Work Package 2: Technological Innovation for Sustainable Development

Deliverable T2.3.1: Project report (Addendum)

Drone Surveying for the Protection and Preservation of Natural and Built Heritage Sites (Addendum)

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SUSTAINABLE RESILIENT COASTS

Project Partners

Landbúnaðarháskóli Íslands

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Executive Summary

Drone or Uncrewed Aerial Vehicle (UAV) technology is rapidly becoming an important tool across a broad range of coastal applications. This report, an addendum to Giannoumis (2021), provides practical examples of how drone technology has been employed on Rathlin Island, Northern Ireland, offering potential to improve the protection and preservation of natural and built heritage sites. We focus on the use of consumer grade, off-the-shelf drones and standard software to create 3D models of both a natural geological formation (Doon Point columnar basalt site) and a built structure (East Lighthouse).

Firstly, some background information on Rathlin Island and the regional geology is provided. Next, an overview of the method used to generate the 3D models, Structure from Motion (SfM) photogrammetry, is presented. This is followed by the practical workflows used to create SfM models in two locations: the Doon Point headland and the East Lighthouse compound. Additionally, more simple approaches, such as video capture and 360° panoramic photos, are also discussed. This guide will allow coastal managers and other users to understand the process of digitally protecting and preserving important sites, while also providing a means of making inaccessible locations accessible to more people through interactive digital environments.

The report has been produced as part of the European Regional Development Funded Sustainable Resilient Coasts (COAST) project, a collaboration between partners from Iceland, Finland, Ireland, and Northern Ireland focusing on the future challenges and development of coastal areas in Europe's Northern Periphery and Arctic (NPA) region. The project seeks to deliver practical guidance for coastal local authorities to support resilience building and coastal sustainability. This document is therefore intended to enable local authorities with limited experience but a desire to understand and use drone technology for the assessment and survey of coastal resources. Further project reports, such as Giannoumis and Holloway (2020), Giannoumis (2021) and Hayes *et al.,* (2021) can be found at the COAST website: http://coast.interreg-npa.eu/

Acknowledgements

CCGHT and UCC, on behalf of the Sustainable Resilient Coasts project would like to extend thanks to Rathlin Island community including the Rathlin Island Development Community Association, residents and landowners for engaging and supporting this drone surveying field work. A special thanks to the following landowners: The McMullan Family, J. McQuilken and The Commissioner of Irish Lights.

Acronyms and Abbreviations

CMOS	Complementary Metal Oxide Semiconductor
COAST	Sustainable Resilient Coasts
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EASA	European Union Aviation Safety Agency
GCP	Ground Control Point
GDPR	General Data Protection Regulations
GeoTIFF	Tagged Image File Format (Geo = containing georeferencing information)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSD	Ground Sampling Distance
IAA	Irish Aviation Authority
ITM	Irish Transverse Mercator
LiDAR	Light Detection And Ranging
MP2	DJI Mavic Pro 2
MVS	Multi-view Stereo
Mya	Million years ago
NPA	Northern Periphery and Arctic
SD	Standard Deviation
SfM	Structure from Motion
SOP	Standard Operating Procedure
UCC	University College Cork
UAV	Uncrewed Aerial Vehicles
VLOS	Visual Line of Site
WGS	World Geodetic System

1 Introduction

Until the last decade, the cost, experience and expertise required to create fine scale 3D digital models using photogrammetric methods excluded all but a narrow range of potential users. Nowadays the tools have been simplified, processing methods and software established, and with affordable, high-quality cameras becoming widespread, Structure from Motion (SfM) photogrammetry is now being applied to a rapidly growing range of disciplines. Furthermore, with the rapidly expanding range and affordability of drones equipped with high quality cameras and GPS/GNSS (Global Positioning System/Global Navigation Satellite System) devices, SfM methods can now be applied to sites covering many square kilometers and regions too difficult or dangerous to reach by ground. Drones provide a unique way to digitally document and aid in the preservation of important cultural, built and natural coastal sites.

This document is an addendum to Giannomous (2021), providing practical guidance on how to generate 3D SfM models by example of two distinctive sites on Rathlin Island, Co. Antrim – the Doon Point columnar basalt site and the East Lighthouse. This document is arranged as follows:

- Some background information on the geographical and geological context of Rathlin Island and the surrounding region
- A description of the two main sites, Doon Point and East Lighthouse
- An overview of the SfM photogrammetry principles and methods
- A description of the surveying and processing of the Doon Point
- A description of the surveying and processing of East Lighthouse
- A few examples of other ways that drones can be used for digital documentation and preservation
- Some concluding thoughts and suggestions

Further details and descriptions on drone surveying can be found in Gianoumis (2021), Hayes et al., (2021), while information on other coastal applications of drone surveying can be found in Kandrot and Holloway (2020) and Kandrot *et al.,* (2021).

2 Rathlin Island

Rathlin Island is located 9.6 km off the north coast of Co. Antrim, Northern Ireland (Figure 1). It is the most northerly point in, and the only inhabited offshore island of, Northern Ireland. The L-shaped island is approximately 5.5 km from north to south and 7.5 km from east to west. Rathlin's landscape features numerous hills, the largest reaching little over 130 m, several lakes, and the coastline contains countless small headlands, bays and cliffs. The cliffs contain clear geological exposures, highlighting the main geological strata that formed the landscape.

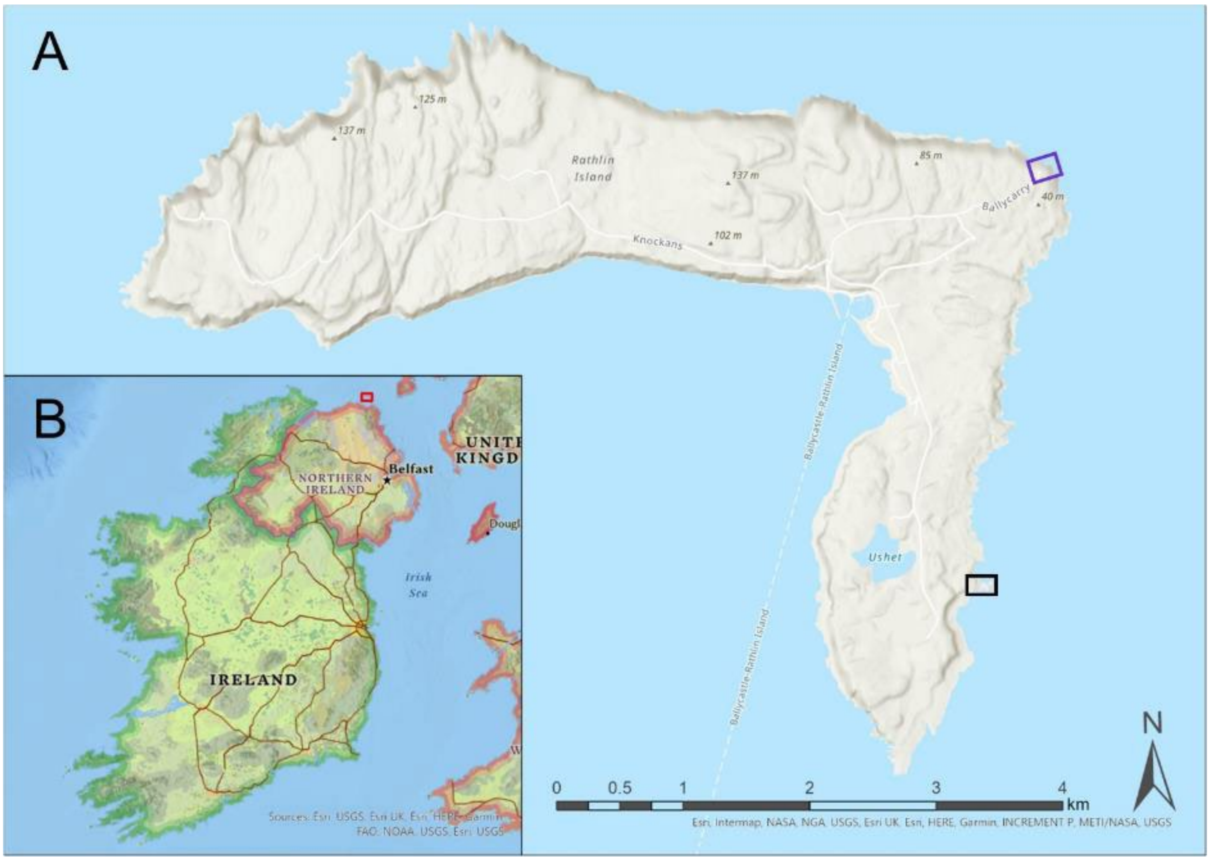

Figure 1: Rathlin Island (A) with Doon Point and the East Lighthouse shown by the black and purple boxes respectively, with an inset may showing Rathlin Island in relation to the island of Ireland (B)

2.1 Geological setting

Rathlin Island primarily consists of a base of white limestone from the Cretaceous period, about 145 to 66 million years ago (Mya), atop of which lies basalt from Paleogene lava flows about 60 Mya (Figure 2A). Weathering after the initial lava flow created distinctive red laterite bands, after which several more lava flows occurred producing further basalt layers (Figure 2B), including those associated with the Giant's Causeway and Causeway Coast UNESCO World Heritage Site (Porter, 2000). The combination of the laterite layers with further basalt intrusions contributed to the formation of porcellanite on the island, a rock used in neolithic tool making, such as for axe heads, and potentially traded throughout Europe (Mandal et al., 1997).

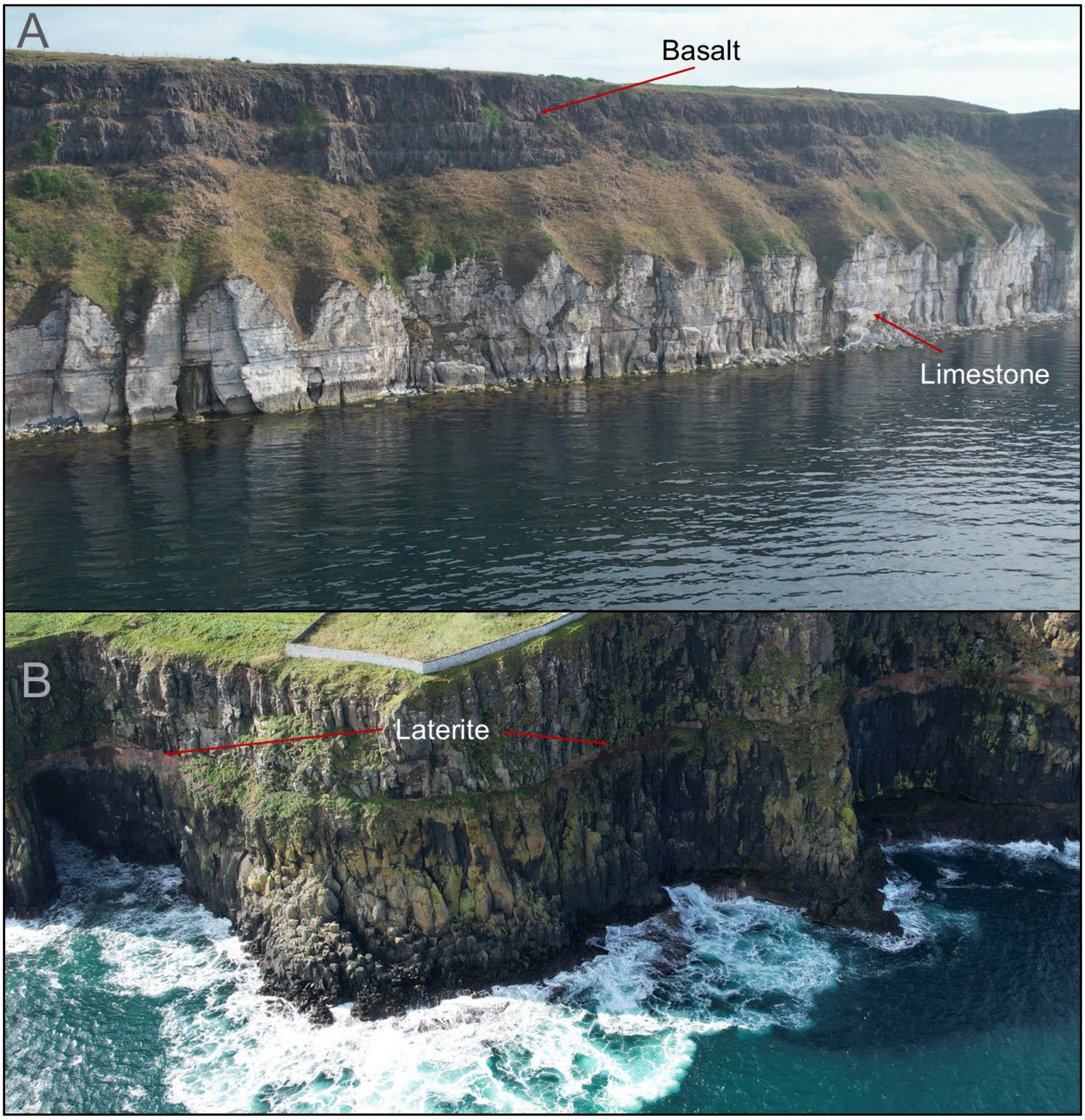

Figure 2: Limestone base topped with basalt on the south facing coast near Church Bay (A) and distinct red laterite bands in between basalt beds below the East Lighthouse (B).

2.1.1 Doon Point

Located on the southeast shore of Rathlin Island (black box, Figure 1A), Doon Point is a small headland extending about 170 m from the average shoreline (Figure 3A) and covering approximately 20,000 m^2. Located on its southern flank is an exposure of columnar basalt (Figure 3B), formed during the Paleocene epoch about 60 million years ago. This is one of the few clear examples of basalt columns in Northern Ireland, aside from the Giant's Causeway, and an important site for the region. It has not been developed as a tourist attraction, access to the site can be slightly difficult. As such, this is an area in need of digital documentation, both for analysis and maintenance, but also for demonstrating the ability of drone-based photogrammetry to produce 3D digital models capable making the site accessible to those unable to visit it in person.

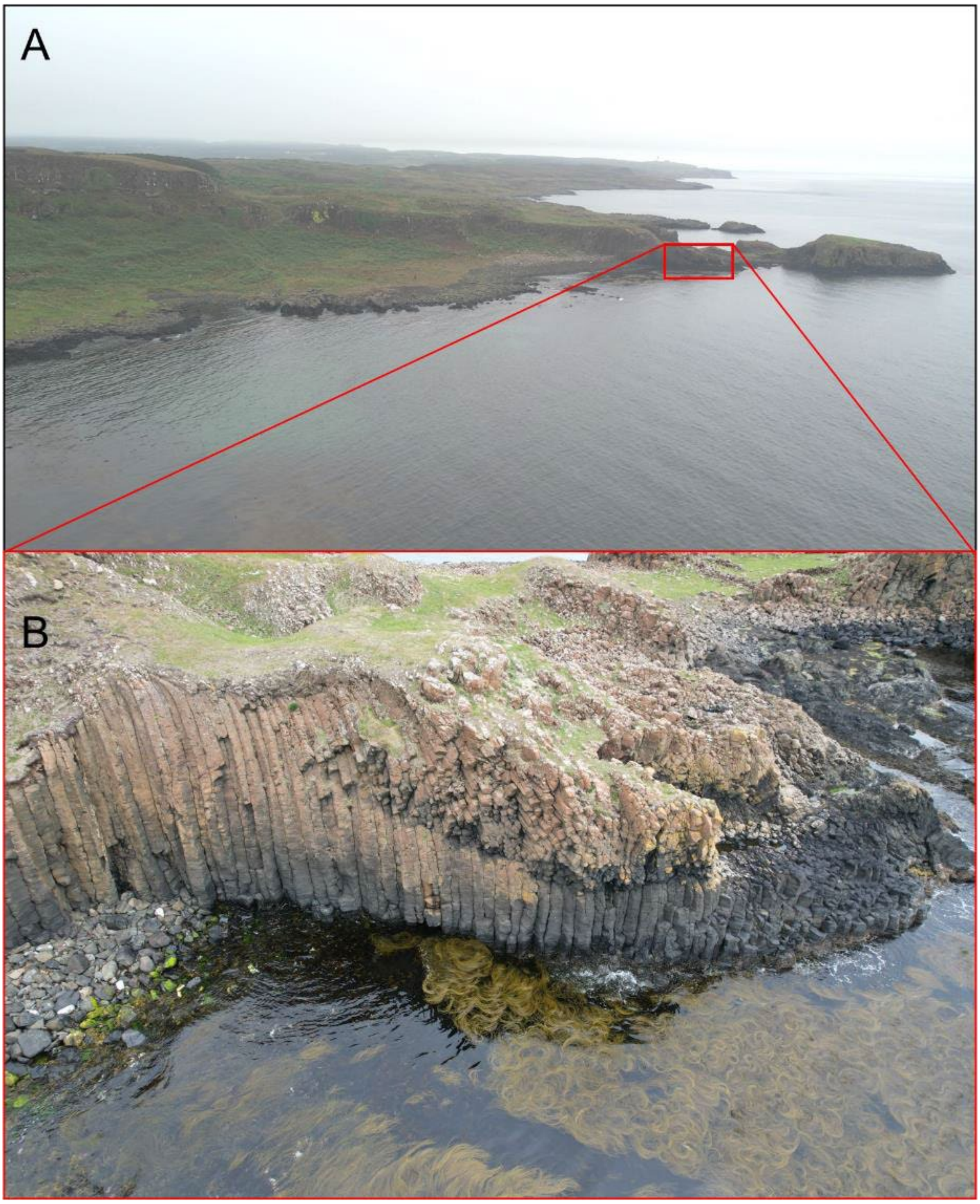

Figure 3: A view of Doon Point (A) and a close-up of the basalt columns (B)

2.1.2 East Lighthouse

Completed in 1856, the East Lighthouse is located on the northeast corner of Rathlin Island (blue box in Figure 1A). The main light of the lighthouse stands at 26.8 m above the ground but is well over 70 m above high-water when including the cliff below (More information can be found here: https://www.irishlights.ie/tourism/our-lighthouses/rathlin-east.aspx). The lighthouse compound features several buildings and a perimeter wall, enclosing an area of approximately 8,000 m^2 (Figure 4). Plans are in place to renovate the lighthouse compound over the coming years. As such, providing digital models of the compound in its current form can provide a means of digital preservation and prove useful in documenting its changes over time.

Figure 4: East Lighthouse with perimeter wall and additional buildings

3 Survey Approach

There are numerous ways in which to conduct surveys that can produce 3D outputs. These include, but are not limited to:

- Terrestrial Laser Scanning
- Airborne LiDAR
- Total station surveys
- GNSS Surveys

All survey methods come with positives and negatives. For example, terrestrial laser scanning can be used to create point cloud data sets with high levels of accuracy across areas of up to a square kilometre. However, the scanner itself, while also being expensive (typically >€20,000), needs to be carried to the locations of use, making this approach dangerous or even impossible in particular landscapes.

Airborne LiDAR can cover large areas, and even get to remote or dangerous locations. Once more, however, it is highly expensive, doesn't have as fine a ground sampling distance (GSD – the distance between adjacent pixels) as other methods and may struggle along cliffs and complex geological structures.

Total stations and GNSS surveys allow the user to capture only data that is necessary, reducing the computational workload. However, the fieldwork, should detailed data be required over a large area, can be incredibly time consuming and suffers from similar limitations in terms of site access.

On the other hand, SfM can be highly versatile. Fine scale objects and areas with easy access can be surveyed using consumer grade handheld cameras, while large areas, including cliffs, building and complex structures in remote or difficult to access locations, can be surveyed using drones. Even historical aerial imagery can be used. These can all produce 3D models with a desired spatial resolution, including visual data, and for a cost much less than most other methods.

3.1 Principles of Structure from Motion

Examples of the SfM workflow in this report come from the Agisoft Metashape software, which was used for the SfM processing. Several other SfM software packages also exist, such as ESRI's Drone2Map (https://www.esri.com/en-us/arcgis/products/arcgis-drone2map/overview), Pix4D (https://www.pix4d.com/) or free, open source software such as Open Drone Map (https://www.opendronemap.org/). However, the underlying principles of the method, regardless of the software used, are largely the same.

3.1.1 Image Capture and Sparse Point Cloud

This section provides a brief overview of the SfM workflow images captured via drone of a house and processed in Agisoft Metashape. The first step involves taking a sequence of overlapping images of the object of interest (Figure 5) and uploading them to the software. The object should be captured from multiple angles, making all surfaces visible while also ensuring a good overlap (~70%) between images. Avoiding strong shadows can be important in this scenario, so diffuse lighting (such as on a cloudy day) typically works best. In general, the more detail you can see within the photos (whether by taking multiple close-up images or using a high-quality camera), the more precise the rendering of later 3D models will be. However, with more or larger images comes an increase in processing time.

Figure 5: A sequence of photos orbiting a house to catch the exterior from multiple angles

The next step involves the creation of the sparse point cloud. This involves identifying features within an image, called key points, that are clear and consistent regardless of viewing angle and lighting (i.e., are invariant). The key points that can be identified across multiple images are called tie points, and make up the sparse point cloud (Figure 6). As well as producing tie points, this process also calculates the orientation and position of the sensors and images.

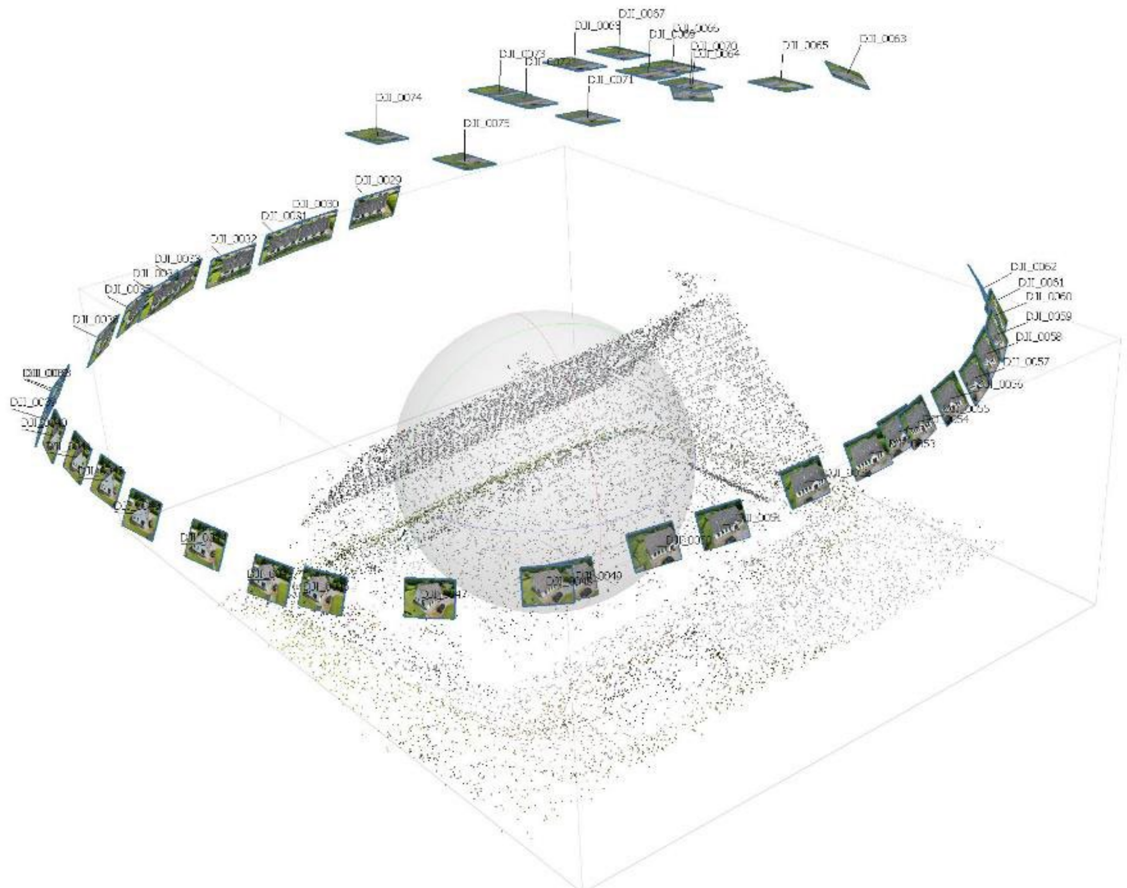

Figure 6: Sparse point cloud of the house with camera positions and orientations

3.1.2 Dense Point Cloud and Model

The next stage is the creation of a dense point cloud (Figure 7), which involves the identification and display of potentially millions of key points using the images that now have their orientation and positions calculated. This is accomplished through a complex triangulation process called Multi-view Stereo (MVS).

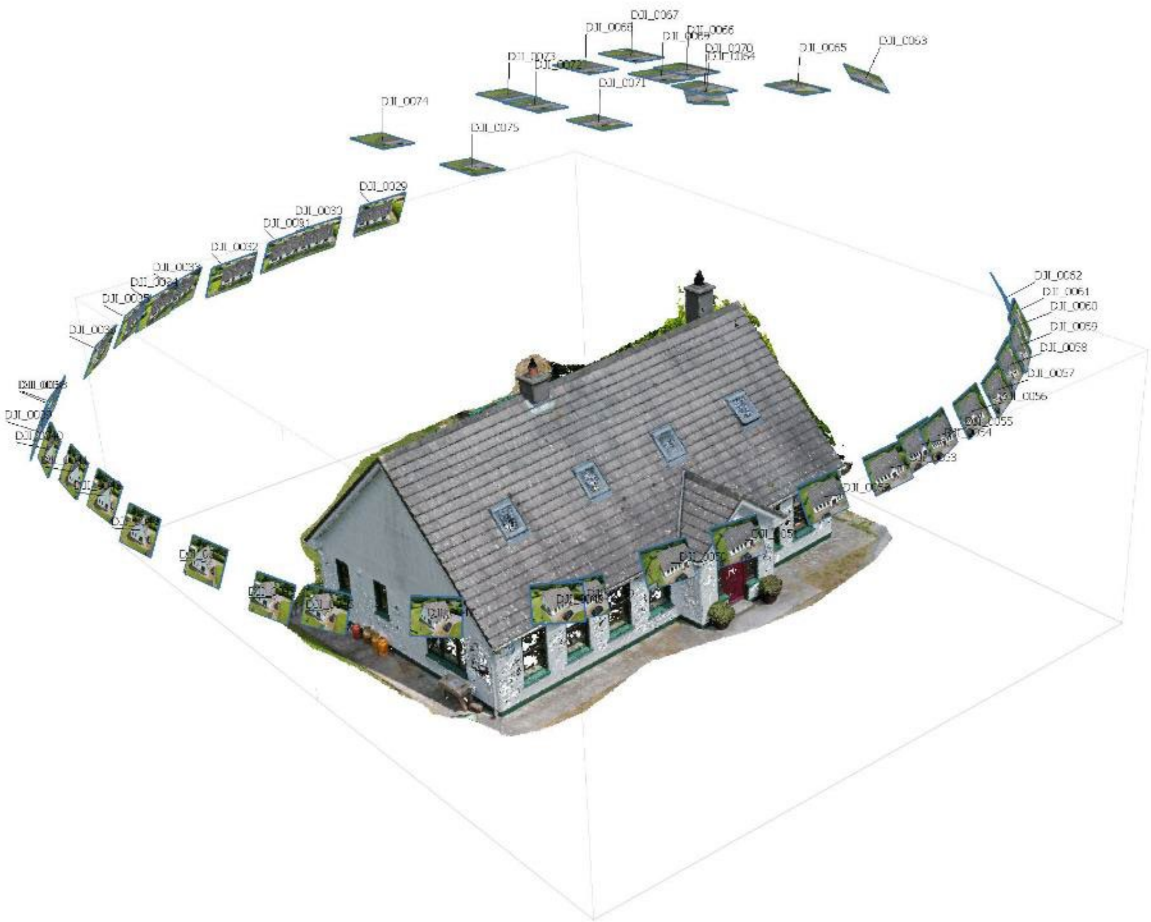

Figure 7: Dense point cloud of the house

From the dense point cloud, many different steps can be taken. The point cloud can be exported, a Digital Elevation Model (DEM) can be created or, as is the case here, a mesh is created. The mesh is formed by representing the surface of the object using polygons. Where the surface is mostly featureless, the polygons will be large, whereas along surfaces with complex geometry, the polygons will be small and dense. The texture (colour derived from the photos) can then be added to the polygon mesh, creating a photo realistic model (Figure 8). Analysis can be performed on these models, or they can be exported in a variety of different formats for use in anything from 3D printing to creating computer generated images (CGI) environments for video games or movies.

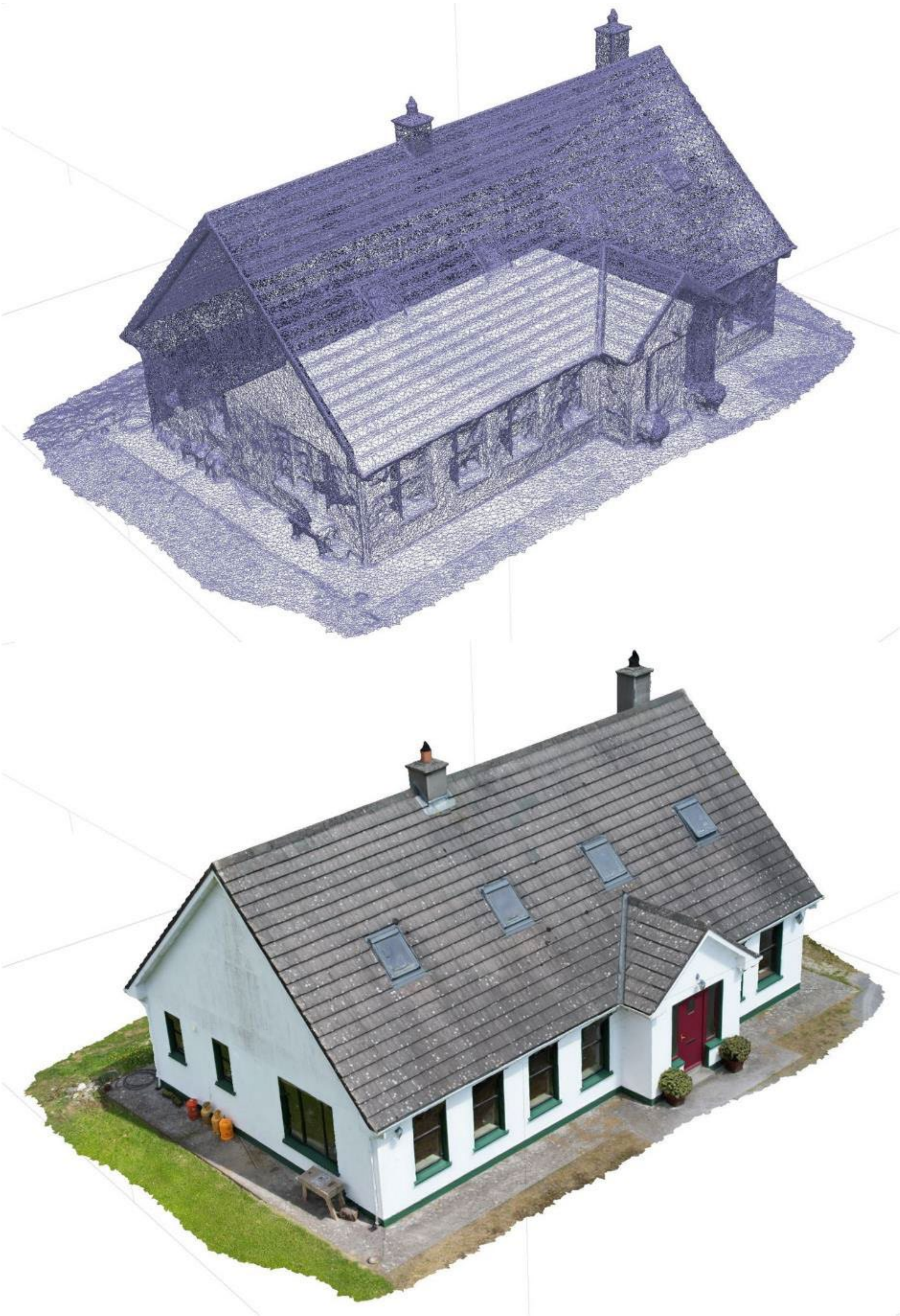

Figure 8: Mesh model (top) and textured model (bottom) of the house

4 Rathlin Island Surveys

This section will describe the production of the 3D models for the two sites, first Doon Point and then the East Lighthouse. Both will start at data capture (via drone), SfM processing (as described in section 3.1) and editing of the models.

All surveys were carried out using the DJI Air 2s. This drone can take 20MP still images and record video footage up to 5.4K resolution. It also came with numerous automated features, such as 360 panoramic photo generation, which was also used in the survey and described in more detail later. All SfM processing occurred in Agisoft Metashape.

This section is focused on the processing and production of the 3D models, but details on planning and conducting drone surveys, on the use of software to plan and partially automate data collection, the use of ground control points, and more, can be found in our previous reports (Giannoumis and Holloway, 2020; Gianoumis, 2021; Hayes *et al.,* 2021).

4.1 Doon Point

4.1.1 Field Survey

Before conducting the surveys at Doon Point, the landowner was identified and permission gained to conduct drone surveys on his land, where Doon Point is located. Two separate surveys were conducted for Doon Point. The first was in June 2021 and consisted of 170 images at a variety of angles, providing a fine level of detail of the columnar basalt features. After this model was created, it was decided to return to the site, in September 2021, and conduct a high-elevation survey covering the surrounding area to provide local topographic context to the Doon Point site itself. This survey resulted in 35 additional images, a small number, but suitable for providing a broad overview of the surrounding terrain.

4.1.2 Processing

Images from both surveys were aligned using a high accuracy setting, and all other settings remained on default. All images were aligned successfully, and the camera details optimised. After removing erroneous points, the first survey had 105,885 points and the second had 29,678 points (Figure 9).

The next step involved the creation of a dense point cloud. For the first survey, quality was set to high and depth filtering was mild. This allowed for the complex geometry of the basalt columns to be accurately represented and with fine detail, resulting in a dense cloud with over 40 million points. For the second survey, as the detail required was lower than the first survey and it was intended to capture the general features of the local landscape, the quality was set to low and the depth filtering to moderate. This resulted in a cloud consisting of almost 1.4 million points.

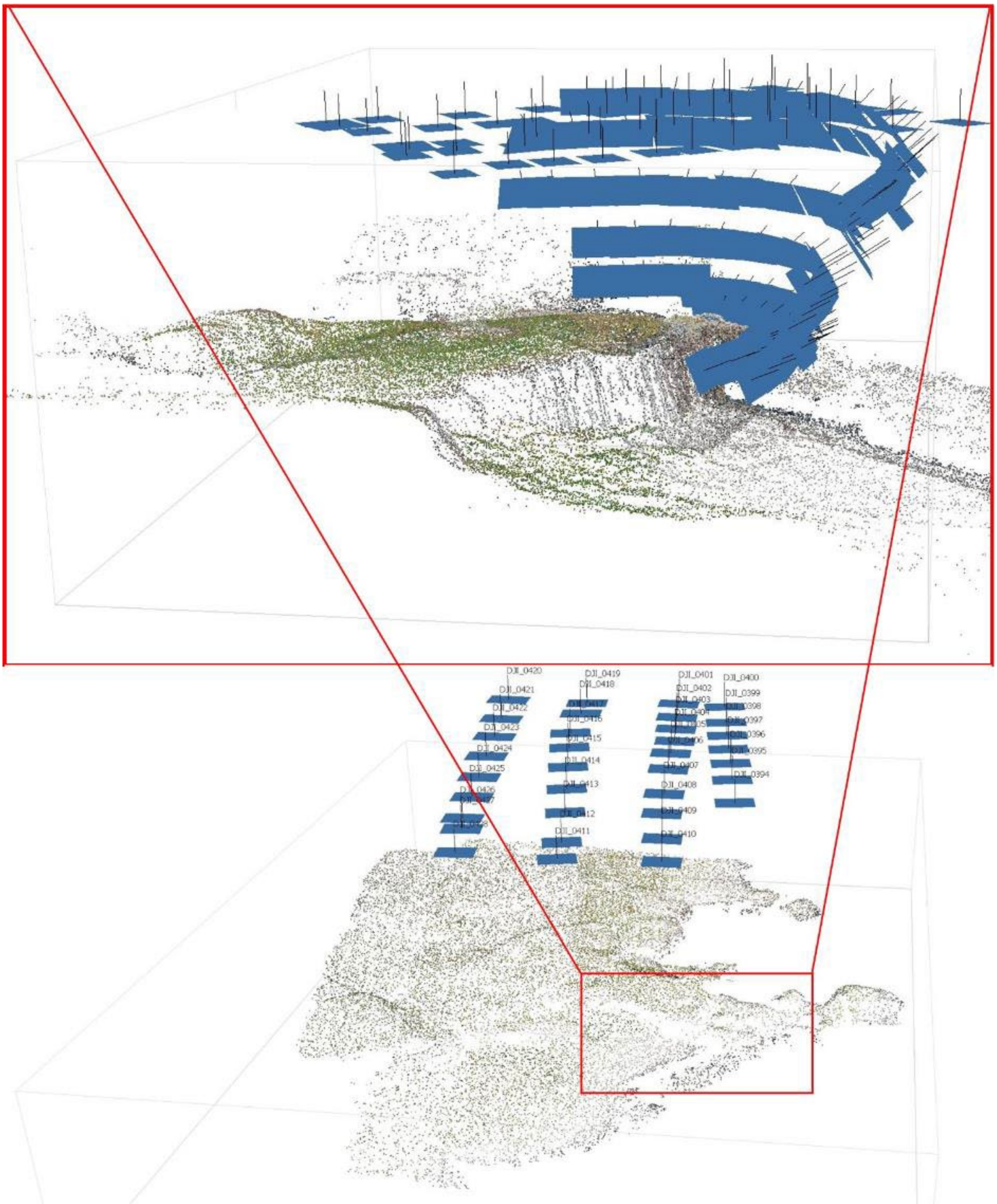

Figure 9: Point clouds and camera positions/orientations from the first survey (top) and the second survey (bottom)

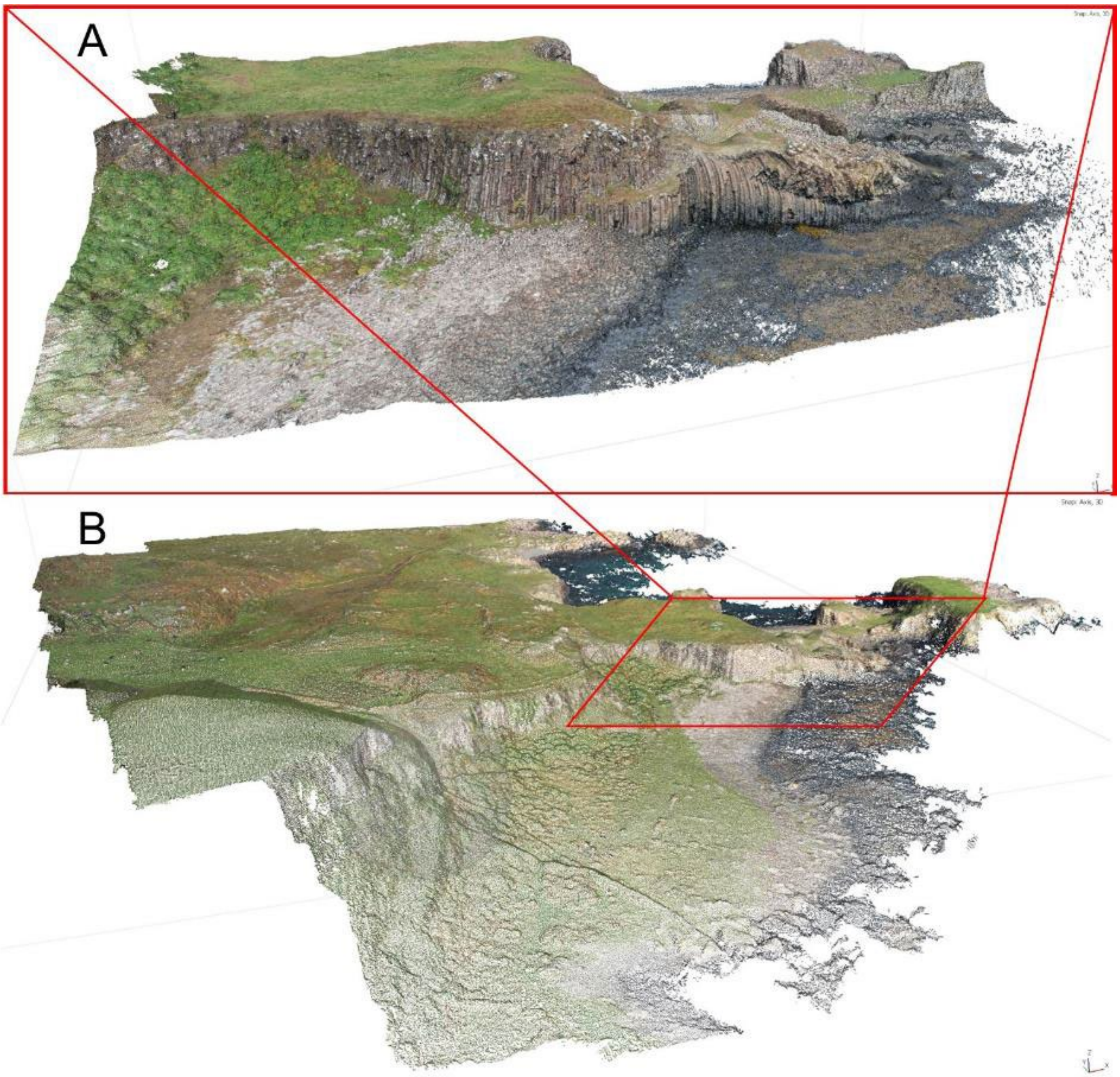

Figure 10: Dense point cloud from survey 1 (A) and survey 2 (B)

The next step was creating the meshes. For survey 1, a high face count (a large number of polygons) and an arbitrary surface was selected to enable the detail to be best represented (A). For survey 2, a moderate face count and 2.5D surface was chosen, as this required less detail and represented a broader overview of the landscape, reducing the processing time (B). Default settings were used when creating the texture for both models.

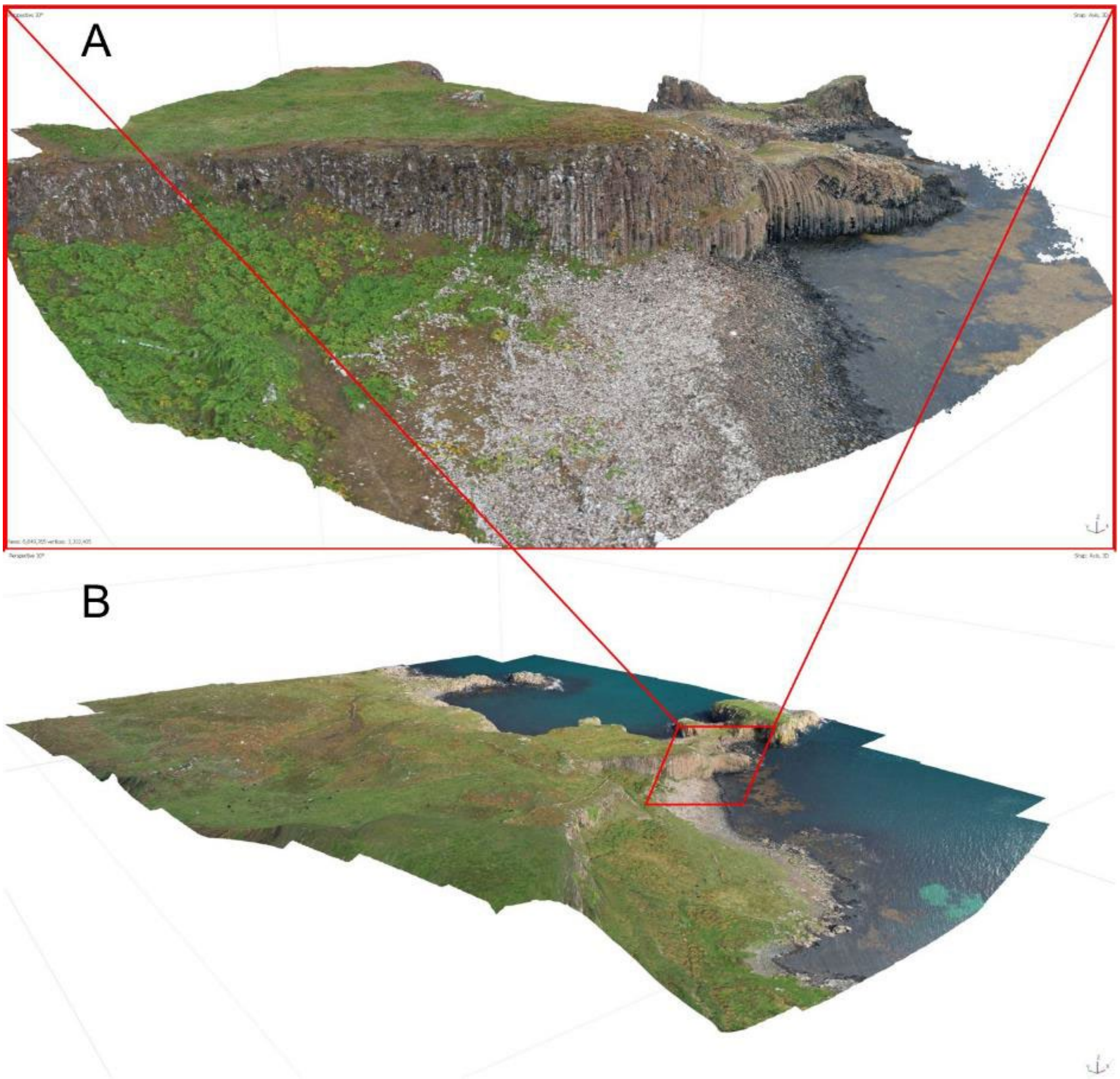

Figure 11: Textured models from survey 1 (A) and survey 2 (B)

4.1.3 Merging the Models

Although having two separate models is useful in itself, it is also possible to merge the models, providing the best of both worlds. This allows the user to see the broader landscape in relatively low resolution and allows the user to zoom into the basalt columns and view them in high resolution, all whilst minimising the file size. In order to accomplish this, the two datasets must be aligned. This involved distributing 15 markers across the overlapping areas that could be used to make the models spatially consistent with each other. This is done by opening the original photos in each data set and finding common and clearly identifiable points across each set of images (Figure 12). By right clicking on a feature within the image, a flag can be placed and named. The same feature then needs to be identified in the other data set, and a flag of the same name placed there. The point clouds can then be aligned through the workflow menu (align chunks), making sure to select "markers" as the method.

Figure 12: 15 markers distributed across the overlapping area of each dataset (top) and close up examples from photos in each data set for two of the markers (bottom).

The next step is to merge the datasets. The free form selection tool was used to reduce the size of the first model, and to cut out a hole in the second model where the first would occupy. This prevented sections from each model overlapping and causing distortions. Finally, from the workflow dropdown menu, merge chunks was selected, and both point cloud and models chosen for merger. The resulting model can be seen in Figure 13. Discontinuities where the models merge are highlighted in the blue ellipses. This is difficult to avoid, given the large difference in spatial resolution between the two models. Another minor issue is in the colouration difference between the models. As the surveys were conducted several months apart, variations in the vegetation cover and lighting conditions creates additional discontinuities. These issues would be minimised by conducting both surveys at once or closer to the same time of year and with similar lighting.

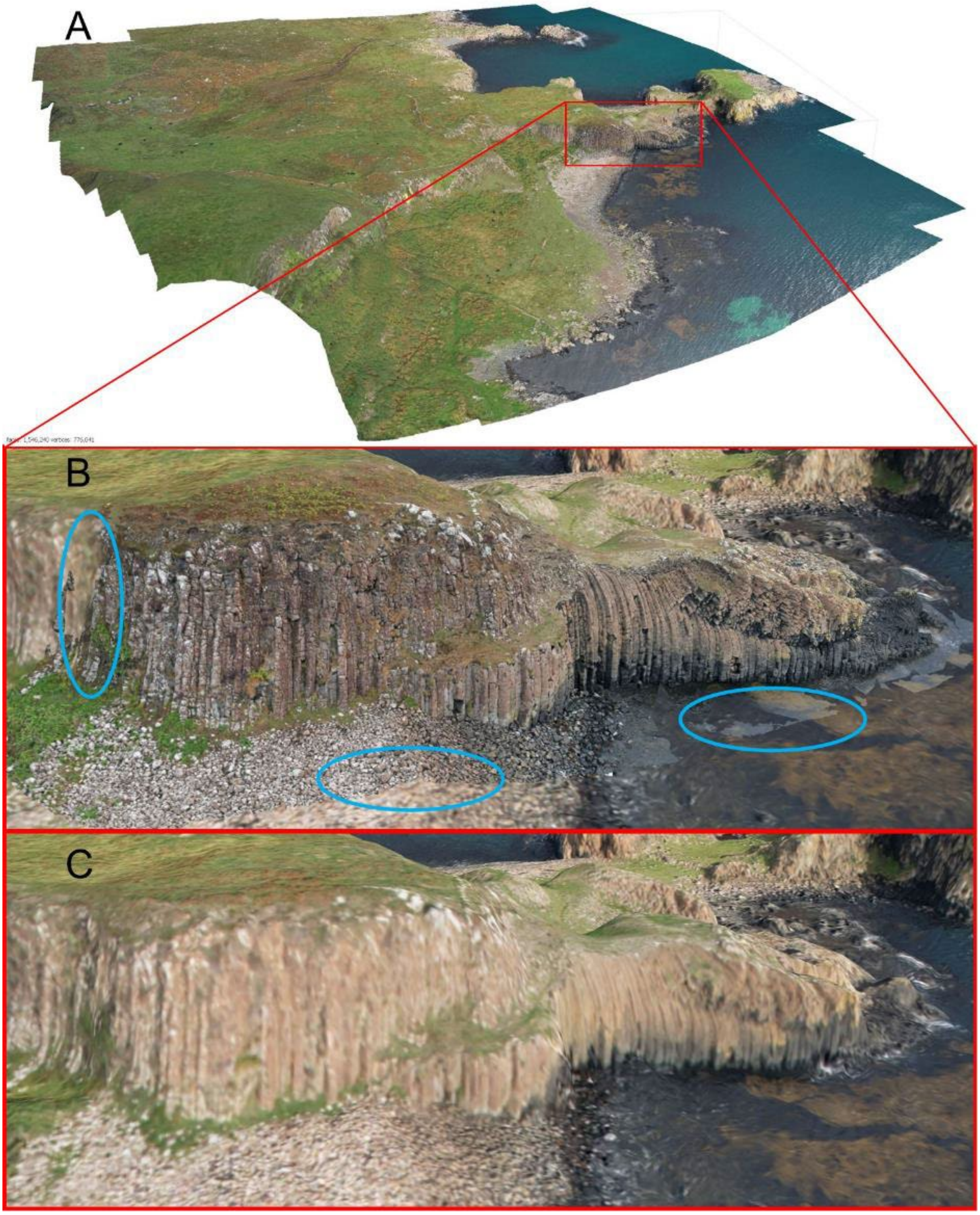

Figure 13: The overall merged model (A), and zoom in of the detailed section from survey 1 with blue ellipses highlighting were the two model resolutions meet (B) and the same area as B but from the low resolution model from survey 2 (C).

4.2 East Lighthouse

Before beginning survey work on the East Lighthouse, permission was sought from the Commissioner of Irish Lights (https://www.irishlights.ie/). We were informed that once the drone took off and landed from outside of the lighthouse grounds, we had permission to survey the lighthouse and surrounding buildings.

4.2.1 Field Survey

On September 27th around noon, the survey of the East Lighthouse was conducted. It consisted of 119 images looking vertically down over the site, seven images of the cliffs and 37 images circling the lighthouse itself, from different elevations. Conditions were dry and bright, but the wind was relatively strong, resulting in the propellors appearing in some of the video footage as the drone banked to compensate for the wind. However, the still images all appeared sharp and ideal for building the model.

4.2.2 Processing

As with Doon Point, the processing was split into two separate chunks. The first (survey 1) was a moderate resolution survey of the entire site (163 images) and a second (survey 2) high resolution survey of the lighthouse building itself (57 images). All 163 images were uploaded to metashape for the first chunk, with 57 images added separately for the second chunk. Both surveys were aligned using high accuracy settings and all images aligned successfully. After optimising the cameras and editing out erroneous points, there were 111,381 points in the first, and 5,736 points in the second survey (Figure 14).

The next step was to build the dense point cloud. For survey 1, accuracy was set to high and depth filtering to low. This allowed the detail along the cliff and the buildings to be captured accurately. Once erroneous points had been edited, the resulting point cloud had almost 53 million points. For survey 2, the quality was set to ultra-high and depth filtering was also set to mild. After editing, a dense cloud of 15.5 million points remained (Figure 15).

Once the dense clouds were created it became apparent that the processing method struggled around the lighthouse building itself. The problem areas were primarily:

A. The relatively featureless colour and surface variation along the bulk of the building (Figure 16A & B).
B. The detail at the top, such as the red fencing and support structures (Figure 16C & D).
C. The large windows also produced some errors as they are transparent and distort features within and as seen through the glass (Figure 16C & D).

Problem A could be largely solved by careful editing of the points around the building edge to ensure the resulting model produced a smooth surface. Problems B and C could be reduced slightly with point editing, but the problems could not be solved. Some potential solutions include being able to survey from within the compound. This would have allowed the drone to fly closer to the railings at the top and capture them from multiple angles, allowing the detail and shape to be better defined. Similar is true of the finer details and windows, which may have been captured with greater detail using a closer flight path – something not possible to achieve safely from outside the compound walls. All that being said, the points were edited finely to ensure as accurate a model as possible could be created.

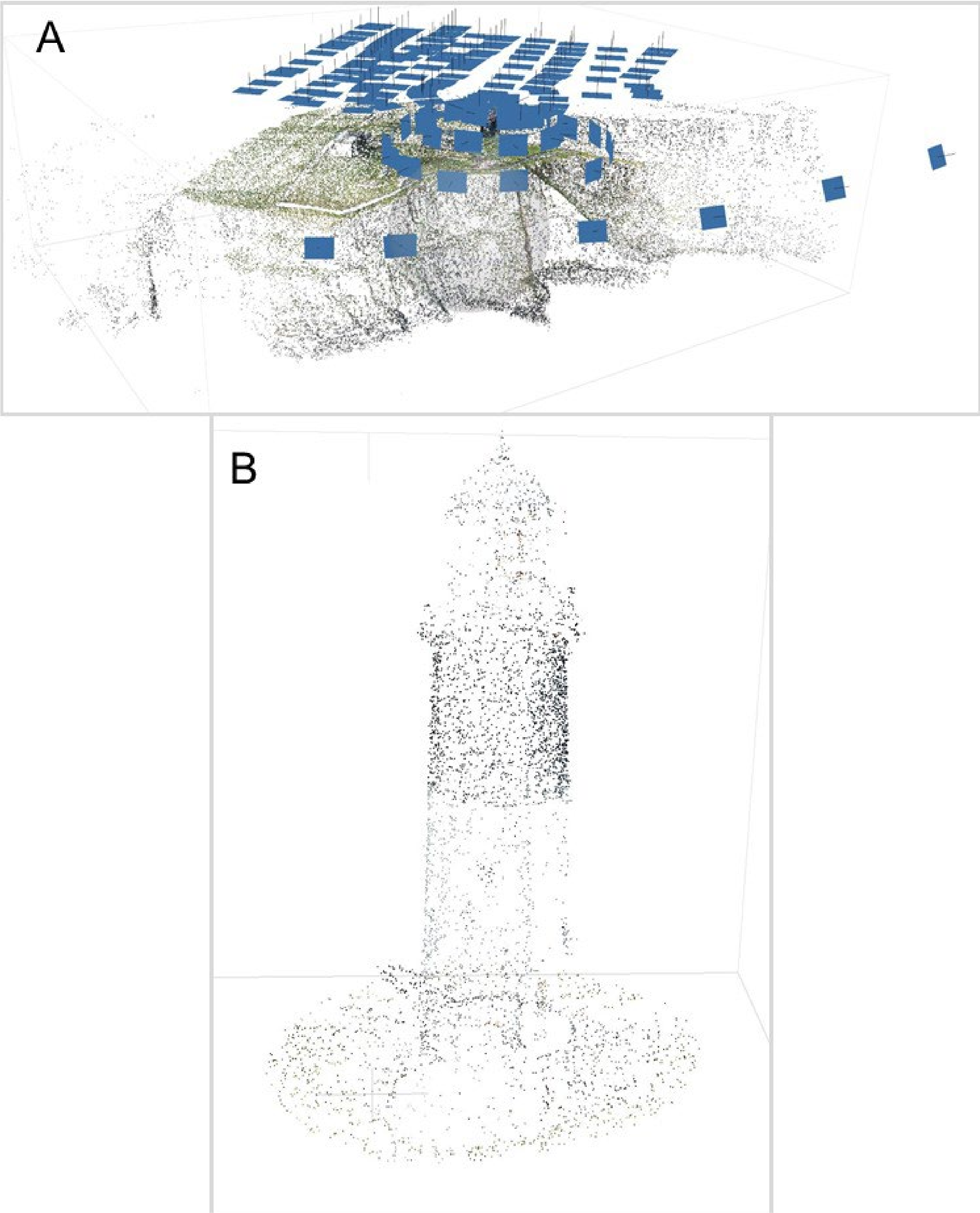

Figure 14: Survey 1 (A) showing the sparse point cloud and camera positions and the sparse point cloud from survey 2 (B)

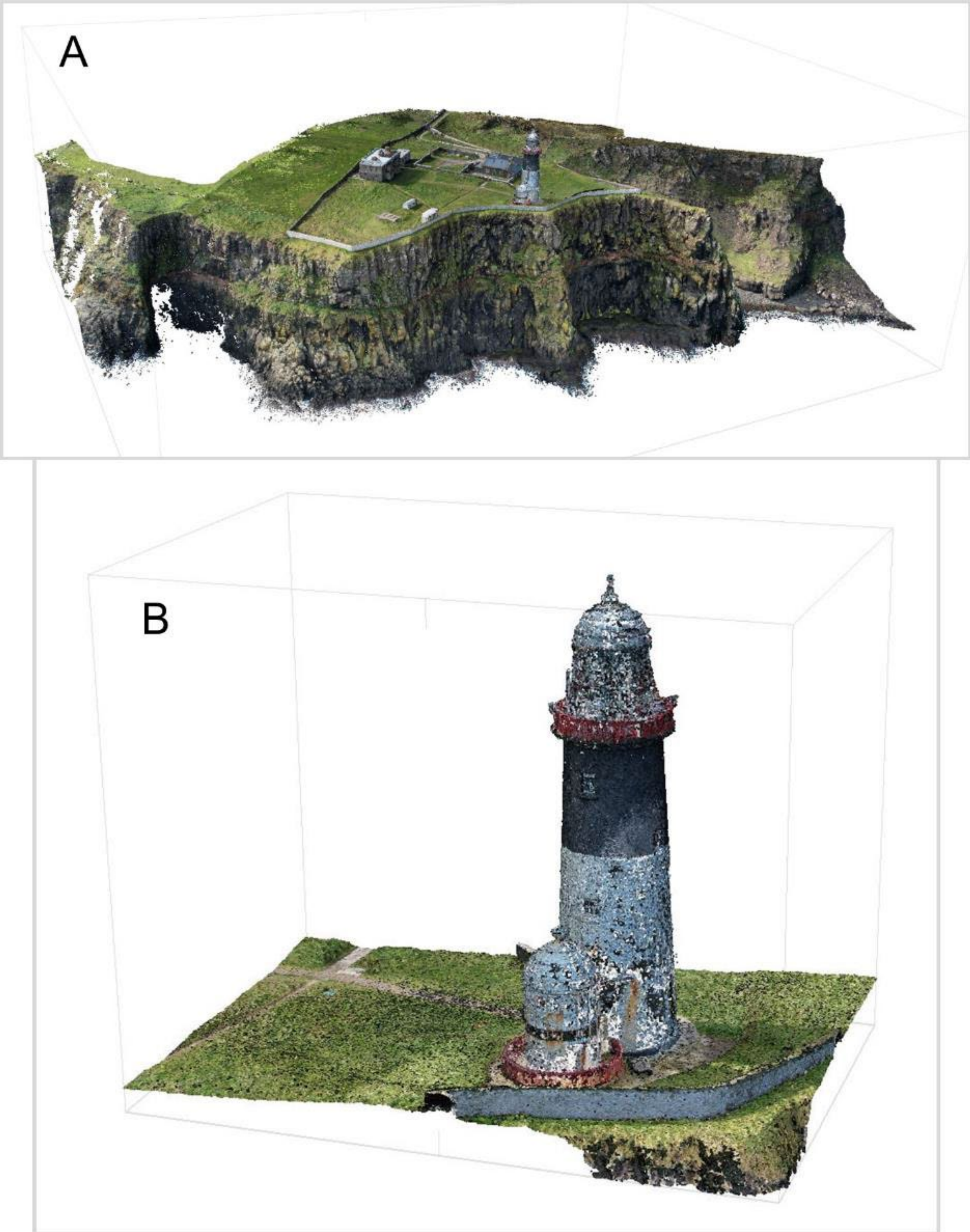

Figure 15: The dense point clouds from survey 1 (A) and survey 2 (B)

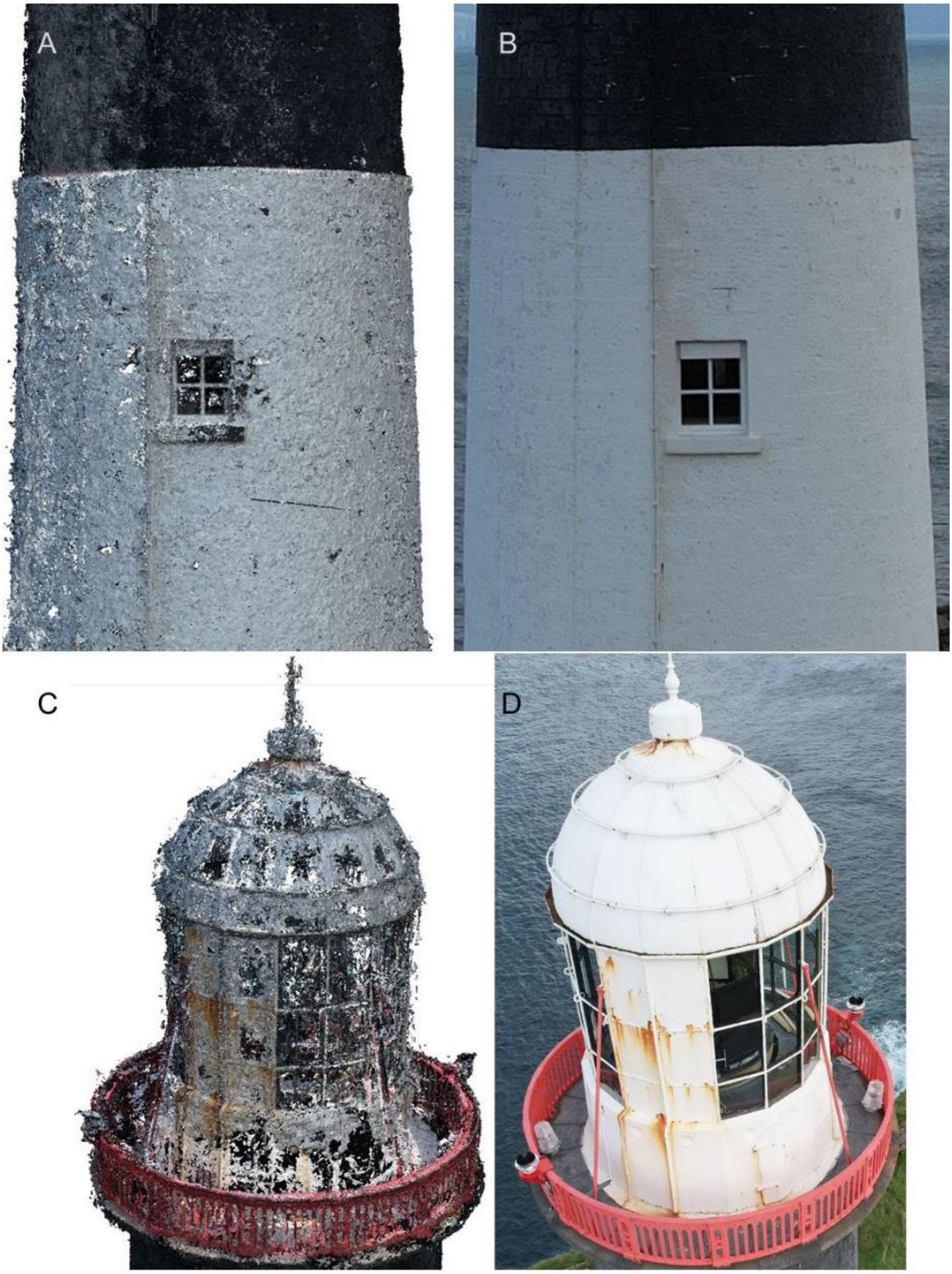

Figure 16: Close up view of the dense cloud showing the edge points and errors from on the mid-section of the lighthouse (A) and a corresponding photo (B) and errors at the top of the lighthouse (C) and corresponding photo (D)

The next step was to build the meshes and add the texture. Both meshes were created using a high face count, as arbitrary surfaces and with interpolation enabled. For survey 1 (Figure 17A), the cliff, land and surrounding buildings were modelled well overall, but with a few errors under gutters and in narrow spaces. Furthermore, the area around the lighthouse was cut out to help with merging the chunks later. The detailed survey around the lighthouse itself worked well for most of the building, but the top with the finer structures contained some errors (Figure 17B).

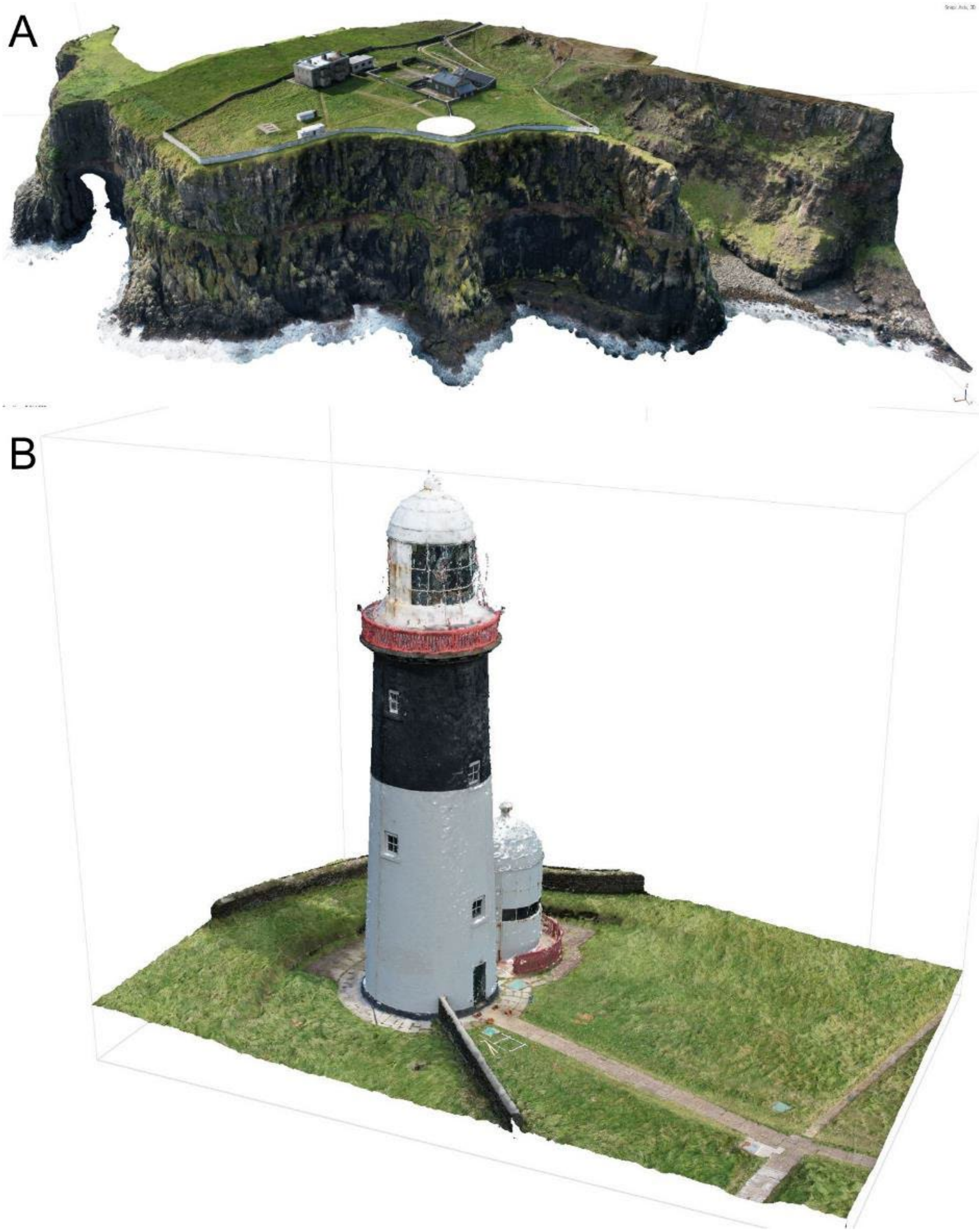

Figure 17: Model from survey 1 with the lighthouse cut out (A) and model from the detailed lighthouse survey 2 (B)

4.2.3 Merging the Models

The two models were then aligned by placing markers on six clearly identifiable features in the overlapping region, three on the lighthouse itself, one on the wall along the cliff face and two on objects on the ground. The alignment process appeared to work well, and the models and point clouds were then merged. The merger appeared successful and, as the two chunks were part of the same survey, the two models blended seamlessly together. Views of the merged buildings can be seen in Figure 18. Aside from some errors around the lighthouse, the buildings geometries and colouration appear to be accurately represented, and even small objects laying on the grounds during the survey captured well. A broader view of the modelled area can be seen in Figure 19. Here the cliffs appear to be accurately represented, down to details of rocks on the slope to the west of the lighthouse (Figure 19C).

Figure 18: Views of the buildings of the East Lighthouse site after the two chunks were merged

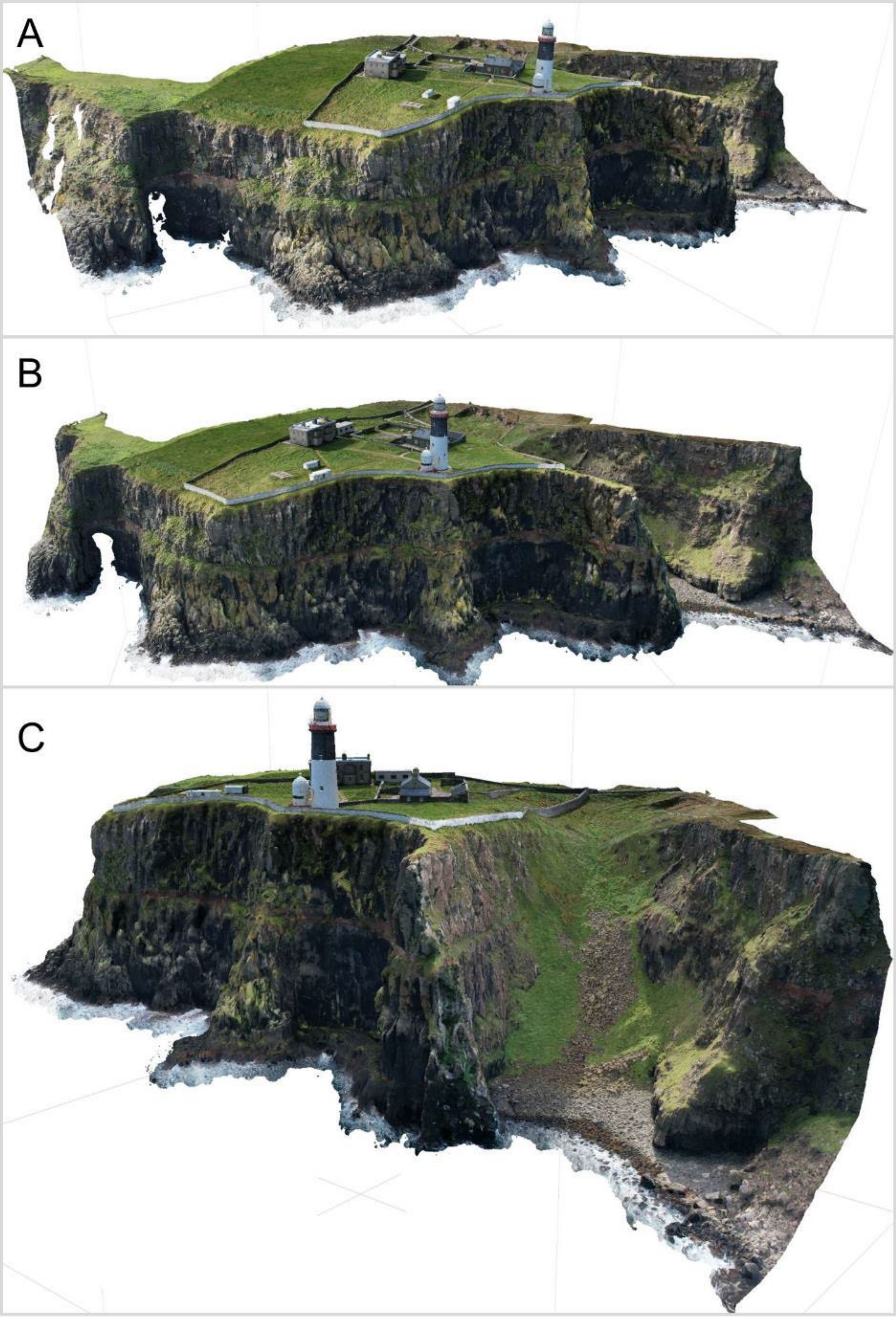

Figure 19: Broad scale views of the merged model from different perspectives

4.3 Alternative Drone Methods

There are several simpler approaches to recording sites with drones. The most basic involve photo and video capture. Many drones, that even cost below €500, are capable of recording videos in 4K resolution or higher and capturing photos of high-quality. This can allow a user to record a site from multiple perspectives with high-quality footage for a minimal price and with little expertise. Furthermore, modern drones can come with a suite of automated features, allowing users to create timelapses, automate cinematic video capture or to create 360° panoramic photos. For the latter, two examples are provided below for both Doon Point and the East Lighthouse. While these panoramic images have not been edited to a publishable standard, they provide clear examples of an easy and versatile form of media.

Doon Point 360°: https://www.skypixel.com/photo360s/doon-point-rathlin-island?utm_source=copied&utm_medium=PCWeb&utm_campaign=share&sp=0

East Lighthouse 360°: https://www.skypixel.com/photo360s/rathlin-island-east-lighthouse?utm_source=copied&utm_medium=PCWeb&utm_campaign=share&sp=0

These 360° panoramic photos can be used as standalone image, interacted with on a desktop or mobile device, or viewed through a virtual reality headset (Figure 20). Despite taking just a few minutes to create, this form of media has a wide utility range and can prove useful in tourism websites, visitor centres, or as a tool in the digital preservation and documentation suite.

Figure 20: View of the Doon Point 360 panorama from with a Virtual Reality environment

5 Recommendations

From the data collection, processing and resulting SfM models described here, ten recommendations are presented:

1. Experiment with the data collection and processing. This will ensure that you understand the number of photos, angles and other requirements of the survey before starting.
2. Ensure that you have permission from the landowner/s of the site you wish to survey.
3. Take time to plan the survey and understand the requirements before beginning.
4. Understand the end products and their users. Complex models may not always be best.
5. When possible, conduct surveys in calm winds with diffuse lighting (i.e., cloudy days with a high sun angle).
6. Where needed, multiple surveys of a site should be carried out on the same day. Otherwise, carry the surveys out in similar lighting conditions in as narrow a timeframe as possible.
7. Use flight-planning software and incorporate ground control points where necessary and possible to improve data collection efficiency and mode accuracy.
8. Keep the detailed, high-resolution modelling to the main areas of interest. This will reduce data collection and processing time.
9. With complex geometries, try to capture images from multiple angles and as close-up as possible. This will allow for more accurate modelling.
10. Take time to carefully edit the point clouds and models during processing. This will significantly improve the accuracy of the final model.

Details on many of these recommendations can also be found in the previous project reports (Giannoumis and Holloway, 2020; Gianoumis, 2021; Hayes *et al.,* 2021).

6 Conclusions

This report has provided an overview of the SfM process, two practical examples from Rathlin Island and a list of 10 recommendations. Using a consumer grade drone and the SfM method it was possible to create high-quality digital models of both a complex geological and built structures. We also describe how more simple approaches, such as with video, photos or 360° panoramic photos, can contribute towards the protection and preservation of natural and built heritage sites. Furthermore, these techniques can provide valuable visualisation tools, making relatively inaccessible locations more accessible through interactive and non-interactive virtual environments.

Following the workflows and recommendations above can improve the efficiency and accuracy of the data collection and model creation process in many scenarios. However, it may not be possible to apply all recommendations to a given survey for a variety of reasons. For example, at Doon Point the two surveys were carried out at different times of year resulting in different illumination conditions and changes in vegetation. This makes blending the two models together more difficult. Limited survey time and access due to weather conditions and COVID-19 restrictions acted as a significant constraint in conducting the surveys in ideal conditions.

With an ever-growing range of affordable drones with high-quality cameras and user-friendly means of creating digital models, drone technology is increasingly presenting itself as a highly valuable and versatile tool for coastal managers.

7 References

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