisable on the images; they can be natural points of the scene or they can be made on panels of impermeable and high-contrast material (e.g. black and white or yellow and black); their size varies according to the Ground Sample Distance (G.S.D.) value and consequently according to the flight altitude of the UAV(Alfio et al., 2023). In addition, each UAV device may have its own integrated camera so that, depending on the sensor, the GSD value must be established at the survey planning stage, which will then adjust the maximum attainable flight height (Pepe et al., 2018). Considering F_s the scale of the frame and L the width of single image footprint on the ground:

$$\frac{1}{F_s} = \frac{d}{L} \tag{1}$$

the following relationship can be defined:

$$GSD = \frac{Z}{c} \cdot d \tag{2}$$

where:

Z represents the flight altitude above the ground;
c represents the focal length of the sensor;
d size of the side of a photo sensor pixel.

Furthermore, relating Eq. (1) to Eq. (2) gives:

$$GSD = F_s \cdot d \rightarrow F_s = \frac{GSD}{d} \tag{3}$$

with which it is possible to relate the frame scale to the characteristics of the sensor used, the distance and the photographic lens.

3.2. SfM and MVS algorithms for point cloud generation

After the frame acquisition phase, through the SfM and MVS algorithms, it is possible to conduct the photogrammetric processing of the acquired dataset and obtain the dense cloud. In the first phase, after a calibration of the photographic sensor to establish the internal orientation parameters, the external orientation parameters defining the position and orientation of the camera during the shooting phase are also calculated; they consist of 3 translation components and 3 rotation angles. The next stage of dense cloud generation is based on depth maps calculated with dense stereo matching. The depth maps are calculated for the overlapping image pairs, considering the relative external and internal orientation parameters estimated with the Bundle Adjustment (BA).

In general, although BA is not strictly part of the SfM approach, it is a very common step used to refine and refine the initial SfM model. Given a set of camera parameters and a set of traces, BA minimises the following non-linear least-squares error (Furukawa & Hernández, 2015):

$$E(P,M) = \sum_{j} \sum_{i \in V(J)} \left| P_i(M^j) - m_i^j \right|^2 \tag{4}$$

where:

P_i	camera parameters
M^j	3D co-ordinates of a track
m_i^j	2D co-ordinates of the projection of its image
$V_{(j)}$	list of camera indices where the point is visible M^j
$P_i(M^j)$	co-ordinate of the projected 2D image of the 3D point M^j in the camera i using the camera parameters P_i.

After the generation of the dense cloud, it is possible to assess the metric quality of the generated 3D model by taking GCPs and CPs into account and calculating the relative Root Mean Square Error (RMSE) using the formula:

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(x_{i,est} - x_i)^2 + (y_{i,est} - y_i)^2 + (z_{i,est} - z_i)^2}{n}} \tag{5}$$

where:

x_i, y_i, z_i are the input values of the coordinates respectively x, y, z.

$x_{i,est}, y_{i,est}, z_{i,est}$ correspond to their estimated positions.

After processing the dense cloud, a triangular surface mesh can be generated; this surface can be textured to obtain a photorealistic digital representation of the object/scene. The irregular mesh, or Triangulated Irregular Network (TIN), is a surface in which the known points in the three coordinates, however they are distributed in space, are joined by lines that form flat, adjacent triangles and allow the surface of the object to be represented with continuity, respecting Delaunay's triangulation criterion.

3.3. Digital model and orthophoto processing

Through the photogrammetric processing pipeline, it is possible to generate Digital Surface Models (DSM) and Digital Terrain Models (DTM), in which the elevation information is recorded within a regular grid that can be represented with a numerical matrix. Usually, the grid has a square mesh, more rarely triangular or rectangular, whose lateral dimension provides the cell size (cell size or pixel size), which corresponds, once the projection is fixed, to the spatial resolution of the digital model. The steps involved in constructing and analysing a digital height model lead to a number of errors related to the measurement and/or data processing processes, generating model uncertainties. The quantification of error in such models can be performed by calculating the Root Mean Square Error (RMSE) of the digital model according to the following formula:

$$RMSE = sqrt\left(\frac{\sum(z_{i,est} - z_i)}{n}\right) \tag{6}$$

where:

z_i represents the quote of DEM.

z_j represents the reference measurement.

n the number of samples considered.

Within photogrammetric software, DEMs can be rasterised from a dense point cloud, a sparse cloud, a mesh or generated directly from depth maps. Using point cloud classification algorithms, such as ATIN - Adaptive Triangulated Irregular Network, PTIN - Progressive Triangulated Irregular Network or MCC - Multi Curvature Classification, it is possible to classify the point cloud (Łącka, 2021) into other semantic classes and process the DTM, which represents the topographical terrain surface, without taking into account anthropic elements (trees, vegetation, etc.), i.e. artificial objects or elements (buildings, cars, etc.).

Starting from the processing of the dataset, it is possible to obtain the orthophoto, i.e. a composition of geometrically corrected photograms by means of an orthorectification process; furthermore, the orthophoto, considering the information obtained from the processing of the GNSS survey data, can be georeferenced so that the scale of representation becomes uniform throughout the territory. To construct this output, it is necessary to use a DEM to define the orthoimage matrix, where each pixel corresponds to an element of the ground plane. In order to improve the final result and eliminate projection differences and preserve the correct positions of objects and terrain features (Lamsters et al., 2020), it is possible to process a "True Digital Orthoimage" using a DSM instead of a DEM and ensuring the geometric accuracy of features and visibility of features (Shoab et al., 2022).

3.4. From photogrammetric processing to sustainable spatial planning

All outputs obtained from photogrammetric processing can be imported into various design and analysis software, (e.g. General Authoring software in the BIM field or parametric modelling, GIS, CAD, etc.) and help to strengthen design activities, guaranteeing high product quality standards and greater accuracy. In fact, for example in the BIM field, photogrammetric techniques provide an accurate basis for modelling objects. Also with a view to environmental design, the acquisition of datasets from UAV platforms for the generation of DEMs and DTMs as well as up-to-date orthophotos with high geometric resolution plays a fundamental role in the field of hydrological/hydraulic modelling, to support the realisation of new interventions and in the performance evaluation of existing ones. In this context, all photogrammetric products, which are fully interoperable with the various software available today, are able to create a valid multi-scale and multi-level support in the knowledge of the territory, representing an important basis for planning, as well as an indispensable metric support for conducting all the necessary design operations.

4. RESULTS

4.1. SfM-MVS approach and output processing

To acquire the photogrammetric dataset of the entire study area, a survey with UAV DJI Mavic 2 PRO developed by DJI Company, Shenzhen, was conducted. This device is a quadricopter equipped with a high-resolution colour camera Hasselblad L1D-20c with a 1" sensor and 20MP resolution. In particular, two different types of mission were carried out with this device: an automatic mission to cover the entire area with nadiral captures (flight planning app and Pix4Dcapture acquisition) and a manual mission (app for real-time image transmission and DJI GO 4 camera settings) for the 3D reconstruction of the masonry bridge; for this last dataset it was necessary to acquire a series of images with a camera tilted at 30° and 45° from different flight altitudes. The entire dataset consists of 175 images and covers an area of approximately 10,000 square metres.

In order to scale and georeference the point cloud, a survey with GNSS receiver Leica Viva GNSS 12 was performed. Nine GCPs were surveyed in kinematic Stop and Go mode. The GNSS survey data were processed using appropriate software and using the nearest HxGN SmartNet permanent station as the Master station. The coordinates of the acquired points were referred to the RDN2008-UTM zone 33N (E.P.S.G. code 6708), i.e. to the national implementation of ETRS89 (European Terrestrial Reference System), which is an ECEF (Earth-Centred, Earth-Fixed) geodetic Cartesian reference system. Using the Agisoft Metashape photogrammetric processing software, it was possible to obtain a dense cloud consisting of more than 20,000,000 points. According to Equation (5), the RMSE value was calculated, which in geometric terms was 0.037 m and in terms of pixel reprojection was 1.086. After the point cloud generation phase, the polygonal mesh model was then processed and textured with a photographic resolution of 6 mm. The DEM and a series of orthophotos projected onto different reference planes were also processed and generated. In addition, in order to obtain a suitable DTM, an automatic classification of the point cloud was carried out to identify the class "Ground Points"; starting from this classification and through a triangulation process, the digital terrain model was then defined. **Table 1** below summarises the main characteristics of the outputs produced as part of this processing.

Table 1.

Pipeline of the described methodological approach

Output	Features	Memory
Dense Cloud	Points: 20,511,813 points	275 MB
TIN	Faces: 1,402,948 faces - Vertices: 707,546 vertices	74.81 MB
3D textured model	Resolution: 6 mm/pix	311.26 MB
DEM	Size: 5,954x4,983 pix - Resolution: 2.42 cm/pix	76.10 MB
Orthomosaic	Size: 23,816x19,932 pix - Resolution: 6.04 mm/pix	3.62 GB

4.2. DEM, DTM and orthophotos for the design of a cycle path

After an accurate hydrological-hydraulic analysis of the study area, using the information contained in the DTM, a series of contour lines were generated, and a cycle-pedestrian route was identified with a view to environmental sustainability and functionality. The route was identified by superimposing the information on the road layout on the generated orthophotos and thus identifying a suitable route connecting the provincial road to the cove, passing under the bridge at the second external arch. On the basis of the extracted profiles, in defining the hypothetical route, the topographical course of the terrain was evaluated so that a design profile could be drawn up that was as linear and adherent as possible to the terrain itself. By means of 3D modelling and the processing of orthomosaics on different projection planes, a series of design drawings and 2D graphic tables in a CAD environment were then produced to support the entire design cycle of new interventions and the maintenance of existing ones (**Appendix 1**).

4.3 DTM for hydrological land assessment

In the case study presented, through a photogrammetric approach, the accurate processing of a georeferenced DTM, with a high geometric resolution, allowed the elaboration of a hydrological analysis of the surface on an ArcGIS platform. The processing of the DTM in the GIS environment allowed the extraction of various information to support the estimates regarding the hydrology of the area and the basin considered, such as the perimeter and area of the basin, contour lines, slope map, drainage grids, etc.

In fact, the combined use of these 2.5D models and GIS tools makes it possible to identify sinks, flow directions, delineate watersheds and create flow networks. In particular, the use of an elevation raster or a digital elevation model as input makes it possible to automatically reconstruct a drainage system and quantify the characteristics of the system in order to identify the areas of the basin that are subject to flooding or all the areas that allow water to drain away.

In this context, it is obvious how the precision and accuracy of appropriately processed DTM (obtained from a UAV photogrammetric survey), as well as its spatial resolution offer greater homogeneity and uniformity of the data over larger areas, making the analyses and subsequent determinations of all factors and parameters involved in hydrological-hydraulic modelling more accurate, as well as in the more detailed construction of river profiles (**Appendix 2**).

4.4 BIM modelling of the bridge

A further application use in engineering of the point cloud obtained with the survey is the realisation of a BIM information model. Modelling according to the BIM approach, in fact, makes it possible to create a digital copy of the object to which useful information can be associated for constructing, managing, and monitoring the work during its useful life.

In particular, in the case under study, the dense cloud processed by the photogrammetric software was first filtered and cleaned by means of appropriate tools and algorithms; with this data treatment phase, any edge effects and outliers of the model were also removed. After this treatment phase, the cloud was imported into the Revit software, which allows three-dimensional modelling of objects, using both fundamental operations such as extrusions, unions, revolutions, sweeps, and classic Boolean operations for the manipulation and creation of new objects, as well as creating parameterised families. These operations are applied to 3D objects to obtain new complex shapes from the combination of simpler shapes.

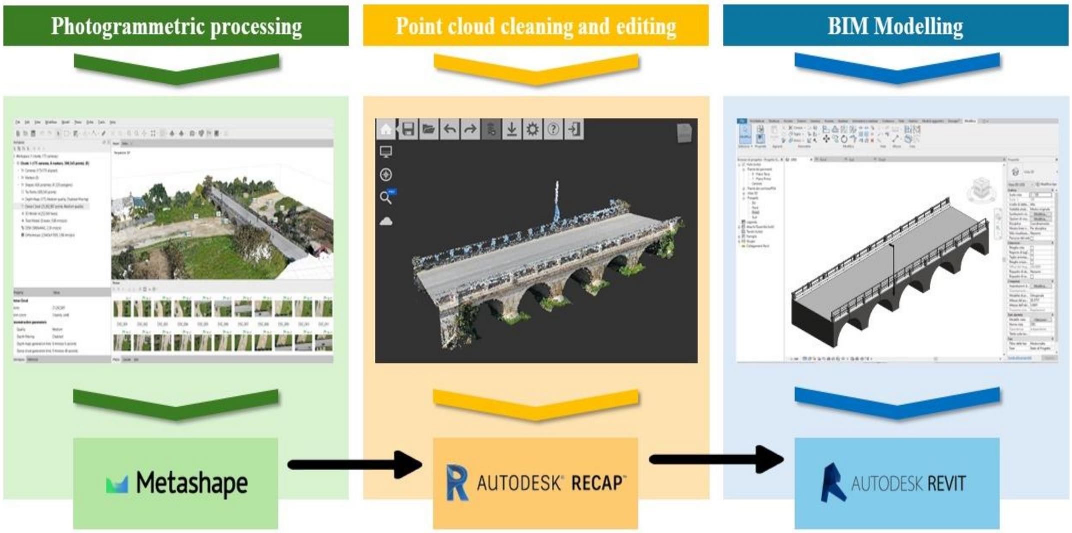


Fig. 3. Bridge BIM modelling in Revit software.

By importing the point cloud, it was possible to model the different components of the bridge and reconstruct the geometries of all the objects of which it is composed. In particular, by associating a series of semantic information for each element, the structure of the piers and arches, the road pavement, the safety barriers and the road lighting elements were modelled (**Fig. 3**). In this way, it is possible to keep track of the operations that have been carried out over time, from the installation of the components to maintenance operations, managing the work and reporting criticalities detected during inspections for the planning of future interventions.

4.5. High-resolution orthophotos for maintenance status assessment

The possibility of photogrammetrically generating an orthophoto with high geometric resolution also makes it possible to verify the state of maintenance, as in the case study, of the road pavement. In this way, it is possible to characterise the condition of wear and tear and optimally plan restoration work. In the case under examination, an orthophoto characterised by a pixel size of less than a centimetre made it possible to identify the most damaged areas in GIS environment; furthermore, the georeferencing of the model in the appropriate reference system makes it possible to identify the areas subject to the phenomenon under investigation, locating them more easily and enabling the priorities and types of intervention to be defined in the maintenance phase (**Appendix 3**).

UAV surveying in this context is most advantageous as it allows the acquisition of very high-resolution digital images even in areas that are difficult to access, possibly characterised by high traffic density, while still guaranteeing the safety of operators and workers.

5. DISCUSSION AND CONCLUSIONS

This manuscript shows an integrated approach to utilising the different outputs of photogrammetric image processing acquired from a UAV platform to support all design activities in the field of civil and environmental engineering. The proposed method shows how, in less time than traditional survey methods, it is possible to obtain a three-dimensional, accurate and geometrically correct dataset useful in all engineering design phases.

With UAV platforms, the possibility of reaching areas that are not easily accessible makes it possible to obtain a complete dataset that serves as a support in the drafting of all the design drawings required by the client (plans, elevations, typological sections, etc.), attributing a high degree of detail and with relatively low time and investment costs. Last but not least, by using a pipeline such as the one shown in this manuscript, it is possible to carry out all the desired measurements directly on the 3D model, completely eliminating the need to interrupt the operation of the infrastructure and design service for the acquisition of new information.

Analysing from a statistical point of view the scientific literature concerning the use of UAVs, it is possible to note that, to date, there are over 70,000 articles.

In particular, by setting up a series of search filters using keywords such as UAV, Unmanned Aeria Vehicle, UAS, etc., the publications in the Scopus database were classified and categorised with respect to a series of fields of application. **Fig. 4** below shows the results of this analysis and the relative percentages with respect to the different fields of application.

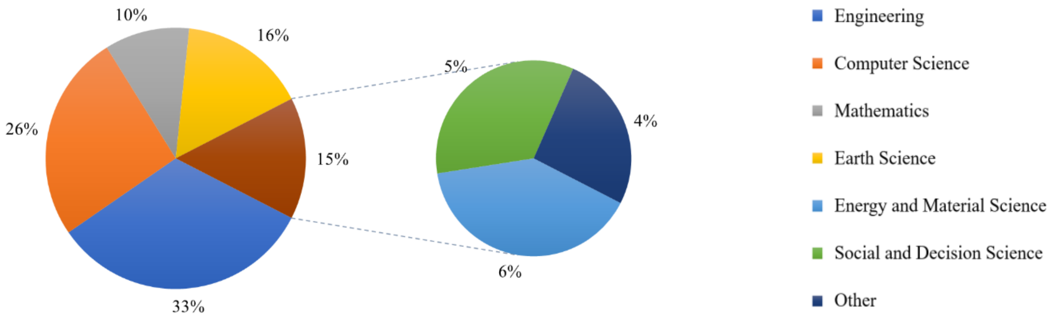
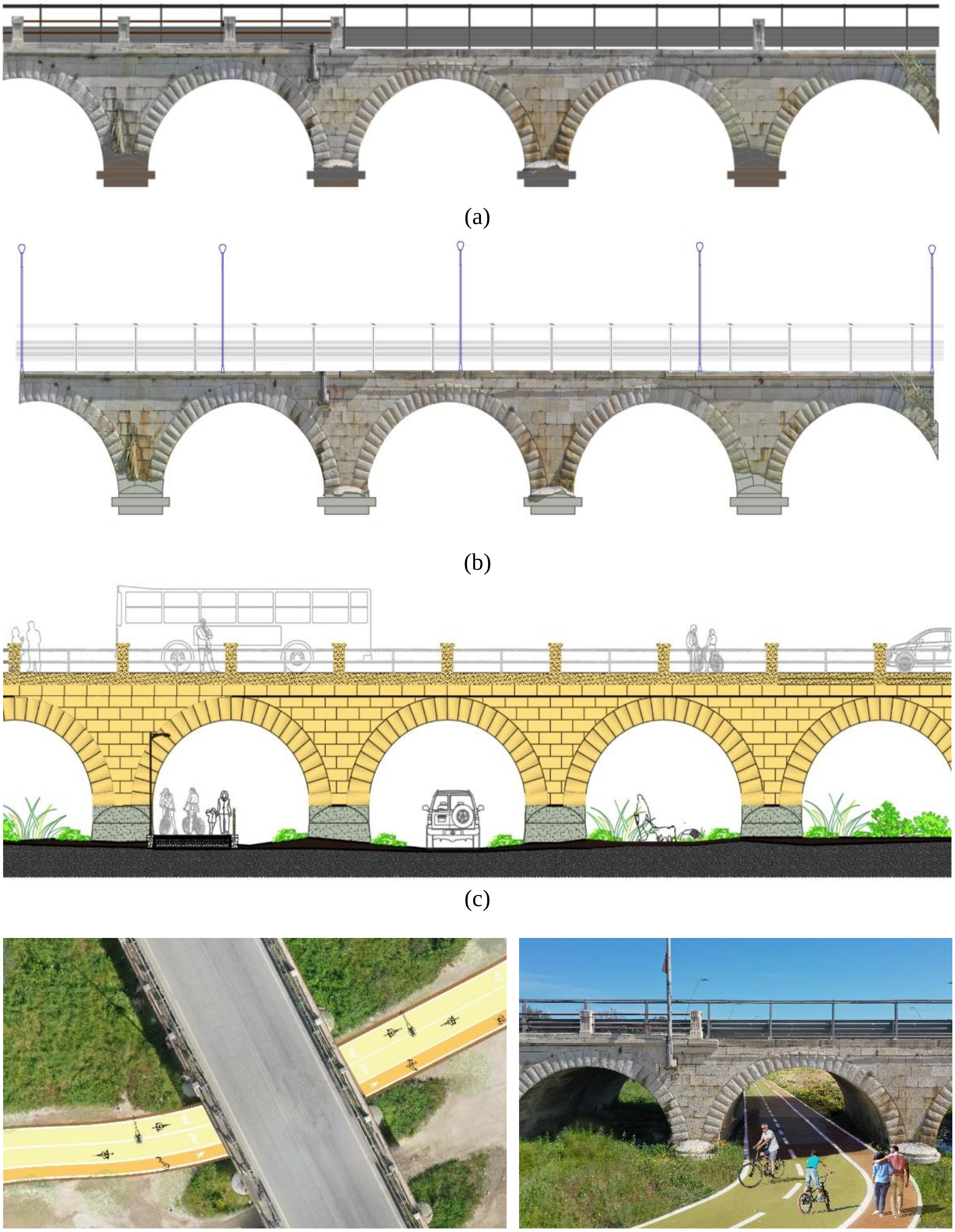


Fig. 4. Analysis of the different fields of application of UAVs.

In addition, the processing of the point cloud and the transition to a 3D model lend themselves well to interoperability, for example in BIM design, where it is possible to model with high accuracy objects characterised by complex geometries, which are difficult to achieve with classic 3D modelling operations. Certainly, greater detail in the three-dimensional representation of the topographical surface and the objects and infrastructures present in the observed scene, improves the quality of analysis and the level of final design.

Finally, thanks to the development of advanced algorithms, tools for the automatic extraction of features, filters for the classification of data and Artificial Intelligence (AI), it will be possible to map and monitor even in real time the phenomenon under investigation and send the relevant information and datasets acquired directly to a cloud system for subsequent processing.

APPENDIX 1



(a)

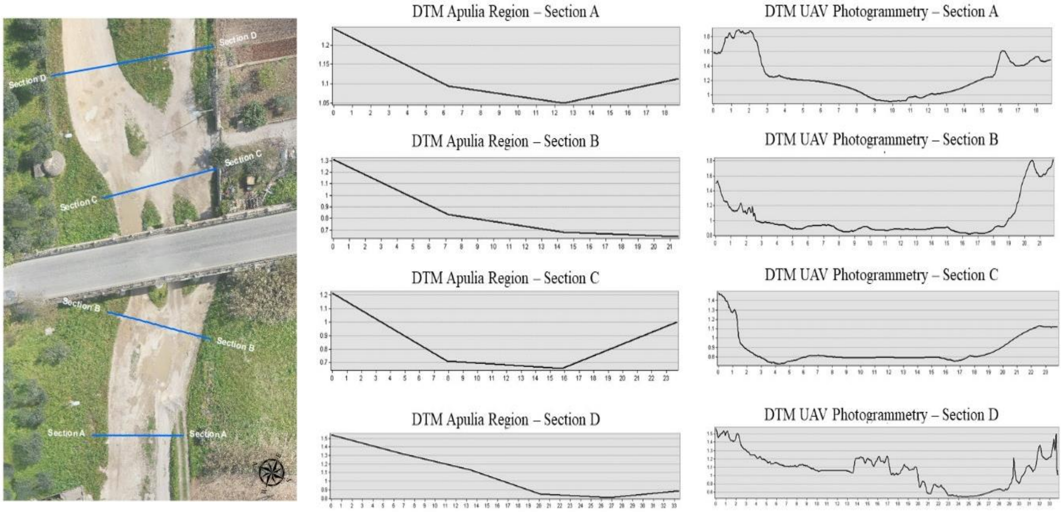
(b)

(c)

(d) (e)

Appendix 1. Design of the cycle path: orthophotos of the bridge elevations (a,b), 2D CAD reconstruction of the bridge façade (c), road axis of the cycle path based on orthophotos (d) and final photo insertion (e).

APPENDIX 2



Appendix 2. Difference in the reconstruction of the riverbed profile using a DTM from the Apulia Region and a DTM obtained from a UAV photogrammetric processing. In particular, sections A and B are located upstream of the bridge while sections C and D are located downstream.

APPENDIX 3

(a) (b)

Appendix 3. Identification of the state of cracking of the road pavement: difference between the orthophoto of the Apulia Region (a) and the orthophoto produced by photogrammetric processing (b).

REFERENCES

Adade, R., Aibinu, A. M., Ekumah, B., & Asaana, J. (2021). Unmanned Aerial Vehicle (UAV) applications in coastal zone management—A review. *Environmental Monitoring and Assessment*, *193*(3), 154. https://doi.org/10.1007/s10661-021-08949-8. https://doi.org/10.1007/s10661-021-08949-8.

Agueera-Vega, F., Carvajal-Ramirez, F., Martínez-Carricondo, P., López, J. S.-H., Mesas-Carrascosa, F. J., García-Ferrer, A., & Pérez-Porras, F. J. (2018). Reconstruction of extreme topography from UAV structure from motion photogrammetry. *Measurement*, *121*, 127–138. https://doi.org/10.1016/j.measurement.2018.02.062.

Alfio, V. S., Costantino, D., Pepe, M., Rossi, G., & Leserri, M. (2023). Production of high geometric resolution orthophotos by photogrammetric approach for the Royal Racconigi Castel park documentation. *Geographia Technica*, *18*(2). http://doi.org/10.21163/GT_2023.182.03.

Baiocchi, V., Fortunato, S., Giannone, F., Marzaioli, V., Monti, F., Onori, R., Ruzzi, L., & Vatore, F. (2023). LiDAR RTK Unmanned Aerial Vehicles for security purposes. *Geographia Technica*, 34–42. https://doi.org/10.21163/GT_2024.191.03.

Costantino, D., Pepe, M., Dardanelli, G., & Baiocchi, V. (2020). Using optical Satellite and aerial imagery for automatic coastline mapping. Geographia Technica, 15(2), 171-190. http://dx.doi.org/10.21163/GT_2020.152.17

Furukawa, Y., & Hernández, C. (2015). Multi-view stereo: A tutorial. *Foundations and Trends® in Computer Graphics and Vision*, *9*(1–2), 1–148. http://dx.doi.org/10.1561/0600000052.

Gaspari, F., Ioli, F., Barbieri, F., Belcore, E., & Pinto, L. (2022). Integration of UAV-LiDAR and UAV-photogrammetry for infrastructure monitoring and bridge assessment. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLIII-B2-2022*, 995–1002. https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-995-2022.

Goncalves, J. A., & Henriques, R. (2015). UAV photogrammetry for topographic monitoring of coastal areas. *ISPRS Journal of Photogrammetry and Remote Sensing*, *104*, 101–111. http://dx.doi.org/10.1016/j.isprsjprs.2015.02.009.

Greenwood, W. W., Lynch, J. P., & Zekkos, D. (2019). Applications of UAVs in Civil Infrastructure. *Journal of Infrastructure Systems*, *25*(2), 04019002. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000464.

Jeelani, I., & Gheisari, M. (2021). Safety challenges of UAV integration in construction: Conceptual analysis and future research roadmap. *Safety Science*, *144*, 105473.

Klapa, P. (2023). Integration of terrestrial laser scanning and UAV-based photogrammetry for heritage Building Information Modeling. *Geomatics, Landmanagement and Landscape, no. 1*. https://doi.org/10.15576/GLL/2023.1.23.

Łącka, M. (2021). Analysis of algorithms for automatic classification of photogrammetric point clouds to build a digital terrain model in a shoreline area. *Zeszyty Naukowe Akademii Morskiej w Szczecinie*. https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-26147478-b6f4-4e47-9686-fc9a357e39fb.

Lewicka, O., Specht, M., Stateczny, A., Specht, C., Dardanelli, G., Brčić, D., Szostak, B., Halicki, A., Stateczny, M., Widźgowski, S. (2022). Integration data model of the bathymetric monitoring system for shallow waterbodies using UAV and USV platforms. *Remote Sensing*, 14(16), 4075. https://doi.org/10.3390/rs14164075

Lamsters, K., Karušs, J., Krievāns, M., & Ješkins, J. (2020). High-resolution orthophoto map and digital surface models of the largest Argentine Islands (the Antarctic) from unmanned aerial vehicle photogrammetry. *Journal of Maps*, *16*(2), 335–347. https://doi.org/10.1080/17445647.2020.1748130.

Lattanzi, D., & Miller, G. (2017). Review of Robotic Infrastructure Inspection Systems. *Journal of Infrastructure Systems*, *23*(3), 04017004. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000353.

Lin, J. J., Han, K. K., & Golparvar-Fard, M. (2015). A Framework for Model-Driven Acquisition and Analytics of Visual Data Using UAVs for Automated Construction Progress Monitoring. *Computing in Civil Engineering 2015*, 156–164. https://doi.org/10.1061/9780784479247.020.

Mancini, F., Dubbini, M., Gattelli, M., Stecchi, F., Fabbri, S., & Gabbianelli, G. (2013). Using unmanned aerial vehicles (UAV) for high-resolution reconstruction of topography: The structure from motion approach on coastal environments. *Remote Sensing*, *5*(12), 6880–6898. https://doi.org/10.3390/rs5126880.

Mandirola, M., Casarotti, C., Peloso, S., Lanese, I., Brunesi, E., & Senaldi, I. (2022). Use of UAS for damage inspection and assessment of bridge infrastructures. *International Journal of Disaster Risk Reduction*, *72*, 102824. https://doi.org/10.1016/j.ijdrr.2022.102824.

Masafu, C., Williams, R., Shi, X., Yuan, Q., & Trigg, M. (2022). Unpiloted Aerial Vehicle (UAV) image velocimetry for validation of two-dimensional hydraulic model simulations. *Journal of Hydrology*, *612*, 128217. https://doi.org/10.1016/j.jhydrol.2022.128217.

Mazzoleni, M., Paron, P., Reali, A., Juizo, D., Manane, J., & Brandimarte, L. (2020). Testing UAV-derived topography for hydraulic modelling in a tropical environment. *Natural Hazards*, *103*(1), 139–163. https://doi.org/10.1007/s11069-020-03963-4.

Medvedev, A., Telnova, N., Alekseenko, N., Koshkarev, A., Kuznetchenko, P., Asmaryan, S., & Narykov, A. (2020). UAV-Derived Data Application for Environmental Monitoring of the Coastal Area of Lake Sevan, Armenia with a Changing Water Level. *Remote Sensing*, *12*(22), Article 22. https://doi.org/10.3390/rs12223821.

Outay, F., Mengash, H. A., & Adnan, M. (2020). Applications of unmanned aerial vehicle (UAV) in road safety, traffic and highway infrastructure management: Recent advances and challenges. *Transportation Research Part A: Policy and Practice*, *141*, 116–129. https://doi.org/10.1016/j.tra.2020.09.018.

Pepe, M., Alfio, V. S., & Costantino, D. (2022). UAV platforms and the SfM-MVS approach in the 3D surveys and modelling: A review in the cultural heritage field. *Applied Sciences*, *12*(24), 12886. https://doi.org/10.3390/app122412886.

Pepe, M., Fregonese, L., & Scaioni, M. (2018). Planning airborne photogrammetry and remote-sensing missions with modern platforms and sensors. *European Journal of Remote Sensing*, *51*(1), 412–436. https://doi.org/10.1080/22797254.2018.1444945.

Remondino, F., Barazzetti, L., Nex, F. C., Scaioni, M., & Sarazzi, D. (2011). UAV photogrammetry for mapping and 3D modeling: Current status and future perspectives. *Proceedings of the International Conference on Unmanned Aerial Vehicle in Geomatics (UAV-g): 14-16 September 2011, Zurich, Switzerland*, 25–31. https://research.utwente.nl/en/publications/uav-photogrammetry-for-mapping-and-3d-modeling-current-status-and.

Robador González, M. D., Nieto-Julián, J. E., Millán-Millán, P. M., Galera-Rodríguez, A., Bruno, S., Debenedictis, D., & Moyano, J. (2023). Management properties and procedures in the information model of the historic building HBIM on building facades. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVIII-M-2–2023*, 1323–1330. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-1323-2023.

Sferlazza, S., Maltese, A., Dardanelli, G., & La Mela Veca, D. S. (2022). Optimizing the sampling area across an old-growth forest via UAV-borne laser scanning, GNSS, and radial surveying. *ISPRS International Journal of Geo-Information*, 11(3), 168. https://doi.org/10.3390/ijgi11030168

Shoab, M., Singh, V. K., & Ravibabu, M. V. (2022). High-precise true digital orthoimage generation and accuracy assessment based on UAV images. *Journal of the Indian Society of Remote Sensing*, *50*(4), 613–622. https://doi.org/10.1007/s12524-021-01364-z.

Shults, R., & Annenkov, A. (2023). BIM and UAV photogrammetry for spatial structures sustainability inventory. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLVIII-5-W2-2023*, 99–104. https://doi.org/10.5194/isprs-archives-XLVIII-5-W2-2023-99-2023.

Son, S. W., Kim, D. W., Sung, W. G., & Yu, J. J. (2020). Integrating UAV and TLS Approaches for Environmental Management: A Case Study of a Waste Stockpile Area. *Remote Sensing*, *12*(10), Article 10. https://doi.org/10.3390/rs12101615.

Teizer, J. (2015). Status quo and open challenges in vision-based sensing and tracking of temporary resources on infrastructure construction sites. *Advanced Engineering Informatics*, *29*(2), 225–238. http://dx.doi.org/10.1016/j.aei.2015.03.006.

Tmušić, G., Manfreda, S., Aasen, H., James, M. R., Gonçalves, G., Ben-Dor, E., Brook, A., Polinova, M., Arranz, J. J., & Mészáros, J. (2020). Current practices in UAS-based environmental monitoring. *Remote Sensing*, *12*(6), 1001. http://dx.doi.org/10.3390/rs12061001.

Zanutta, A., Lambertini, A., & Vittuari, L. (2020). UAV photogrammetry and ground surveys as a mapping tool for quickly monitoring shoreline and beach changes. *Journal of Marine Science and Engineering*, 8(1), 52. https://doi.org/10.3390/jmse8010052