Beauty and Danger: the Għar Lapsi case for spatial information integration

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Keywords

Erosion, Unmanned aerial vehicle (UAV), Terrestrial laser scanner (TLS), Backpack scanner, Caves, Tunnel, Data integration, WebGL, Cloudisle.org

Note

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Introduction

Spatial data integration across diverse technologies, methods and analytics is gaining ground through enhanced research functionality throughout the data cycle. Projects employing the entire data cycle in conjunction with readily available tools both open-source and proprietary, have become common place across the domains, as evidenced in this publication. The terrestrial, bathymetric, aerial and underground domains spanning the physical, natural and social environments have reached fulfillment in delivering useful outputs that are fundamentally spatial based. Spatial information has reached the desks of policy makers and decision takers, such that it is becoming increasingly difficult for the makers and takers to push forward an outcome when faced by an informed public and significant others who posit their feedback and consultations on an informed based: a spatial baseline. This case study depicts an exploration into the integration of various methods and technologies to aid decision-makers to preserve a beautiful but also a dangerous site. Use of a drone (UAV), a terrestrial laser scanner and a backpack laser scanner, enable the creation of an integrated dataset that depicted the structural status of the area, interesting findings and a case for intervention.

Technological imperatives in integrating data

Capturing reality through scanning devices or photogrammetric processes delivers 3D outputs for the former and 2D/3D outputs when the latter is used. Integrating both data acquisition outputs would generate more accurate data. Aerial data capture using unmanned aerial vehicles, commonly referred to as drones delivers highly accurate 2d and 3D outputs as delivered through photogrammetric processing (Adnan et al, 2019), whilst terrestrial laser scanners (TLS) are instrumental in capturing 3D point clouds (Fabbri et al, 2016) as are backpack laser scanners (Erdal et al, 2021).

Whilst the UAV method seeks reality capture from an elevated position, it may be limited in capturing low or underhanging areas such as cave beneath overhangs or door beneath balconies. At the other end TLS captures data from the ground up and acquires those areas not captured by UAV technologies. The TLS, however fails to capture the elements above those areas which are being scanned such as roofs and treetops unless access is sought. Laser scanners borne by UAVs are an option to overcome these lacunae, whilst videos and imagery acquire at ground level counter the UAV image capture loss. Integrating the data implies a need to use the same coordinate system, in this case UTM WGS84, adjusting heights of the captured data since both UAVs and TLS acquire z-values that requires anchoring to pre-captured Ground Control Points (GCPs) (Cunha et al, 2021).

The study of the evolving importance of these capture systems, which whilst recently available to researchers and operational entities in more accessible relative-inexpensive technologies has focused on UAV-dedicated photogrammetric processing (Jaud et al, 2019), multi-platform UAVs (rotor and fixed wing) (Gutiérrez et al, 2020), TLS-dedicated measurements (Eltner et al, 2013) in combination with targets placement (Abdulrahman et al, 2014). The availability of mobile backpack laser scanners has enabled studies to be carried out in rapid capture through walking modes or Segway-assisted devices in an urban environment (Formosa, 2019), whilst (Erdal et al, 2021) mapped historical buildings, forestry (Ko et al, 2021; Xie et al, 2022). Integrating these different technologies and methods results in multi-scalar outputs as exemplified by Jaillet et al (2017) through the use of photogrammetry and TLS to study rock art (increasing capture iterations from micro areas to entire landscapes.

Various studies have been carried out that investigate the data capture process and how it is employed in the study of urban and rural structure, notably on beach topography (Zimmerman et al, (2020), sand dunes (Pintado et al, 2018), cliff monitoring (Kersten et al, 2020; Jaud et al, 2019), its erosion (Letortu et al, 2017) and collapse Dewez et al, 2016.

Other studies focused on coastal monitoring (Zimmerman et al, (2020), sedimentology (Kordic et al, 2019), volume measurement through erosion (Hayakawa et al, 2020; Obanawa et al, 2018) and through mining (Correia, 2020; Jaroslaw et al, 2021), landslides (Garnica, 2021), and forensic engineering that studied accidents sites (Cappelletti et al, 2019; Urbanová, 2017). In terms of the scanning of underground areas inclusive of caves, Walters et al (2020) and Fabbri et al (2016) investigate issues emanating from TLS scanning of large natural caves, taken further through its analysis through visualisation by Buchroithner (2015).

Study Scope

This paper covers a study designed to investigate the coastal landform in the Maltese island areas called Għar Lapsi, an area exposed to significant wave and wind erosion (Figure 1). The paper does not delve into the study of coastal erosion which is being investigated in another research activity but focuses on the methods used to capture the data, the technologies employed, the analysis taken up and the eventual outputs.

This document reports the findings pertaining to the spatial analysis of the site under study as related to erosion indication by the Erosion Unit within the Public Works department. The spatial analysis reviews the points of interest identified by this Unit and creates a 3D model of the area. The latter was particularly crucial since the area is deemed as a potentially dangerous structure or is inaccessible due to sheer cliff-faces or underwater cavities. This renders any filming and in-situ analysis as difficult or impossible to access. The use of remote technology and 3D generation helps the investigators to revisit the site in a digital immersive format.

The scope of the analysis was to carry out baseline data capture as well as build a 3D model of the zone for operational implementation, an output that could be measured online through a normal web-browser that pushes spatial data towards the general public and academics, away from those with proprietary tools and access rights. This process ensures that the output leads to a democratisation of spatial data whilst ensuring that analysts from multiple domains can contribute to the safety and security of the zone as well as furthering the study to include predications of structural change (Garnica, 2021).

Figure 1: Għar Lapsi - Scene Location

Figure 1a: Għar Lapsi location in Siggiewi Local Council

Source: Topographic Data

Figure 1b: Scene Zone LiDAR colour map: GridCell: 447_3965 and 448_3965

Source: LiDAR data: SIntegraM, 2018

Figure 1c: Għar Lapsi West Zone

Figure 1d: Għar Lapsi East Zone

Figure 1e: Għar Lapsi West Zone Erosion

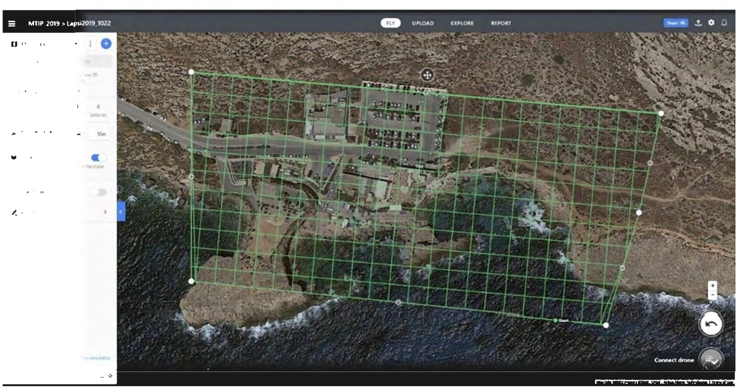
Figure 1d: Għar Lapsi East Zone Erosion

Capture Considerations

Whilst Cunha et al's (2021) indicated UAV capture at 20m and 40m distance, the Għar Lapsi study focused on heights of 30m, 60m and 100m, thus ensuring less data loss through oblique (65deg within the grid and 45deg at the perimeter) and nadir capture. This was carried out in conjunction with GCPs acquired through a previous national LiDAR scan (SIntegraM, 2018), and a set of image-based targets set in visual sight of each other to ensure capture in areas where GPS is in accessible (Abdulrahman et al, 2014). The process to capture same data through the Backpack scanner that employs SLAM technologies and GNSS enables a better capture (Xie et al, 2022).

The Għar Lapsi data capture was carried out in grid format to ensure cross-shore and along-shore capture in both directions (Figure 2 - Drone deploy). Whilst aerial laser scanners are best suited for the study of zones as is the Għar Lapsi area, digital photogrammetry is recognised as a viable method to survey sea-cliffs and areas that are difficult to observe from the land sides, particularly in areas liable to collapse and safety issues. Obanawa et. al (2014) state that the method lowers the cost and enables frequent measurements particularly through the need to scan multiple times due to the erosive impact of sea waves on cliff sides (Obinawa et al, 2018), is the case in Għar Lapsi. The indicated non-contact surveying method that UAVs offer enable cost and capacity reduction as well as enable multiple runs to aid the spatio-temporal analysis of cliff face, cave and environmental movements (Kordic et al, 2019). The method however may be subject to changing weather conditions that may hamper capture (Letortu et al, 2017), mainly temperature, wind and rain. Human factors such as operator and pilot adherence to IMSAFE regulations may also hamper capture, however such still result in quicker data capture than traditional means using land-based and sea-based measurements.

Figure 2: Drone Deploy: Planning the flights



Technologies Employed

Technologies employed for this study were dual in nature, based on UAV (Unmanned Aerial Vehicle) and Laser Scanning, the latter on TLS (Terrestrial Laser Scanner). The technologies employed included a DJI Mavic Pro 2 AUV, a RiEGL VZ400i Terrestrial Laser Scanner and a GreenValley LiBackpack50. Software used in the study included Agissoft Metashape, Pix4D, Lidar360 and RiScanPro. Additional output software that was used for immersion analysis include Unity 3D and the MagicLeap applications, whilst the WebGL outputs were published using LasPublish as published on www.cloudisle.org.

Methodology

This study involved a main method of data acquisition that aided the creation of the 3D scene reconstruction:

An Image-based data capture process. This process employed the main method using drone technology taken from a gridded mission at 60m height; (Figure 2)
A Terrestrial LiDAR scan rendered at 50,000 points per sec transmission; and
A Backpack LiDAR scan rendered at 200,000 points per sec transmission.

The site was generated using multiple technologies where, the 3D model was created through the implementation of LIDAR (Light Detection and Ranging) data acquired through the SIntegraM project that delivered point data at a 40-120 points per meter squared resolution, which allowed for the generation of a triangulated image that enables 3D extrusion of the base map for easier visualisation. Further data analysis enabled the integration of the aerial photos and the 3D data to deliver a virtual replication of the study site.

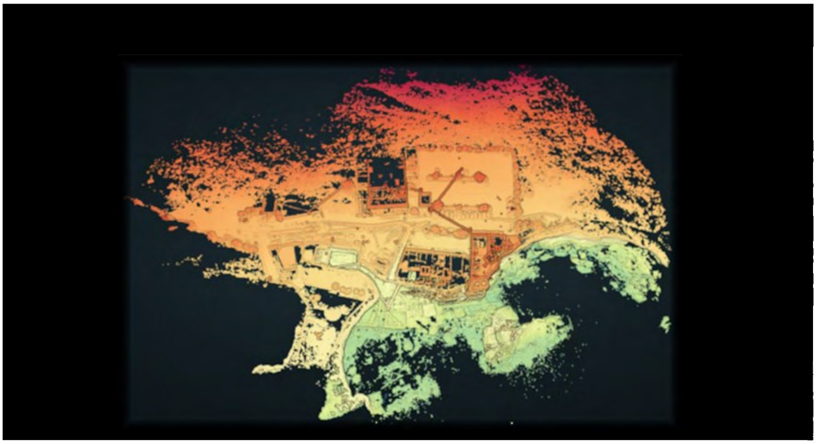
- The video-to-image-to-pointcloud generation was based on a 4k image-based approach that allowed for the generation of a 3D interactive model that allows the user to rotate and view the model from different perspectives which allowing for visual analysis of the Għar Lapsi scene, particularly as it offers the users a tool through which to one can revisit the scene digitally (Figure 3).
- The Terrestrial Laser Scanner enabled the direct pointcloud capture through the generation of a 3D interactive model that can be exported to various formats for analysis as well as for export to a web-based light interactive tool as indicated in the video-image-pointclouds process (Figure 4).
- The Backpack Laser Scanner enabled the direct pointcloud capture through a walkthrough of the area which process captured a composite non-colour pointcloud using LiDAR and SLAM technologies (Figure 5).

- Additional videos and in-situ imagery were also employed in the real to virtual data conversion.

Figure 3: Photogrammetry aerial (lacks oblique capture)

Figure 4: TLS LiDAR terrestrial (lacks building roofs)

Figure 5: BackPack Laser scanner output



The process to investigate the area and identify scene dynamics required the generation of the area in 3D. The process entailed the following:

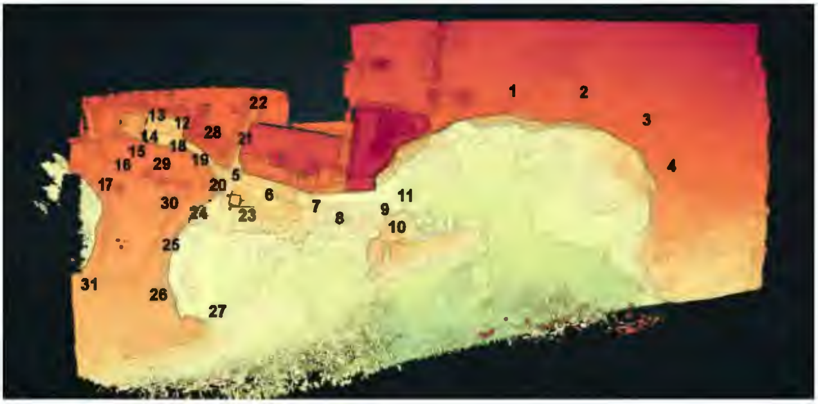
Phase A: Raw data and imagery acquisition

The data acquisition phase (Phase A) required a series of scene-related imagery and locational information which serves as the foundation for the generation of a 3D model (Phase B) and the later analysis in Phase C of the scene.

The process entailed the following steps:

- The acquisition of LiDAR data that included z-height (to determine the actual laser height of each point in the Għar Lapsi area. Source: SIntegraM 2018;
- The acquisition of aerial remote-acquisition imagery (to identify the coordinates and imagery of the points of interest). Source: SIntegraM 2018;
- The acquisition of drone imagery/videos taken during the Għar Lapsi scene investigation process; and
- The acquisition of terrestrial laser scans taken during the Għar Lapsi scene investigation process. Thirty one (31) scan positions were taken (Figure 6).

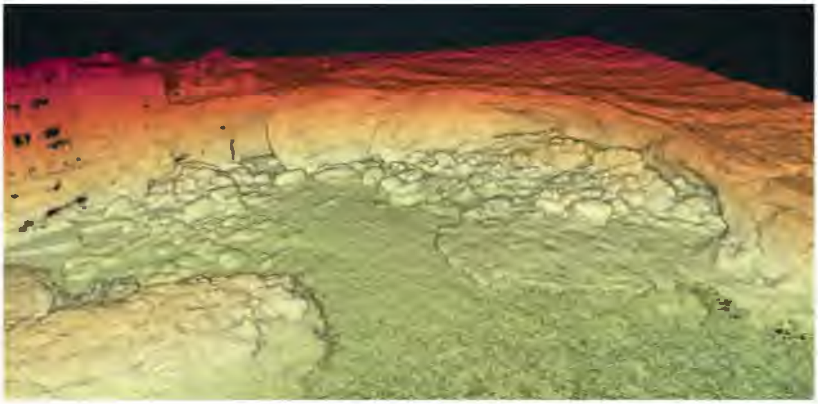
Figure 6: Scan Positions: 1 – 31



Phase B: Data extraction

The data extraction exercise employed various technologies and processes that converted the diverse Phase A technologies into pointcloud information which would allow analysis of the scene in a 3D virtual environment. The different imagery and data were integrated into a spatial information system using diverse data conversion technologies and a 3D model of the area was generated. The output was such that due to very clear waters at the moment of image capture (best taken just before sunrise which would cause thermals and in turn waves), a clear 3D scan of the seabed could be derived. The output as depicted in Figure 7, shows the bathymetric part clearly highlighting the rocky bottom.

Figure 7: 3D pointcloud Oblique Height Perspective – Facing NW



Phase C: Scene dynamics and analysis

The 3D virtual environment was used to visit the scene from various angles and perspectives as well as to allow the erosion experts to identify potential scene dynamics. The resultant model was available in different formats that included the 3D model as pointclouds and meshes.

Data was made available in various formats to allow users to employ the data in proprietary software and applications. The data captured from the different scans were initially rendered on their own, then integrated within one pointcloud. The results were then prepared for publishing through WebGL and uploaded to the links indicated in the text. Such does not need a powerful computer but a common web-browser. The LasPublish (potree) WebGL tool employed for this exercise allows for coordinate identification, measurements, 3D movement, profile generation and export. DEM, DSM and DTM outputs were resultant through the spatial analytics carried out through Pix4D and Global Mapper in conjunction with outputs from the proprietary TLS software (RiScanPro) and backpack (Lidar 360). In this study, error generation (Cunha et al, 2021) through data lacunae was reduced through the integration of data from the aerial imagery and terrestrial laser capture. The resultant DSM was employed to anchor the 3D data covering the caves, the erosion zones and the underground tunnel (Correia, 2020).

Scene Dynamics: Transacts

This section is based on the calculations pertaining to the scene under study. The area has a generic length of 30.8m with heights varying from contact with sea-level to 6.4m. The transacts indicate a length of 21.3m and a height of 4.2m for transact 1, a length of 20.1m and a height of 4.9m for transact 2, a length of 1.6m and a height of 3.4m for transact 1 (Figure 8).

Figure 8: Transacts

Figure 8a – Transacts Lines

Figure 8b – Transacts Buffers of 3m, 8m and 20m (accommodates the feature width)

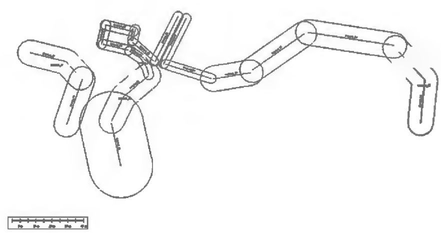


Figure 8c – LiDAR data in Transacts Buffers of 3m, 8m and 20m (accommodates the feature width)

Figure 8d – Area 1 Transact 14 Line and Buffer 8m plus TLS data

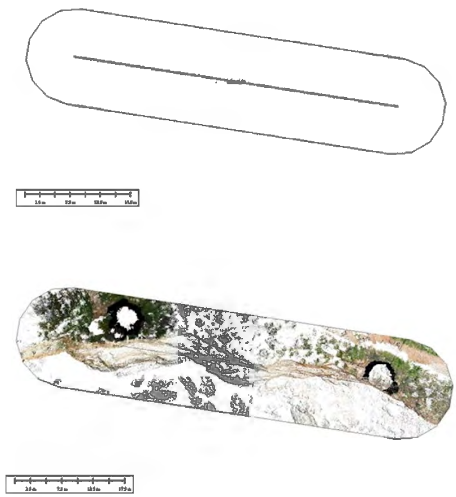
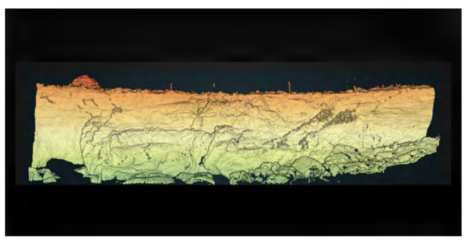


Figure 8e – Area 1 Transact 14 Data Face Frontal RGB

Figure 8f - Area 1 Transact 14 Data Face Frontal Elevation



Scene Dynamics: Erosion visuals

A quick measurement based on the point clouds from the extreme ends of the dataset indicate that the eroded areas vary in dimensions of 4.5m (depth) by 4.5m (width) by 1.5m (height) for Area 1, 6.4m (depth) by 7.4m (width) by 2.4m (height) for Area 2 and 4.97m (depth) by 2.2m (width) by 2.6m (height) for Area 3 (Figure 9). Note that these are based on random points that need extensive measurements through dedicated programmes.

Erosion prone spots can be analysed through a side visual as depicted through LasPublish output that allows for profile visuals and measurements.

Figure 9: Erosion Visuals

Figure 9a – Area 1 Intra-Rock (view from inside the rock) Oblique RGB Perspective – Facing N

Figure 9b - Area 1 Intra-Rock (view from inside the rock) Oblique Height Perspective – Facing N

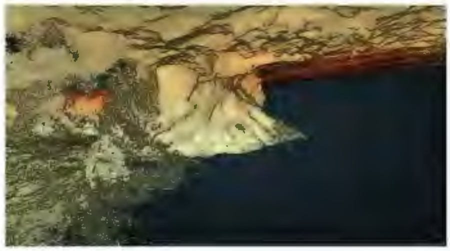


Figure 9c - Area 1 Exterior Oblique Height Perspective – Facing N

Figure 9d - Area 1 Exterior Oblique Height Perspective – Facing N

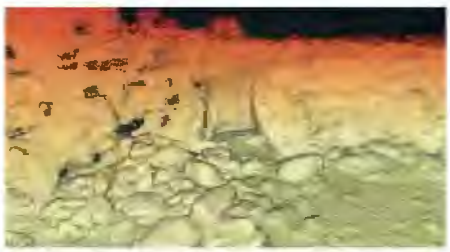


Figure 9e - Area 1 Intra-Rock (view from inside the rock) Nadir RGB Perspective – Facing E

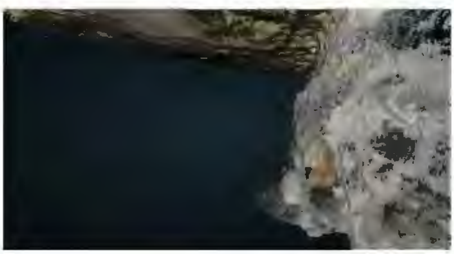


Figure 9f – Area 1 Intra-Rock (view from inside the rock) Nadir Height Perspective – Facing E

Comprehending the Spaces

In order to comprehend the spaces involved in the Għar Lapsi scene, the purpose of this study was aimed at recreating the scene in 3D which would allow the decision-makers to be able to revist the Għar Lapsi scene in an interactive 3D output. The process to create and eventually to render the scene of investigation is a laborious and intensive process requiring high-end computing power and tools that were necessary to allow investigators and the actors to acquire an accurate model of the scene under study.

The model, in conjunction with the GIS component allows the decision-makers to identify those areas that are depicted as potential areas serving as line of sight through scene rotation and immersion as well as a more detailed depiction of the scene (Refer to the Online Data Results and Resources section for an interactive data experience).

It is of importance to note that this exercise was verified through the use of the two methods (photogrammetry and laser scanning), which interestingly also enabled the rendering and measurement of caves (Figure 10), eroded spaces (Figure 11) and tunnels dug beneath the earth (Figure 12), one of which penetrated right through to the cliff, currently used as a boathouse (Figure 13).

Figure 10 depicts the main cave as being 30.48m in depth from the outermost jetty corner, 3.96m in height and 4.37m below street level, a cave that has been protected from erosion through netting installed in place by the Public Works Department.

Figure 10: Għar Lapsi main cave dimensions
TLS Area 2 Intra-Rock (view of Cave from inside the rock inclusive of surface underside)
Height Perspective – Facing N

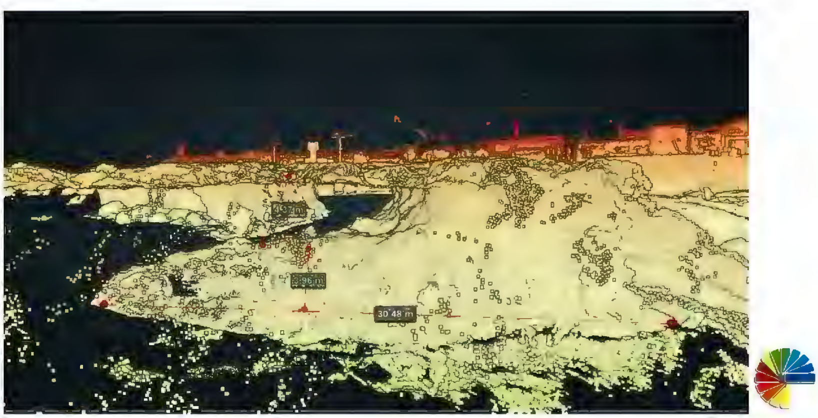


Figure 11 depicts the incursion of (Figure 9) wave action that eroded a section of the eastern bay cliff 5.66m in a horizontal direction beneath a 13.92m cliff face. Note that the eastern part of the bay shows an extensive collapse history.

Figure 11: Eroded areas (beneath cliffs) dimensions - Area 1 Profile 1

Figures 12 and 13 depict the western Bay that posits an old concrete cliff-face balcony which was traced to a boatyard in the hill that resulted in a 25.70m rock-cut tunnel of 1.86m height and located 3.26m beneath the yard floor. The Lapsi Area is littered with boathouse windows overlooking the sea, which would posit a need for future studies in order to map the entire zone and analyse the entire Lapsi area for its safety and security as well as danger potential. The technologies employed in this study could be complemented by Ground Penetrating Radar to enable the discovery of underground spaces, which output can be integrated within the model resultant from this study.

Figure 12: Area 2 Measurements Tunnel/Boathouse

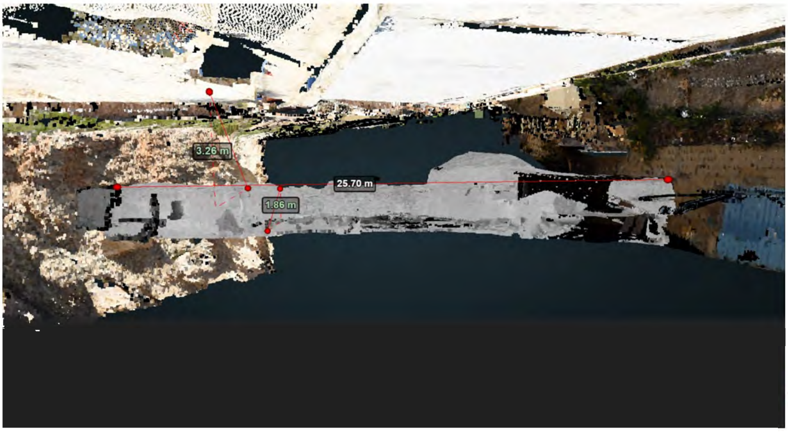


Figure 13a: Identification of tunnel exit through a cliff hanging balcony

Figure 13b: TLS Intra-Rock Tunnel linking Area 2 with Area 3 (view of tunnel from inside the rock inclusive of surface underside) RGB Perspective – Facing SE

Conclusions

Integrating diverse datasets for analytical purposes resulted in a comprehensive information system comprising aerial (top down), laser (Bottom up) and laser façade capture. The Għar Lapsi study enabled the researcher to analyse the dimensions of the entire zone, inclusive of the main cave, eroded areas that might point towards hazards such as cliff collapse, rock falls, amongst other safety and security issues. The process employed related to studies on cliff monitoring (Kersten et al, 2020; Jaud et al, 2019), the erosion in the western and eastern Lapsi areas (Letortu et al, 2017) and potential and real collapse in the eastern bay (Dewez et al, 2016). The study highlighted the technologies required to scan a large zone and the depiction of results that can be accessed through WebGL.

Online Data Results and Resources

HTML Links for online 3D datasets:

3D Lidar Point Clouds

- Imagery Source: UAV DroneDeploy Mission
https://www.um.edu.mt/projects/cloudisle/DATA1/MTIP/47p_lapsi_dji.html

- Imagery Source: UAV Manual Flight Capture (a Balcony area)
https://www.um.edu.mt/projects/cloudisle/DATA1/MTIP/gharlapsi_zone03_ul.html

- Imagery Source: TLS Laser Scanning
https://www.um.edu.mt/projects/cloudisle/DATA1/MTIP/gharlapsi_tls_comb.html

- Imagery Source: Backpack Laser Scanning
https://www.um.edu.mt/projects/cloudisle/DATA1/MTIP/gv_lapsi_2019_walk.html

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