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3D Virtual Visit of the Paleontological Site of Anchrif (Middle Atlas, Morocco): A New Perspective for the Enhancement of Geoheritage

7

Mustapha Amzil and Mostafa Oukassou

Abstract

Anchrif is an important paleontological and archaeological site located about 1.5 km to the West of the Taghrout village in the province of Fez-Boulemane (Middle Atlas, Morocco). It is a Pleistocene paleo-lake that has delivered several vertebrate fossils. Although the most common findings are elephants ascribed to *Elephas*, artiodactyls, turtles, and *in-situ* Acheulean tools were also collected. In this work, we use 3D reality capture solutions for the geomorphological reconstruction of this site. Aerial photogrammetry and terrestrial laser scanning methods will allow to move virtually on the site and access to augmented information. The results constitute a database for online virtual visit of this site and the visualization of the collected fossil specimens. This will bring new perspectives for the valorization of this heritage and its preservation in the form of a digital archive representing a support of value for the scientists and the general public offering varied experiences for education, enjoyment, reflection, and knowledge sharing.

Keywords

Reality capture · Geoheritage · Anchrif · Pleistocene · Middle Atlas · Morocco

7.1 Introduction

The paleontological heritage is increasingly becoming an important component of the cultural heritage. Over the years, the interest was given to purely static-conservative conception of the protection environmental geoheritage that puts everything under protection and that only allows the contemplation of the good. From this dimension, we have moved on to a more dynamic conception, oriented toward an experiential involvement of the public; this is because the cultural heritage, particularly geoheritage, is increasingly considered no longer as a heritage only to be protected but as something destined for public enjoyment and therefore experienced as a tool of cultural, educational, and economic growth of society (Fistola et al. 2020).

But when and how a paleontological site or geosite, in general, emerges from the shadows and anonymity, that the knowledge of a few experts assigns them and manages to enter in the collective cultural heritage, shared and recognized as a good with undisputed value and of which each citizen is a proud holder? In other words, what are the processes that need to be implemented because the promotion of a paleontological site, but also of a concept, a behavior, become effective and permanent and allows for a cultural growth? While it is more immediate to understand the importance of protecting fossils or meteorites or it is not yet sufficiently widespread the awareness of the geological heritage protection, often constituted by nonrenewable resources such as a waterfall, a caver, or a fossil level.

The use of geological heritage, particularly paleontological heritage, as touristic and educational sites, is everywhere an advantage for the local population and promotes scientific knowledge and geoeducation. In this study, we highlight an important paleontological and archaeological site that can significantly contribute to the education and development of geotourism.

Moreover, the paleontological site of Anchrif (Middle Atlas of Morocco) could be an example for all the other paleontological sites that use technological innovation and augmented reality as tools for promoting cultural heritage. The major role of 3D scanning and modeling by the different techniques (photogrammetry and terrestrial laser scanning) does not only lie in its capacity to provide documentation on the sites and objects, but also in its capacity to analyze the collected data. It is a real scientific tool, able to create plans and cross-sections, measure and even compare results. To do

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so, the elements that constitute the virtual visit – from the shooting to the creation of the 3D model – must be accurate. If this is the case, the 3D model and the orthophoto projections can be used as scientific documentation, preservation, and restoration of cultural heritage objects and sites. Technological innovation and augmented reality are even mentioned by UNESCO in their guidelines for World Heritage Sites management (UNESCO 2019).

7.2 Geological Setting

The Anchrif site is located near of the village of Taghrout in the Skoura syncline (Middle Atlas, Morocco) (Fig. 7.1). This area is characterized mostly by Middle Jurassic formations, more specifically of the Bathonian in age. These sediments, although limited throughout the Middle-Atlas accumulate in depressions located around the anticline ridge (Skoura, El Mers, and Marmoucha synclines) (Fig. 7.1b). These Jurassic basins formed due to the extension caused by the opening to the Tethyan Ocean between divergence of Europe and North Africa (Frizon de Lamotte et al. 2008). The uplift of the mountains themselves happened in the Cenozoic, with the possibility of some of that uplift being ante-Miocene (Babault et al. 2008; Charrière et al. 2011).

The Skoura syncline extends between the North Middle Atlas Fault (NMAF) and the Tichoukt anticline ridge and exposes formations ranging from Lower Liassic limestones to late Middle Jurassic regressive deposits (Dresnay 1963, 1969, 1975; Benshili 1989; Charrière 1990; Fedan 1993; Charrière et al. 1994; Oukassou 2018; Oukassou et al. 2016, 2019). In the Skoura syncline, the strata exhibit a gentle dip on the northwestern flank, whereas they are vertical or even overturned on the southeastern flank underlying the Jebel Tichoukt transverse fault. The axis of the Skoura syncline is traversed by the Oued Guigou, which cuts deeply into the Jurassic strata, and the meanders determine picturesque sites such as the perched Kasba of Taferdouste and that Ksar of Taghrout (Aldighieri et al. 2013). The Anchrif area described in this work is located at the west of the syncline axis at about 1.5 km West of Taghrout village (GPS coordinates N33° 28′ 59.79′W4° 37′ 02.76″) (Fig. 7.1b, c).

The Anchrif quarry is a small high-altitude sedimentary basin (50,000 m^2) with paleo-lake deposits, dated to mid-Pleistocene based on mammal material and hominid tools. The outcrops are located in a valley west of a bent in the Guigou river that passes just Southwest of Taghrout (Fig. 7.2a). This valley is around 20 meters higher than the current level of the above-mentioned river. The Quaternary sediments were deposited in the bottom of a paleo-lake whose dimensions should correspond roughly to the size of the valley that we have today, taking into account that is surrounded by modern valley topography of the Jurassic rocks (Marinheiro 2015).

The base of the formation is a detritic rock, a ferruginous conglomerate. The conglomerate is poorly sorted and most of the grains can be classified as fine gravel (not exceeding 3 cm in size). On top of the conglomeratic layer, soft carbonated sediments are found. The limestone strata have several hard concretions made by concentric layers of carbonates (Fig. 7.2b, c).

These concretions are mostly tube-like in shape and many exhibit an empty tube in their center and are more likely rhizoconcretions. It is possible the formation of the carbonated rocks should not be very different than it is today in a waterfall in the nearby town of Skoura (Marinheiro 2015).

In this area, the carbonates in the rocks are accumulated by freshwater algae and are deposited with the development of the algae colonies. The constant accumulation of carbonates forms layers of limestone over time and ends up forming the structures we can see today near the stream that feeds the waterfall. Anchrif concretions could be formed by the accumulation of carbonates using the same method in plant roots, which would explain the tube-like shape of these structures and the hollow interior (Marinheiro 2015).

The carbonated layers have a dip toward the center of the basin. As such the margins of the lake were at the time the carbonates were forming the top of the formation as steep as they are today (Fig. 7.2d, e, f). The inclination of the ground could have provided a natural trap for large mammals such as the elephants.

7.3 History of Anchrif Paleontological Site

In 2003, Mohamed Ikken and other young villagers from Taghrout discovered in Anchrif several large bones which were thought to belong to dinosaurs due to their large size bones and to the known Moroccan Atlas abundance of dinosaur remains. They announced the discovery to local officials and the regional Direction of Cultural Heritage of the Ministry of Culture. The information has quickly spread throughout the village and even beyond, and the rural community decided to ensure the place of discovery a permanent guarding.

At the request of the villagers in 2011, the Director of Moroccan Cultural Heritage accompanied by some specialists in the field visited the site to investigate the findings of 2003. Immediately, the scientific potential of the site was proven and it was decided to set up a multidisciplinary research program to better highlight the paleontological importance of Anchrif deposit, which could be a means of raising tourism in the area, adding to a raise of importance to the region, besides the scientific research.

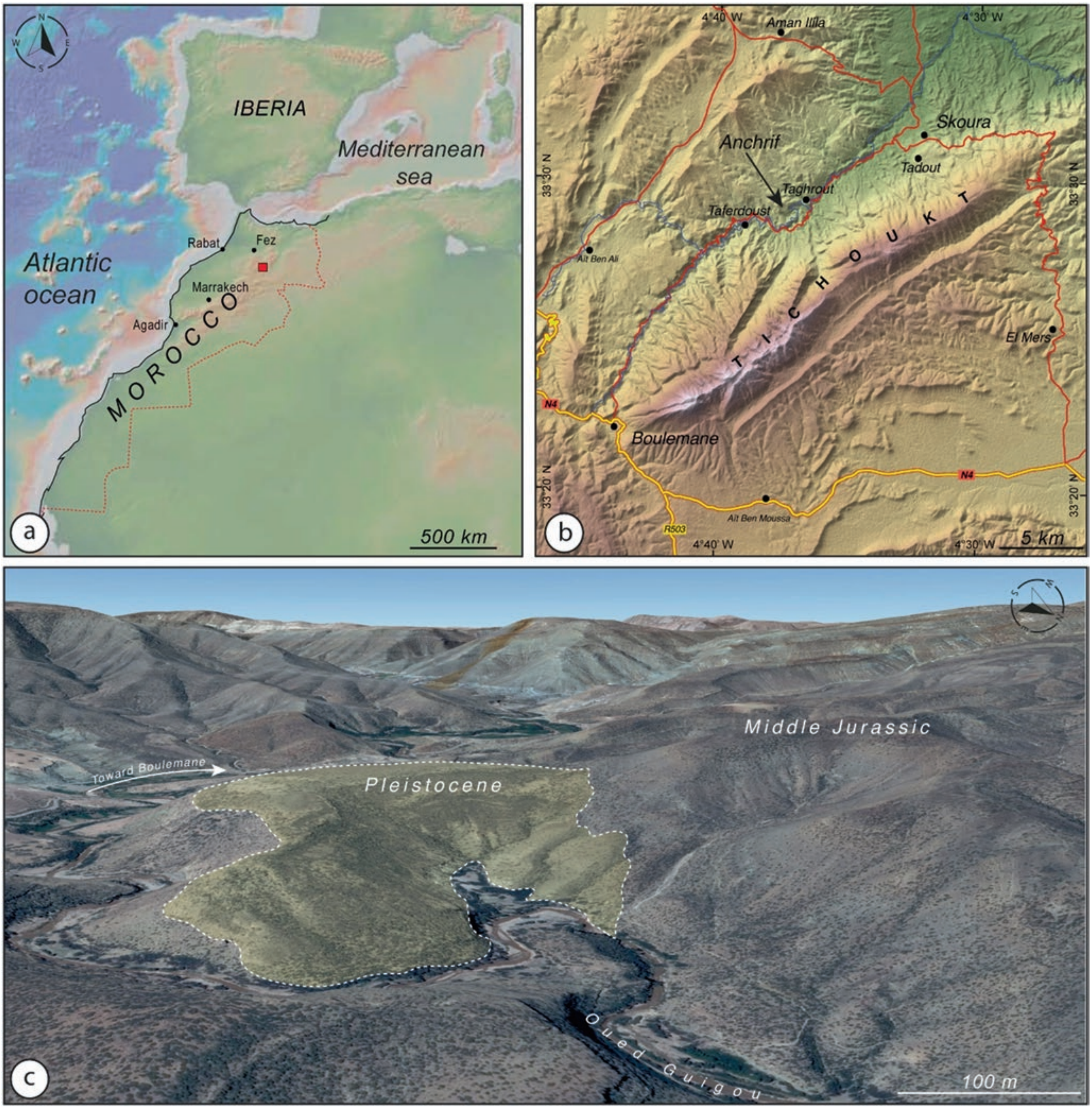

Fig. 7.1 Location of the Anchrif site. (**a**) Geographical map of Morocco. (**b**) Simplified regional geographical map of the vicinity of Anchrif (Middle Atlas, Morocco). (**c**) Landscape view, taken from Google Earth of the study site at Anchrif (Pleistocene paleo-lake) showing aspects of the local geology

The Direction of Cultural Heritage has, therefore, set up through the *Institut National des Sciences d'Archéologie et du Patrimoine* (INSAP), a research program supported by a cooperation agreement established between INSAP and the Nova University Lisbon of Portugal. The two parties have formed a mixed multidisciplinary team and a preliminary visit to Anchrif was planned and made on March 23rd, 2013.

This field mission of March 2013 consisted essentially of methodical excavations in sectors offering tangible evidence of important paleontological remains. The preliminary results of these investigations have immediately invalidated the hypothesis of the existence of dinosaur bones as previously disclosed, but on the other hand, they have allowed to highlight the existence of paleontological riches in the form of bones of *Proboscideans* (an ancient species of elephants) (Mateus 2013).

In September 2013, a protocol was signed between the Direction of Cultural Heritage of Morocco and the Nova

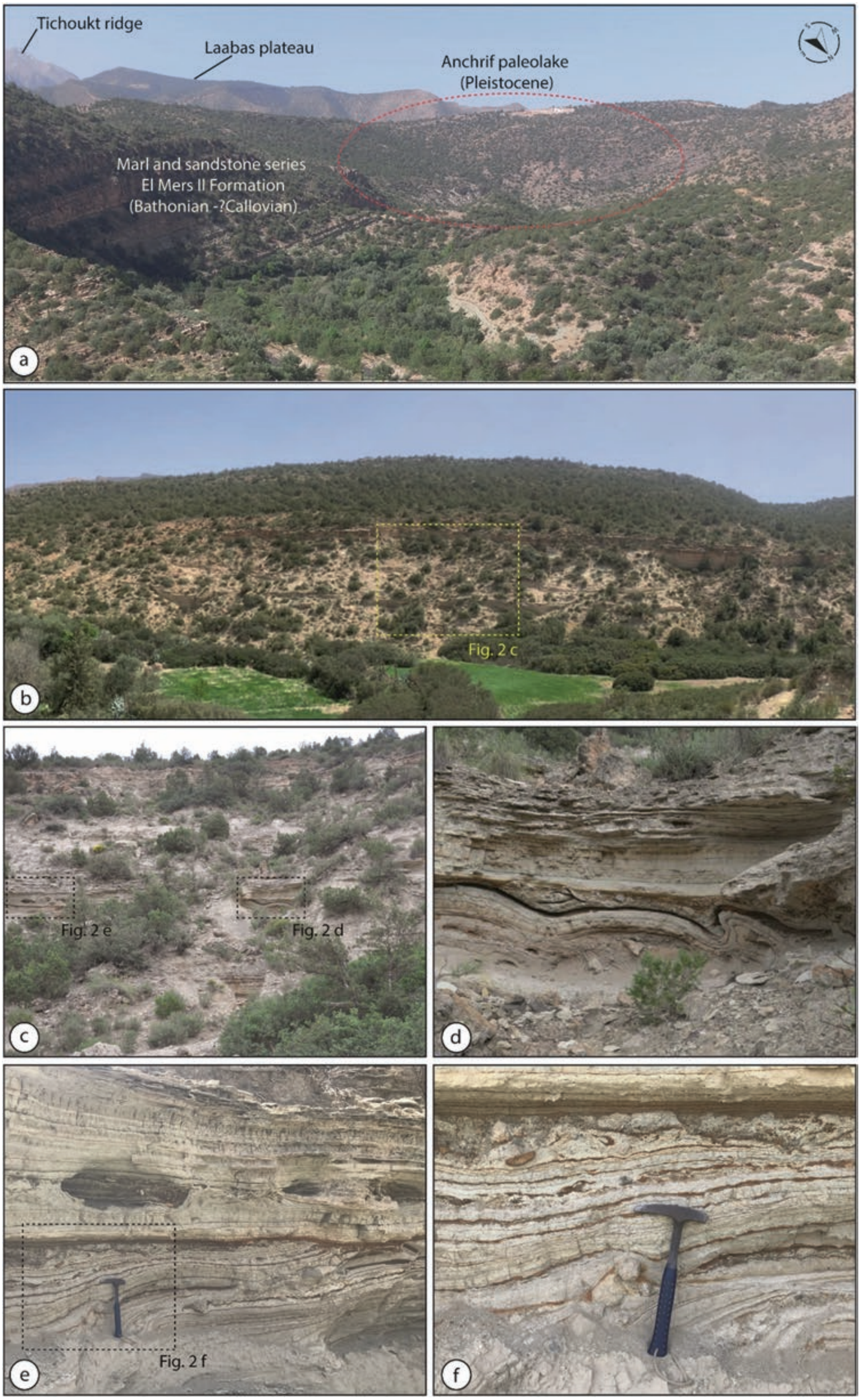

Fig. 7.2 (**a**) Panoramic view from the Northwest over the Anchrif sedimentary basin, near Taghrout, Morocco. (**b**) General view of the Anchrif dig site as seen looking North to South. The whitish beds on the cliffside correspond to the Pleistocene layers. (**c**), (**d**), (**e**) and (**f**) characteristics of the Pleistocene lacustrine deposits of Anchrif

University of Lisbon in order to establish the cooperation of the two institutions in the paleontological and archaeological study of the Anchrif locality and the surrounding Middle-Atlas region (Atlas Mémoire Project, Alaoui et al. 2016).

Field work was scheduled for late September (18th–26th) 2013, a Moroccan-Portuguese expedition made excavations on the site with the help of locals from the village of Taghrout (Fig. 7.3a, b). The excavations yielded new bone material from large mammals. The most common findings are elephants ascribed to the genus *Elephas*, but artiodactyls, turtles, and *in-situ* hominid Acheulean tools were also collected.

Partial results of this research were published in form of scientific communications (Marinheiro et al. 2014a, b) and a Master's dissertation (Marinheiro 2015). This site was also part of a geotouristic trail including other geosites reflecting the geological, geomorphological, and environmental history of the Boulemane-Skoura area (Oukassou et al. 2019). Since this time several educational visits of high schools and universities are organized at the site given its importance due to its educational and pedagogical aspects.

After the inauguration in 2016 of the *Centre d'Interpretation du Patrimoine du Moyen Atlas* (CIPMA) housed in the Cultural Center of Azrou (Alaoui et al. 2016; Lazhar 2019), the Elephantidae material collected during the expeditions is part of the permanent public exhibition of the pavilion dedicated to natural heritage (Fig. 7.3d). It should be noted that other bones, some of large dimensions were left in the site to be dug out in a later date (Fig. 7.3c).

7.4 Methods, Equipment, Software, and General Workflow

Terrestrial laser scanning (TLS) in combination with Unmanned Aerial Vehicle (UAV) and modern computer-based photogrammetry is currently the best approach for the acquisition of high-resolution 3D spatial information. Highly

Fig. 7.3 (**a**) Moroccan-Portuguese scientific team that provided the excavation work during the 2013 field trip, note the two elephant tusks at the researchers' feet. (**b**) J. Russo and J. Marinheiro (Nova University Lisbon, Portugal) during the 2013 excavation. (**c**) Bones, some of them large, were left at the site until the present day. (**d**) Permanent public exhibition of elephantidae material collected during the expeditions at the *Centre d'Interprétation du Patrimoine du Moyen Atlas* in Azrou, Morocco

realistic 3D spatial data sets are becoming the basis for detailed geological studies, providing a multidisciplinary approach in the study and research of both underground and above-ground sites.

Due to the value and potential of the Anchrif paleontological site, one of its main objectives of the work was to produce comprehensive documentation of the entire site with the highest possible degree of accuracy and detail. The proper selection of technologies, equipment, software, and workflow was fundamental to the success of the 3D virtual visit of the site (the entire site is ca. 50,000 m^2; Fig. 7.1c). In this work, we combined two 3D data acquisition techniques: UAV photogrammetry to generate the digital surface model and TLS to obtain the accurate point cloud and 360° views (Figs. 7.4 and 7.5). Subsequently, the 3D virtual visit of the Anchrif site was realized using the Arskan silodata platform, which aims to enable the compression, visualization, management and online sharing of massive 3D data.

7.4.1 UAV Photogrammetry

Digital surface model (DSM) generation is essential to recreating the paleo-lake of Anchrif geomorphology. In this work, the DSM is obtained by using unmanned aerial vehicle (UAV) equipped with a stabilized visible light camera for the images to be photogrammetrically correct (Gašparović and Gajski 2016). This approach is efficient and necessary to allow rapid land survey with high accuracy. For this work and the creation of a 3D model of the Paleo-lake, we used the DJI Mavic 2 Pro (MP) aircraft which is of the rotating wing type (Fig. 7.4e). The major advantage of rotating wing drones is the possibility of vertical landing and take-off and the ability to capture terrain and objects with horizontal and oblique measuring axes (Jiménez-Jiménez et al. 2021; Mulahusić et al. 2022). For the flight planning and image acquisition, we used the Pix4D flight application installed in the Android operating system of the controller (Fig. 7.4f). As for the autopilot shooting mode, one regular mission, that took 18 minutes, was made at the height of 150 m above the ground in order to better represent the shape of the paleo-lake, using GSD (Ground Sample Distance) of 3.51 cm/pixel (Fig. 7.6a). A total of 158 photos covering the entire site were taken by the drone in a single acquisition mission. It should be noted that before the flight with the UAV, the calibration of the aircraft was done in terms of checking all the necessary parameters.

After all the necessary data was collected, the photographs were imported into a photo-based 3D reconstruction software package using 3DF Zephyr Aerial Education version 6.5.0 (www.3dflow.net). The processing steps are as follows: firstly, the importing of raw data (images) in the software; and overlapping images by Structure from Motion (SfM) method (Fig. 7.5). Subsequently, camera calibration in the software (determination of internal orientation parameters); and generate a dense point cloud. Then, importing and combining the 3D point cloud of the laser Scanner RTC360 and the drone using Multi-ICP (Iterative closest point), an algorithm employed to minimize the difference between two point clouds. Multi ICP algorithm allows to merge and colorize multiple point clouds as needed (Fig. 7.6b). Finally, after the rough alignment of point clouds has been completed simply we proceed to photogrammetry processing to generate the high-definition textured mesh (Fig. 7.6c).

7.4.2 Terrestrial Laser Scanning

Before starting the scan acquisition mission, we carried out a reconnaissance visit of the Anchrif paleo-lake in order to avoid obstacles and optimize the number of scan setups then to focus on the main excavation areas. The Leica RTC360 Laser Scanner (Fig. 7.4b, c) was used for the 3D terrestrial lasergrammetry mission. This high-speed scanner (up to 2,000,000 pts./s) has a range of up to 130 m and a High-Dynamic Range (HDR) spherical imaging system composed of 3 cameras of 36 Megapixel and a video inertial measurement system VIS (Visual Inertial System). The purpose of this system is to determine the relative position and orientation between two consecutive scan setups. Based on the relative positioning, the point cloud of the second captured setup can be transformed in the coordinate system of the first. The RTC360 was mounted on a carbon tripod, which makes it easy to move from one setup to another (Fig. 7.4d), as there is a lot of vegetation and the terrain is very rough. The scanner was connected, via a Wifi generic network, with Cyclone Field 360 a free mobile application (www.leica-geosystems.com) installed in the smartphone in order to control, check and adjust alignments of the setups point clouds and immersive images in the field (Biasion et al. 2019).

The field registration workflow (Fig. 7.5) of the RTC360 solution allowed to access directly and rapidly to scan registration in the field. 32 scan stations were placed over the entire site in 2 hours. Each station covered a horizontal range of 360° with a resolution of 6 mm at 10 m. This assured proper overlapping of scans and appropriate density of recorded data (Fig. 7.7).

At the end of the field operations, the collected data is transferred from the RTC360 to an office PC. The multiple scans of the paleo-lake need to be combined and edited. This was done using Leica Register 360 software version 2022.1.0 (www.leica-geosystems.com), with a simple drag and drop and which is used to fine-tune the alignment of scan positions and clean the point clouds by deleting specific sets of unwanted points. During the import, several steps of data

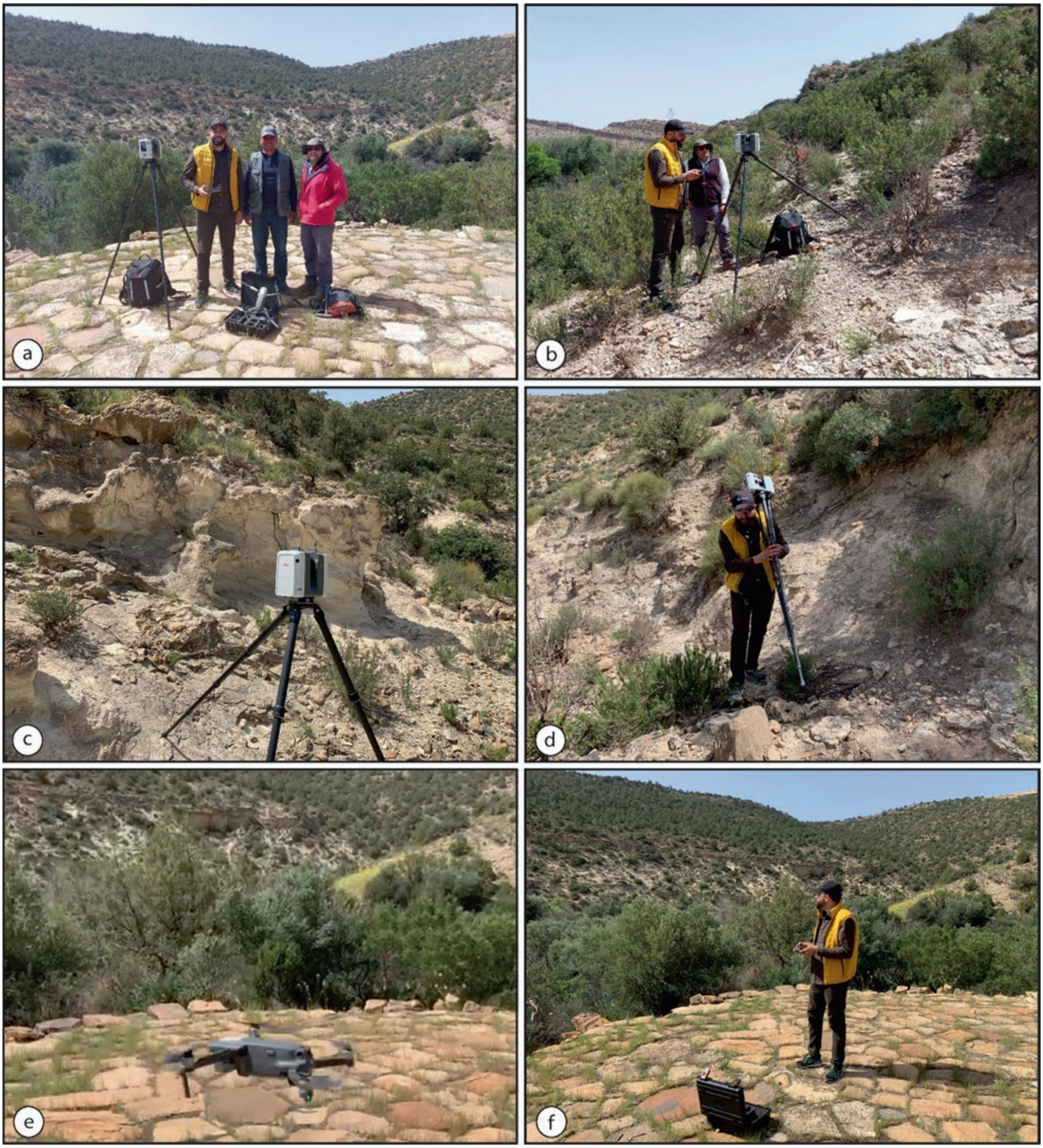

Fig. 7.4 (**a**) Fieldwork at the Anchrif geosite and 3D data acquisition equipment. (**b**), (**c**), and (**d**) 3D terrestrial laser scanning by Leica RTC360. (**e**) and (**f**) Geotagged aerial imagery by the unmanned aerial vehicle DJI Mavic 2 Pro

processing are running. Filters are applied, as mixed pixels and oversaturated points filter. The raw data is processed, with the creation of the panoramic images overlapped on the colored point clouds. Finally, we performed the alignment check of the scans and the quality of the images (Biasion et al. 2019).

7.4.3 3D Virtual Visit

The integration of interactive 360° images in the 3D virtual visit is important, as it allows to have a detailed commented panoramic view of the site. For this, we have used the free

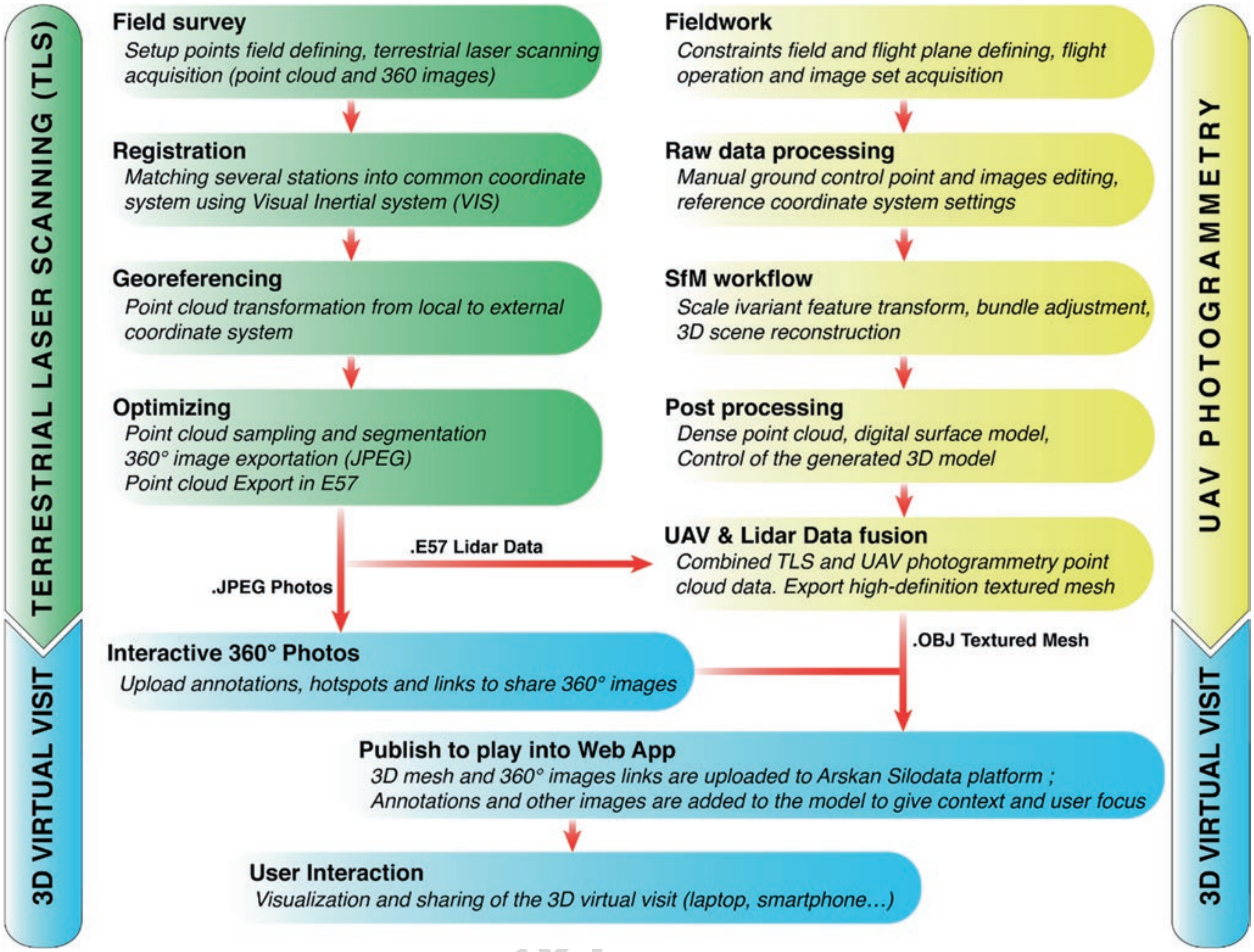

Fig. 7.5 Flowchart showing the workflow for creating the 3D virtual visit of the Anchrif site

online software Momento360 (www.momento360.com). It is the easiest way to make the most of all 360° images and videos through uploading, viewing, and sharing 360° photos and videos all in one place, all from the browser. We have generated links for each 360° image to integrate them into our 3D model of the Anchrif virtual visit.

Finally, to create a 3D Virtual visit model, the textured mesh from 3DF Zephyr was imported into the ARSKAN Silodata platform (www.silodata.arskan.com). It's a collaborative 3D visualization platform to visualize and use massive 3D models; upload and manage 3D data; create secure silos; visualize on PC, Mobile, and VR headset. The imported model is an object file that was combined with the geological data (images, annotations, etc.) extracted from the field investigations, bibliographic review, and from 360° image links, giving a true 3D geological terrain model. Any additional data, such as logs, fossils, and other geological surveys can be added at this stage. The Silodata consists of the scene where digital textured surface models and spatial data are placed to build a virtualized 3D environment which users can interact with. The construction of those scenes varies depending on the visualization context (ground scale, annotations, clipping box, measurements, etc.), to display only relevant information. The main goal of the user interface design is to provide users with a natural interaction experience, including movement dynamics; pointing and selection, immersive data visualization; and scene navigation and measurement tools.

7.5 Results and Discussions

Virtual reality (VR) has been booming since late 2019 after the Covid-19 outbreak and lockdowns, more and more people started to embrace advanced technology in several domains. In fact, virtual reality is now one of the prime technologies in demand. The most significant form of VR technology today is virtual reality tours or simply virtual visits. They are frequently used as a tourist and commercial support; however, they offer many possibilities in the field of

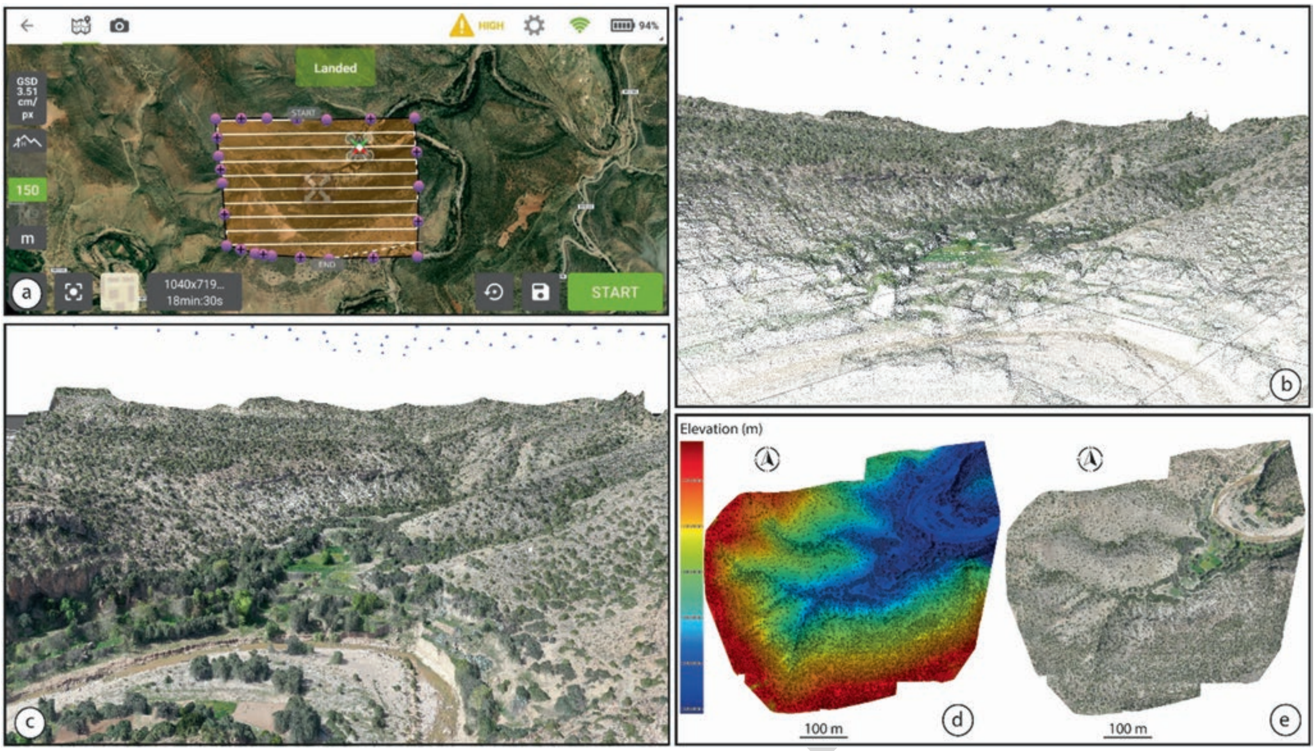

Fig. 7.6 UAV photogrammetry of Anchrif site: (**a**) Screenshot of the pilot application (Pix4D) from the smartphone showing the flight plan and its parameters. (**b**) Colored point cloud. (**c**) High-definition textured mesh. (**d**) Digital surface model. (**e**) Orthophoto

Fig. 7.7 Terrestrial laser scanning of Anchrif site: data preview of survey network and distribution of scanner stations in the import area of Cyclone REGISTER 360

culture and heritage. Thus, a virtual visit can be a way to discover an exceptional place, a geotouristic site or fossils, meteorites, caves, etc.

In this work, given the difficulty of the relief and the access to Anchrif site, the presence of the guide Mr. Ikken throughout our visit has facilitated us essentially to find the exact location of the excavated areas of fossils. Our focus was to digitize the entire Anchrif paleo-lake and particularly to take 360° views of each excavated area.

The preparation of the site by defining the location of the 3D scanning setups and the location of the launching platform of the Drone allowed us to optimize the time of intervention on the field and to collect reliable and exhaustive data as planned for this project.

The processing of the reality capture data is becoming faster and faster thanks to the improvement of the performance of the processing workstations and in particular of the calculation algorithms. The data collected using the 3D laser scanner Leica RTC360 and the drone DJI Mavic 2 Pro were processed in a workstation with the help of the software Leica cyclone Register 360 and Zephyr 3D Flow, the exploitation of the results of the assembly of lasergrammetric and photogrammetric data after testing several desktops and web applications for sharing and pooling 3D data, we chose the Arskan SiloData platform.

Arskan SiloData provides very advanced 3D model visualization compression features that make it easy for the end user to navigate through his models on any mobile device or computer. In the Anchrif 3D model visualization space, the user can navigate through the 3D model in full immersion, measure, create cross-sections and then use the 360° photos to visit each excavation point. The annotations provide a wealth of information related to the paleo-lake such as scientific articles, videos, and photos of bones taken on the site at the time of excavation and also of the fossils we found on the site during our visit. All this information can be used by scientists and students to make their first visit to discover the history of the site, and it constitutes a non-destructive safeguard of this geological heritage. It is a new tool to raise awareness and promote these sites with online heritage values, which allows and continues to keep alive the legacy left by history.

However, the interest of virtual visits in the heritage and geological heritage in particular, is not only to "show or visit." Virtual visits offer a privileged access to informative content: 3D Models, text documents, Measurements, videos, soundtracks, 360° images, illustrations, photos, plans, diagrams, etc. (Figs. 7.8 and 7.9). A lot of scientific information can be added to the visit and enrich it by transforming it into a real interactive guided visit on a simple viewer or by using

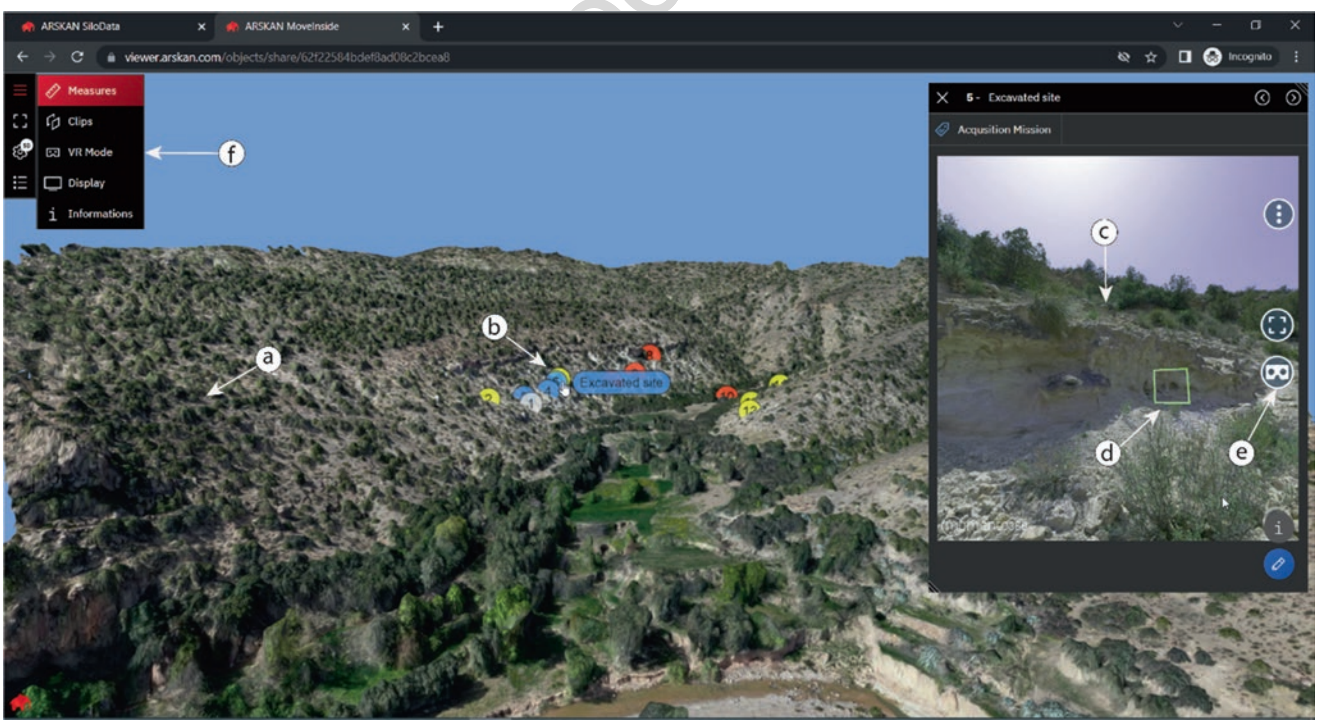

Fig. 7.8 Screenshot of the virtual visit application of Anchrif site via Arskan SiloData platform and these components on the web browser: (**a**) 3D model of Anchrif paleo-lake. (**b**) Annotation. (**c**) 360° image. (**d**) Illustration. (**e**) VR virtual reality mode. (**f**) Tools

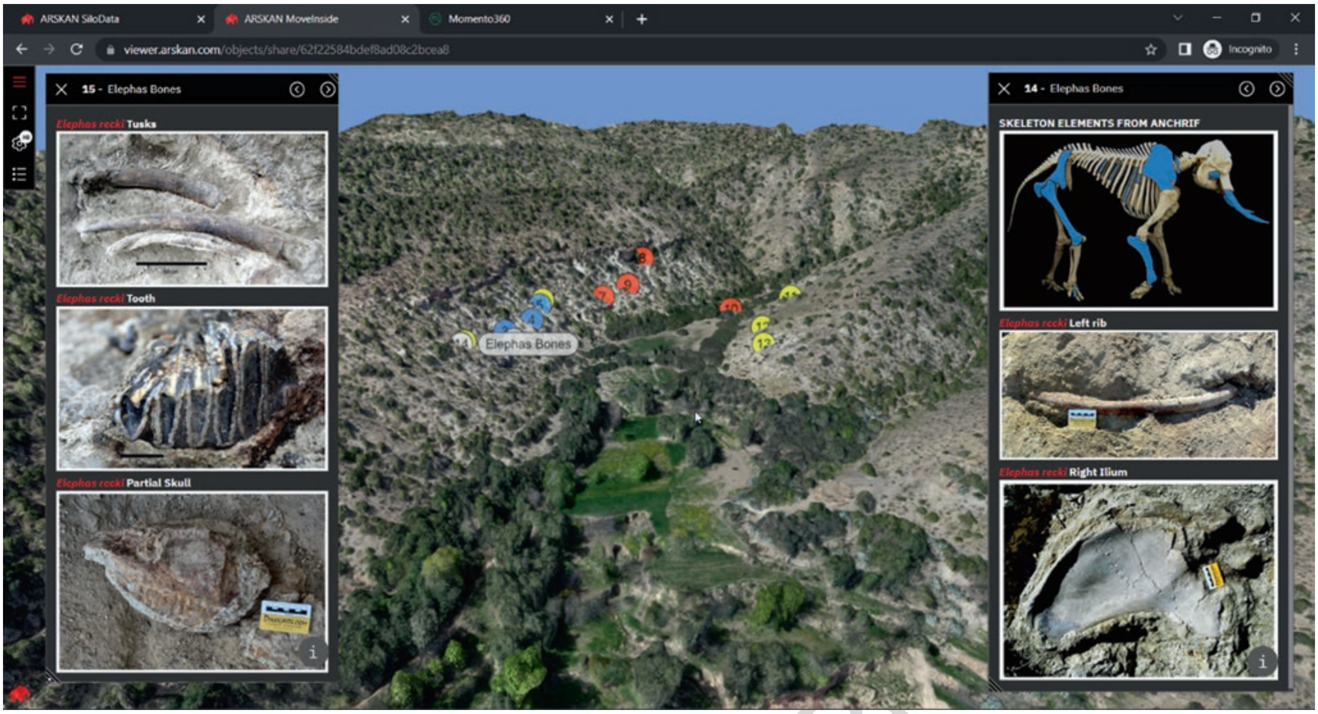

Fig. 7.9 Screenshot of the virtual visit application of Anchrif site via Arskan SiloData platform with example of shared data types

a VR headset for more immersion and interaction with all the data added.

In this reality, the observer uses more than just sight to experience something real and memorable. Thanks to 3D digital models and new technologies allowing interactive exploration, the "passive" viewer becomes an "active user" who decides what to see and what paths to take, and to interact with objects or virtual environments, sharing their sensations and opinions; in this way, the experience remains in the visitor's memory (Barrile et al. 2022).

Digital preservation can be seen as all those processes aimed at ensuring the continuity of digital heritage materials for as long as they are needed (UNESCO 2002). In fact, using the reality capture solution to digitize geological heritage sites allows them to be timelessly preserved when they may be destined to disappear.

As a perspective of this project, we plan to provide this realization to the Center of Interpretation of the Heritage of the Middle Atlas in Azrou in order to benefit from it as an educational support of the pavilion of the natural heritage of the center and to sensitize and encourage the visitors of the museum and the tourists to go physically on site to discover it, which will create a social and economic dynamics in the region. The 360 virtual visits represent a real benefit for tourism professionals. A virtual tour of this kind will never replace the real trip, but it will give the traveler a taste of the next destination and initiate positive emotions toward it, even before planning the trip.

7.6 Conclusion

Paleontological geosites are privileged windows for scientific studies. In the Middle Atlas, Anchrif paleo-lake comprised of Pleistocene deposits in one site is deeply relevant for its paleontological and archeological heritage.

Generally, permanent exhibitions, teaching, and dissemination activities, fieldtrips, and geotourism are the base for the valorization of geosites. Recently, the use of 3D technological innovation would increase the interest in the public converting paleontological geosite in an open-air virtual museum and opens up immense perspectives for educational activities related to the paleontological heritage.

A 3D virtual visit is here suggested, in order to promote and valorize this site. Based on aerial photogrammetry and terrestrial laser scanning methods, will allow the visitors to move virtually in the museum, in the field, or even at home and access to augmented information projecting virtual reconstructions on the background of a real environment. The platform hosting the virtual visit can be fed with informative and didactic documentations on the site to disseminate information about the history of paleontological discovery at this foremost geosite.

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References

Alaoui A, Belatik M, Mahdaoui Fouad, Nejjar A, Filali Nassah F, Lachger M, Najahi N, Nami M (2016) Regards sur le patrimoine culturel et naturel du Moyen Atlas. La documentation du patrimoine culturel marocain N° 2, 109 p.

Aldighieri B, Di Gregorio F, Charrière A, Ouarhache D, El Hamzaoui O, Hessane MA (2013) Taferdoust: la merveille du méandre et du douar perché sur le « Calcaire corniche » (Moyen Atlas plissé, Maroc). In: 8ème International Conference on Geomorphology, Paris

Barrile V, Bernardo E, Fotia A, Bilotta G (2022) A combined study of cultural heritage in archaeological Museums: 3D survey and mixed reality. Heritage 5:1330–1349

Benshili Kh (1989) Lias-Dogger du Moyen Atlas plissé (Maroc), sédimentologie, biostratigraphie et évolution paléogéographique. Doc Lab Géol Lyon 106

Biasion A, Moerwald T, Walser B, Walsh G (2019) A new approach to the Terrestrial Laser Scanner workflow: the RTC360 solution. Geospatial information for a smarter life and environmental resilience. Hanoi, Vietnam, April 22–26

Charrière A (1990) Héritage hercynien et évolution géodynamique alpine d'une chaîne intracontinentale: le Moyen Atlas au SE de Fès (Maroc). (Thèse d'État), Univ Toulouse III. France

Charrière A, Dépêche F, Feist M, Grambast-Fessard N, Jaffrezo M, Peybernès B, Ramalho M (1994) Microfaunes, microflores et paléoenvironnements successifs dans la Formation d'El Mers (Bathonien-? Callovien) du synclinal de Skoura (Moyen-Atlas, Maroc). Geobios 27(2):157–174

Charrière A, Ouarhache D, El Arabi H (2011) Le Moyen Atlas (Middle Atlas). In Michard et al (eds) Nouveaux guides géologiques et miniers du Maroc. Notes Mém Ser Géol Maroc 559, pp 11–164

Dresnay R (1963) Données stratigraphiques complémentaires sur le Jurassique moyen des synclinaux d'El Mers et de Skoura (Moyen-Atlas, Maroc). Bull Soc Geol Fr 7(6):883–900

Dresnay R (1969) Discussions stratigraphiques sur les conditions de gisements de bois fossiles mésozoïques du Maroc étudiés par Melles Y. Attims, F. Cremier et F. Gazeau. Bois fossiles mésozoïques du Maroc. Notes Mem Serv Geol Maroc 210:121–178

Dresnay R (1975) Données topographiques, stratigraphiques et paléontologiques concernant une ammonite citée dans la Formation d'El Mers (Moyen-Atlas, Maroc) et leurs conséquences sur l'âge attribué à cette formation. Bull Soc Géol Fr 7 XVII(6):1144–1146

Fedan B (1993) Évolution géodynamique d'un bassin intraplaque sur décrochements: Le Moyen Atlas (Maroc) durant le Méso-Cénozoique (Thèse Doctorat État), 18. Trav. Instit. Sci., Rabat (1989), sér. Géologie-Géographie physique

Fistola R, Rastelli A, Pham C, Amore1 F.O (2020) Augmented reality for cultural heritage: a new dimension for the perceptual knowledge. IOP Conf Ser Mater Sci Eng 949: 012053

Gašparović M, Gajski D (2016) Analiza utjecaja stabilizatora na određivanje elemenata vanjske orijentacije kamere na bespilotnoj letjelici. Geodetski List 70(93, 2):161–172

Jiménez-Jiménez SI, Ojeda-Bustamante W, de Jesús Marcial-Pablo M, Enciso J (2021) Digital terrain models generated with low-cost UAV photogrammetry: methodology and accuracy. Int J Geo-Inf 10:285. https://doi.org/10.3390/ijgi10050285

Lazhar M (2019) Un chef d'œuvre muséal au Centre Culturel d'Azrou: Le centre d'Interprétation du Patrimoine du Moyen Atlas (CIPMA). Hal-02081231

Marinheiro J, Mateus O, Alaoui A, Amani F, Nami M, Ribeiro C (2014a) New Quaternary fossil sites from the Middle Atlas of Morocco. Comunicações Geológicas 101, Especial I:485–488

Marinheiro J, Mateus O, Alaoui A, Amani F, Nami M, Ribeiro C (2014b) *Elephas* and other vertebrate fossils near Taghrout, Morocco. In: Abstracts of the 74th annual meeting of the society of vertebrate paleontology, p 147

Mateus O (2013) Preliminary results to Anchrif, Marocco, show a high paleontological potential. Unpublished manuscript for the Direction du Patrimoine Culturel du Maroc

Mulahusić A, Gajski D, Tuno N, Topoljak J, Didelija M, Jasmin Ćatić J, Kogoj D (2022) Quality evaluation of 3D heritage monument models derived from images obtained with different low-cost unmanned aerial vehicles. Geodetski List 1:7–23

Oukassou M (2018) Mise en évidence ichnologique des Xiphosures du Jurassique au Maroc : Contexte géologique, paléoenvironmental et paléobiogéographique. Thèse d'habilitation. Université Hassan II de Casablanca. Maroc. 82 p

Oukassou M, Charrière A, Lagnaoui A, Gibb S, Michard A, Saddiqi O (2016) First occurrence of the ichnogenus Selenichnites from the Middle Jurassic Strata of the Skoura Syncline (Middle Atlas, Morocco); palaeoecological and palaeoenvironmental context. Comptes Rendus Palevol 15(5):461–471

Oukassou M, Boumir K, Benshili K, Ouarhache D, Lagnaoui A, Charrière A (2019) The Tichoukt Massif: a geotouristic play in the folded Middle Atlas (Morocco). Geoheritage 11(2):371–379

UNESCO (2002) Charter on the preservation of digital heritage. IFAP-2002/Bureau.II/7, 15 p

UNESCO (2019) Periodic reporting: a handbook for site managers, The world heritage convention third cycle of periodic reporting 2018–2024. UNESCO World Heritage Centre, 76 p

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AU1	Citations Frizon de Lamotte et al. (2008), Babault et al. (2008), Marinheiro (2015) are cited in the body but its bibliographic information is missing. Kindly provide its bibliographic information. Otherwise, please delete it from the body.	