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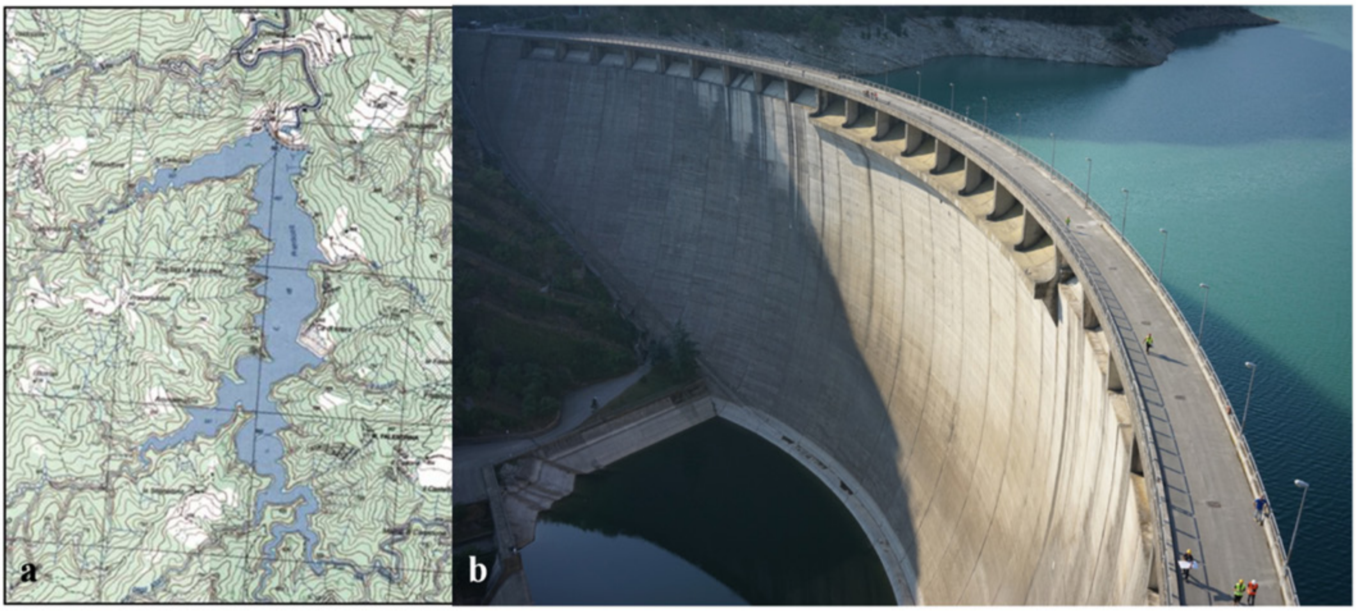
Unmanned Aerial Vehicle (Uav) and Building Information Modelling (Bim) Technologies in Concrete Dam Management: The Case of Ridracoli

KEYWORDS: UAV, Dams, Solid Modelling, BIM, Efficient Management

Safety and proactive vision are key aspects for an efficient management of dams. The reduced accessibility and the large time needed for an inspection by traditional methods do not facilitate their direct visual inspection. Therefore, the use of Unmanned Aerial Vehicle (UAV) is suitable for this purpose, although the support of traditional topographic instruments (i.e. Total Station, GPS Station and Laser Scanner) is still necessary. The UAV survey provides qualitative information, with the aim of recognizing the condition of the materials (i.e. photos, videos), as well as quantitative information, with the aim of modelling the structure (i.e. geo-referenced dense point cloud). Since multidisciplinary aspects are involved in the management of dams, the possibility to share data (i.e. photos, videos) of every detail of the structure, also on different times and in different places, between a large number of specialists (i.e. engineers, architects, geologists, technicians, managers) allows for the effective and efficient resolution of problems. The UAV dense point cloud, integrated also with pre-existing data sets, is the base for the extraction of surfaces which describe important elements of the structure. The solid model is employed in Finite Element Method (FEM) analyses or, including additional information concerning volumes, mechanical characteristics, monitoring data, etc., it could be able to be the basis for a Building Information Modelling (BIM) of the dam system. The aim of the present paper is to explain the products of a UAV survey of a dam useful for storing and sharing information and for developing the starting point of a BIM of the structure. Case of study is the arch-gravity dam of Ridracoli, it has been the object of a technological comparison between traditional topographic instrument and the innovative UAV technique. The photo/video database captures the reference state of the structure and allows to investigate possible damage phenomena over time, moreover, by means of photomodelling technique, it provides the dense point cloud as a basis for a BIM.



INTRODUCTION

As explained by Fornari and Marcello (2012), in Italy there are 541 large dams, with an average life of over 50 years, which may extend to 70 years if the analysis is limited to the Alps. The need to, ever more effectively, combine safety with the containment of maintenance costs directly linked to the service life of the structure requires innovative approaches beside traditional methods.

The reduced accessibility of dams does not facilitate direct visual inspection and a large amount of time is required for an inspection by traditional methods. Although a reliable terrestrial survey is still necessary, as Buffi et al. remind (2017), the use of UAVs is well suited for this purpose, as suggested by Colomina and Molina (2014) and Ellenberg et al. (2015). The use of UAVs is spreading to the safe inspection of sections of infrastructure that would otherwise not be directly accessible, except with expensive and dangerous procedures. The state of conservation of the materials can be monitored in order to guarantee a proactive maintenance of the structure, as reminded by Salvini et al. (2017). However, the use of UAV technique on dams is still rare and at an early stage, Naumann et al. (2013) published one of the first work on this topic.

As reminded by ICOLD (1986, 2013), FEM modelling of dams is paramount in the safety evaluation of dam structures; for structures such as segmented arch dams built on valleys with complex topography, the detailed definition of the structure geometry – including the joints between the different blocks – and of the foundation rock mass is of primary importance in the FEM modelling of such systems. The high accuracy of UAV surveys makes possible the three-dimensional geometry modelling of important structural elements (i.e. construction joints) and/or of ancillary works (i.e. spillways, a stilling basin, weight blocks), as explained by Buffi et al. (2018). Therefore, the behaviour of such important elements can be investigated in static and dynamic conditions.

A survey by drone allows for the investigation of the current state of conservation of important infrastructures such as dams. It is the basis for the creation of an interactive photo and video database and for the metric reconstruction of the three-dimensional geometry of structures. In the spirit of obtaining an efficient and accurate as-built data collection, as summarized by Vacansas et al. (2015), the UAV technology is the main operative tool for the creation of BIM of large infrastructures. Moreover, respect than Laser Scanner technique, as employed by Barazzetti et al. (2016), UAV is faster

Figure 1: (a) The lake created by the presence of the dam, scale 1:500m (INGV); (b) The Ridracoli dam

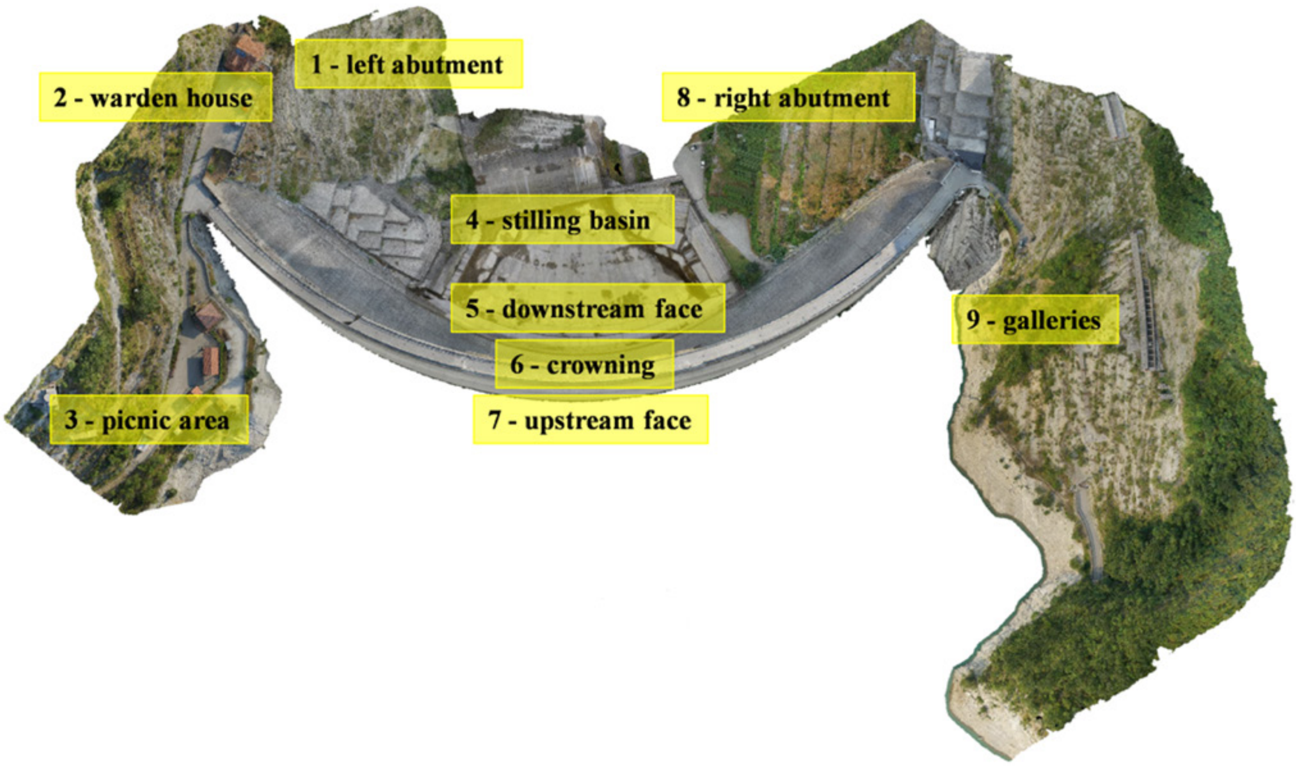
and, for this reason, repeatable over time. The present work aims to explain the products of a UAV survey and their uses into the predictive and proactive maintenance of large structures such as dams. Case of study is the arch-gravity dam of Ridracoli, located in the village of Santa Sofia (FC, Italy), Fig.1a. The Ridracoli artificial lake and its dam represent an aqueduct infrastructures' milestone managed by Romagna Acque S.p.A.. So it is need to maintain the dam effectively and efficiently in order to guaranty safety and a long service life. These important aims require an innovative maintenance method moving from "run to failure" (reactive) approach to a predictive and preventive one. That needs the adoption of a BIM philosophy to collect any data about the dam and building a structural model for evaluating any deformation or stresses under several load conditions. As the first step, the BIM philosophy has the survey of the structure and of the surrounding topography on which a 3D model can be developed. This phase is useful both for collecting data (6d in BIM language) and for evaluating the structural behavior over time and, thus, the risk progressive levels which have to be assumed.

THE RIDRACOLI DAM AND ITS UAV SURVEY

The Ridracoli dam, managed by Romagna Acque Società delle Fonti S.p.A., is the key work of the Romagna aqueduct. The primary use of the Ridracoli reservoir is to supply drinking water of 48 municipalities in the provinces of Forlì-Cesena, Ravenna and Rimini and, since 1989, of Republic of San Marino, providing alone 50% of the entire water needs of the system. The secondary function of the reservoir is the production of hydroelectricity for the surrounding area. The reservoir surface area is 1.035km^2, it has a capacity of 33Mlm^3 and the total surface area of the drainage basin is 87.510km^2. The construction of the Ridracoli dam started in 1975 and it was completed in 1982. After the testing phase, in 1988 the reservoir became operational.

The structure. The simple concrete arch-gravity dam of Ridracoli has a double-curved structure, symmetrical with respect to the main section, resting on a *pulvino* foundation base that extends all around the perimeter of the abutments. The thickness progressively increases from the middle to the sides and along the vertical section from the top to the base, in line with the arch gravity construction type. The connection between the 27 cantilevers of the body dam was ensured by the injection of mortar (fluid concrete) into the vertical joints. The injections were performed through the inspection galleries midway between two blocks, in a radial direction and repeated several times in order to fill the contacts as much as possible. Moreover, during the concrete casting of adjacent blocks, plastic water-stop elements were placed along the perimeter of the inspection galleries and along the external perimeter of the joint. They have the dual function of preventing infiltration of the water and spillage of the cement grout, used for the suture of the joints. The principal dimensions of the structure are: maximum height of 103.50m and crest length of 432.00m, in the key section the top thickness is of 7.00m and the base thickness is of 36.00m. The structure has, in the central part of the crest, eight square free overflow (ogee crest) spillways, the water discharge throughout them

Figure 2: Frame of the downstream face, taken from 30m distance, in which, performing the maximum zoom, the number and the centre of the marker are perfectly detecteble



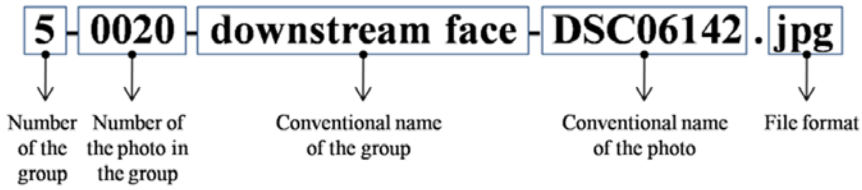
is governed by their geometry, with a maximum capacity of 600m^3/s. During overflow, the flowing water dissipates its energy in the stilling basin constructed at the foot of the downstream face of the dam. Moreover, the dam has a middle height sluice gate, a bottom sluice gate and a depletion sluice gate.

The survey. The Ridracoli dam has been the object of a technological comparison between traditional topographic instruments and unconventional photogrammetry conducted by UAV. The traditional topographic instruments are Total Station (TS30 Leica-Geosystems), GPS Satellite Station (1230 Leica Leica-Geosystems) and Laser Scanner (Z+F 5010 ZoellerFroelich). The UAV is a four propeller HIGHONE 4HSEPRO, with a max. take-off weight of 9kg and an autonomy of 18-30 minutes. The drone has a three-axis stabilized, remotely controlled Gimbal system with SONY Alpha 7R, 36.4 Mpix Full frame camera. Flight operations has been performed in manual mode for strips along the upstream-downstream direction of the structure by a first operator. Image-shooting operations has been followed by a second flight operator who has been able to assess the entity of overlapping frames to be suitable for aerial photogrammetry. The surveyed area is critical both for the strategic nature of the structure and for the presence of people although during the fly operation the access to the dam area has been closed. In August 2015, UAV flight operations were concentrated in a single day performing 19 flights lasting 15min/flight and providing a total of 4051 frames at 36 megapixel resolution. Fig. 2 shows the high resolution of the frames, it is a photo of the downstream face, taken from 30m distance, in which, performing a zoom, the centre and the number of the marker are perfectly detectable. The “Structure from Motion” technique allows for the reconstruction of the geometry of objects through the automatic collimation of points from a series of images. The result is the three-dimensional dense point cloud of the dam system and some parts of the surrounding area at which is associated an RGB (Red Green Blue) information. By means of the marker placement, the traditional topographic survey geo-references and validates the UAV one. Density, point, line and surface analyses have validated the accuracy of the UAV dense point cloud and confirmed the suitability of the UAV technique into the inspection of large structures such as dams. The influence of the number of the placed markers on the level of accuracy of the UAV dense point cloud has been also investigated, as described by Ridolfi, E., et al. (2017).

Figure 3: Interactive summary, in the yellow boxes the hyperlinks which connect to the photo groups of the zones

THE INTERACTIVE PHOTO AND VIDEO DATABASE

As mentioned above, the UAV survey has provided more than 4000 frames at a really high resolution. They are the basis for any subsequent elaboration. First of all, they are the elements for the creation of an interactive photo and video database of every part of the structure. The interactive summary, reported in Fig. 3, is the guide for the consultation of photos of each zone. In the interactive summary, hyperlinks connect to the group of photos which cover the area to which the same link is related to. The structure and the surrounding area are divided in the subsequent groups: left abutment, warden house, picnic area, stilling basin, downstream face, crowning, upstream face, right abutment and galleries, Fig.3. Tab.1 reports the number of frames taken for every area. Every photo is identified by a codification in which are reported, respectively, the sequence number of the group, the sequence number of the photo in the group, the conventional name of the group, the original name of the photo and the file format, an example is reported in Fig.4. Moreover, in every files are included EXIF (Exchangeable Image File) data, useful for storing interchange information: data and time the frame was taken and camera settings such as static information, camera model and manufacturer, and others, shutter speed, orientation (rotation), aperture, focal length, white balance and ISO speed information. In addition, the drone performed also a video of the structure and of the surrounding area, acquiring a general overview of the whole dam system.

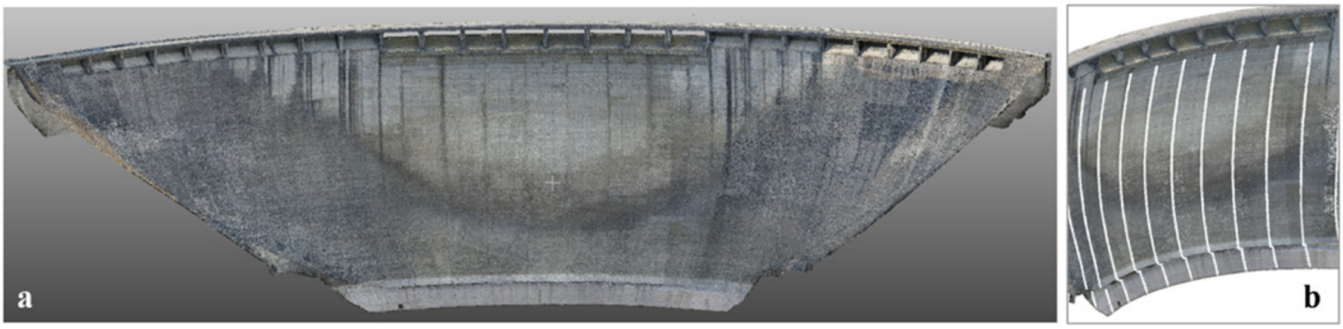


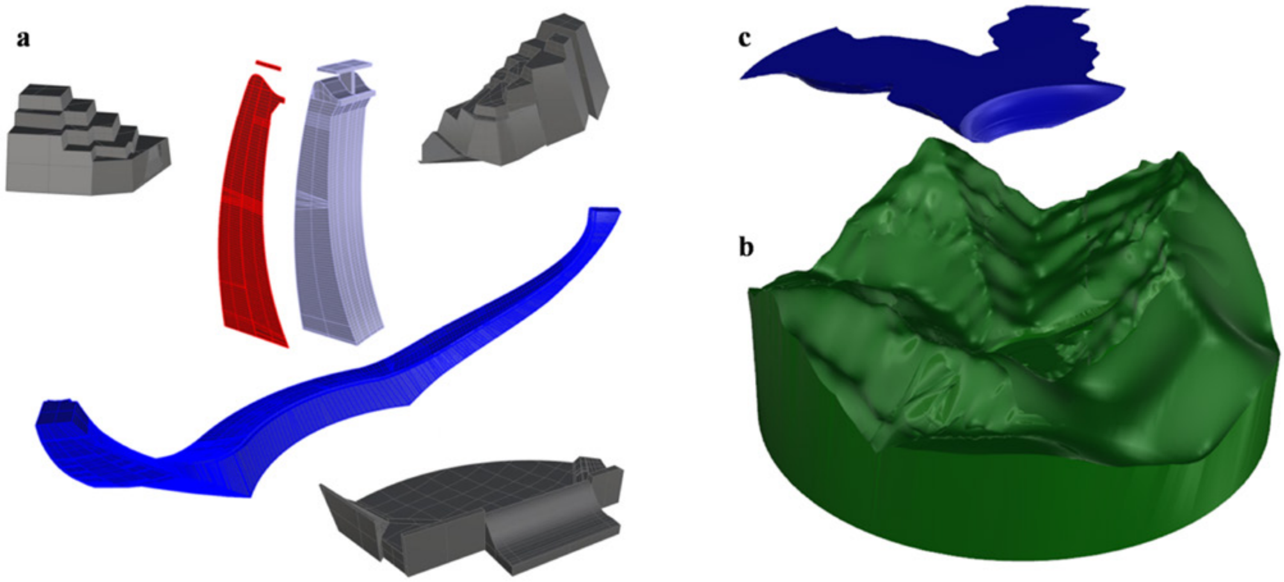
Groups	Number of frames
1 - left abutment	593
2 - warden house	183
3 - picnic area	197
4 - stilling basin	274
5 - downstream face	1630
6 - crowning	163
7 - upstream face	188
8 - right abutment	428
9 - galleries	395
Total	4051

THE SOLID MODELLING

As stated above, starting from the automatic collimation of the frames, the UAV dense point cloud of the structure, Fig. 5a, and of the surrounding area is obtained. This is the base for the construction of the solid model of the dam system. Significant points, that can describe elements with different mechanical characteristics, interactions or boundary conditions, are extracted. The criteria are based on the knowledge of the dam system elements, RGB information associated to the points and/or on the recognizable curvature changes. The selection operations are carried out using the CloudCompare® open source 3D point cloud editing and processing software, by means of the point list picking, Fig. 5b. Subsequently, the extracted points are exported into .txt format and they are imported to the Rhinoceros® commercial 3D modelling software. This is the environment in which data integration procedure with other data sets, such as design geometry, DEM (Digital Elevation Model) of the area and the bathymetry of the lake, are carried out. Connecting the significant points, lines are drawn: these are the contours for close polysurfaces that, including a volume, are solids by definition. The high accuracy of the survey allows for the modeling of some important details such as the vertical

Figure 4: Codification of a photo of the interactive database.
Table 1: Number of frames of each group





joints, the spillways, the stilling basin and the concrete blocks of the right and left sides, Fig. 6. Then, each element is imported in a FEA (Finite Element Analysis) software and, after assigning the properties, the parts are assembled and loads, interactions and boundary conditions are specified. Static and dynamic analyses are performed investigating the linear and non-linear behavior of elements.

CONCLUSION AND FUTURE DEVELOPMENTS

The uses and potential deployment of the UAV product are various. Compared to traditional topographic tools, although still necessary for georeferencing and validate the model, the UAV technique is faster and, for that reason, repeatable over time and cheaper. Moreover, some areas of large structures such as those of the Ridracoli dam, due to their reduced accessibility, would require considerable safety inspections work (involving climbers) and the simultaneous sharing of information among maintenance and management technicians would not always be possible. Therefore, the possibility to have a photographic record of every detail of the structure allows for shared participation and establishes a base level by which to monitor the evolution of the conservation status of the structure so that would

Figure 5: (a) UAV dense point cloud of the dam body; (b) point picking operation in CloudCompare®.
Figure 6: three-dimensional solid of important part of the dam system, (a) weight blocks, blocks, vertical joints, pulvino foundation and stilling basin; (b) rock mass; (c) water.

be possible to pass from a "run to failure" maintenance management to a predictive and proactive one. The speedy flight and its repeatability give the possibility to forecast rapid ageing in order to prevent a partial loss of safety with sustainable costs. For these reasons the UAV technique can be considered the operative tool for the development of BIM of such types of large structures. As with the FEM model, the solid elements developed in the pre-processing software can be characterized by their own mechanical properties. Moreover, the position, functionality and properties of the instrumentation can be included and photos of every details can be stored to provide documentary evidence of the state of conservation.

The management of important structures such as dams is not able to leave an accurate inspection of the state of conservation of the materials and a detailed three dimensional reconstruction out of consideration. The aim is the creation of a 4D model of the whole dam system which includes not only the "static" information but also those which can evolve over time. All the information related to an element would be merged in the same tool, avoiding data fragmentation between the company archives and allowing the immediate sharing of data between all the technicians are involved in, also in different places and time.

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