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Comparing photogrammetric and iPad-Lidar models of exposed faces in the Rogfast tunnel

by

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Abstract

Cameras have become progressively more advanced in the 21st century. They are a ubiquitous feature in electronic devices, which brings more opportunities for collecting data in the field and creating 3D geologic models. However, since there can be many devices to choose between, it may be difficult to know which one to select. Selecting the most appropriate device will depend on cost, ease of use, efficiency in collection and processing, and required detail of the output model.

During tunnel excavation, the rock in the exposed tunnel face is removed (front face) or covered (roof) after the section is deemed completed and reviewed by an-site geologist and deemed completed. The rocks are no longer observable and generally, there is no visual record. By using an electronic device to create a 3D geologic model during excavation, there could be a visual record of the rock exposures for future use.

This has been explored in this thesis by testing two different methods inside an excavating tunnel (part of the larger Rogfast project) in Kvitsøy, Rogaland, SW Norway. One of the methods is camera photogrammetry, which is today a standard method. Generally, it requires a high economical investment and complicated training of staff and data processing to make a virtual model. Because of these relatively high required skillsets, it would be interesting to compare this method with a new, and easier method for 3D modelling, namely the iPad Pro 2020 with a built-in terrestrial lidar scanner (TLS), which requires nearly zero training.

After a comparing the camera photogrammetry and iPad TLS in terms of ease of use, data processing, output models, efficiency, degree of difficulty, stability, and costs, it is concluded that the iPad TLS is the most efficient tool for documenting and collecting 3D geologic models during active tunnel excavation.

Table of contents

List of figures

List of tables

Chapter 1

Introduction

Major developments in the technology of geoscience have helped make process modelling of the Earth's surface easier (Liao, 2021). Photogrammetry and light detection and ranging (lidar) are great assets in collecting structural data in the field. Using handheld devices and programs to run the data collected, 3D models can be constructed to visualize objects, whether man-made or natural, in a user-friendly and efficient way.

Photogrammetry involves taking multiple overlapping photographs and using software that can convert them into accurate three-dimensional models. The software estimates all the positions of the photographs captured and creates a point cloud where all the 3D points merge to resemble the object or structure (Figure 1) (Hodgetts, 2013).

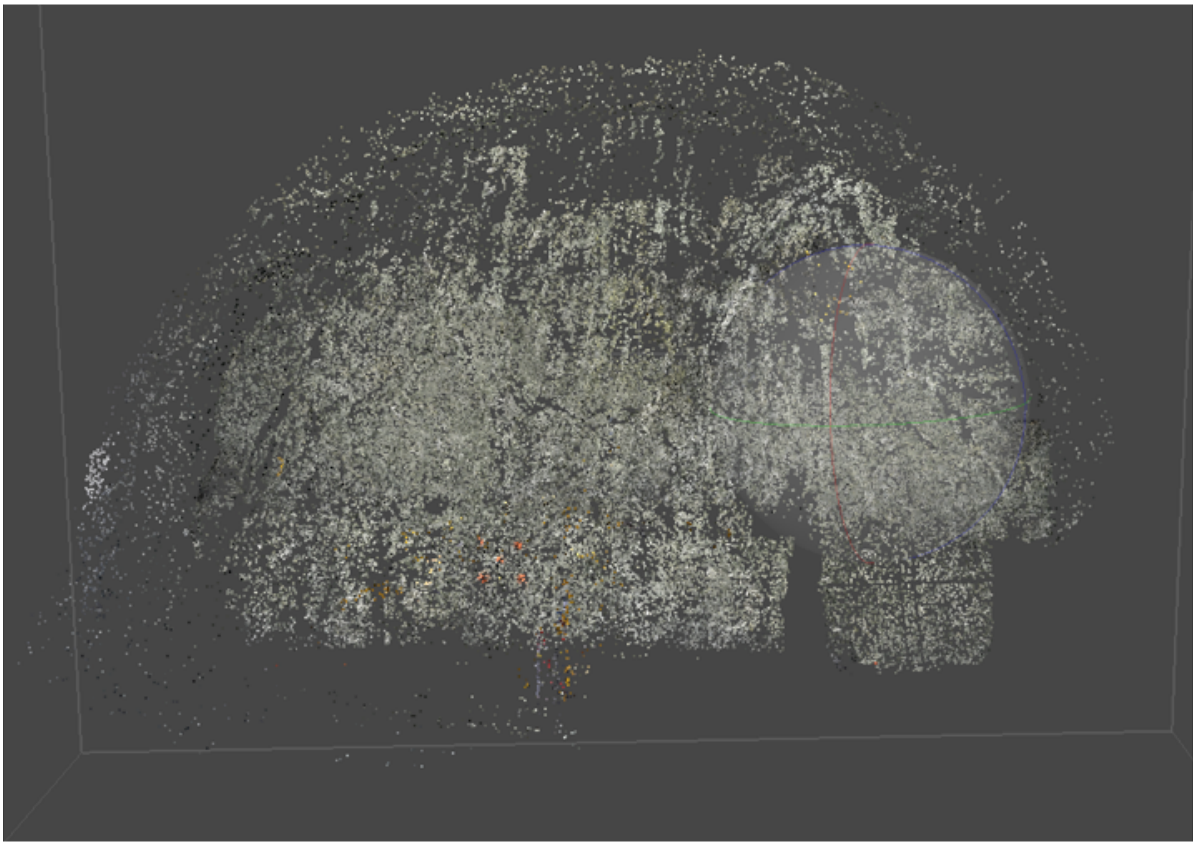


Figure 1: Screenshot from the Agisoft Metashape 3D program, illustrating a point cloud created from photogrammetry.

Lidar is a system that sends pulses of light from a laser to measure distances. There are different ways to measure the ground using lidar. There is airborne lidar, which takes measures from planes, and terrestrial lidar, which is based on ground measurements (Lui, 2008). Recently, new Apple products have short-range terrestrial lidar scanners. These scanners use a combination of lidar and photogrammetry when making 3D models. The lidar provides information about the scale, while photographs show the texture (Liao, 2021).

Both methods, photogrammetry and lidar, have shown to be great tools in different geoscientific situations. Luetzenburg (2021) presented lidar scanning for coastal cliff and beach surveying and showed significant differences between vegetated and un-vegetated areas. Walstra (2007) used digital photogrammetry for landslide monitoring and showed how a photographic archive can contribute to a better understanding of landslide evolution.

Tunnel construction is an ideal setting for testing the use of photogrammetry and lidar as it is a multidisciplinary enterprise, requiring the expertise of geologists, engineers, and urban planners, among others. Due to the nature of tunnel construction, once the tunnel walls are sealed and the face is removed, the opportunity to view and study the rock exposures cease. Having a visual record of the tunnel walls in a 3D model would benefit those involved in tunnel excavation, either as an ongoing project reference, for latter inspection, or for other uses such as research and education. It is unknown which visualization recording method – photogrammetry or lidar – would be most useful for tunnel wall exposure documentation. Therefore, this thesis compares two methods to document and store the rock exposures for future reference. Specifically, this thesis will:

- Compare photogrammetry and iPad-lidar models and methods, and
- Compare information from 3D outcrop models to traditional construction methods.

Chapter 2

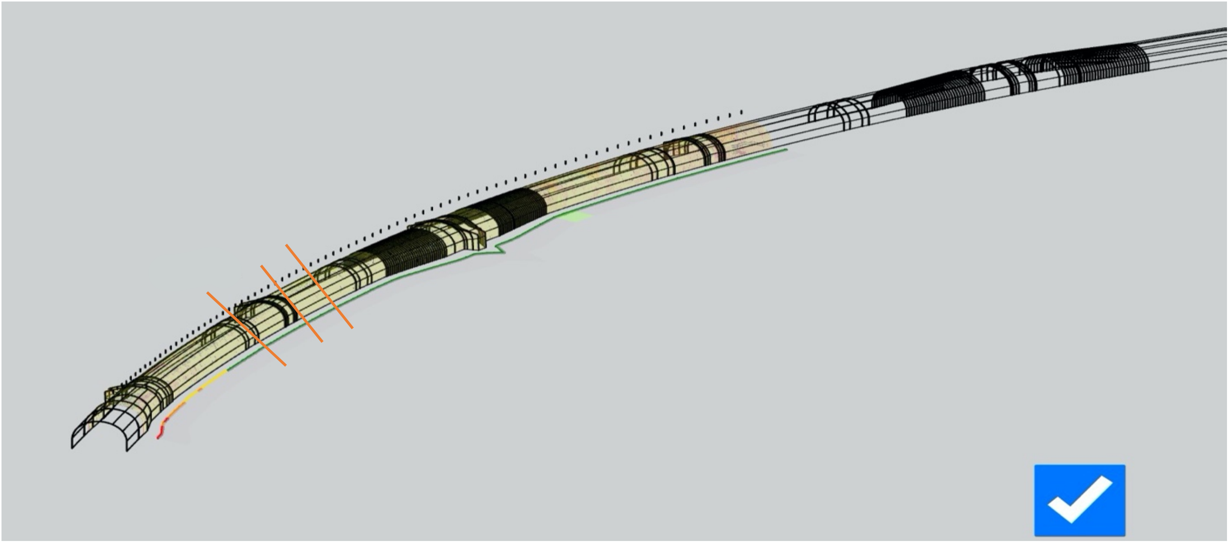
Norway tunnel construction industry standard

Construction of tunnels is a dynamic process where exposed rocks are lost. Each blast consists of blowing up five meters of the rock wall, followed by securing of the roof and the tunnel sides with shotcrete and rock bolts. This process is performed every day, and in one week, 10 to 25 meters are excavated on average. Despite this, there is significantly little time to record every aspect of the exposed rock wall (Colombo, 2016)

The main constraints creating difficulties, while investigating and collecting the geological data in drill and blast tunneling, is the limited time available and the physical contact required (Gaich, 2015). Every day, as the tunnel is blown up, the geologists receive updated data that contributes to mapping the tunnel. How are these data is collected and preserved? There are three sequential steps. First, measuring while drilling (MWD) data updates directly from the drilling rigg by the sensors and drilling arms. As the rock wall is drilled, the data uploads automatically. Second, geological mapping is performed manually with a tablet by a geologist. After the excavation of rock debris, the geologists enter the tunnel and map the rock walls manually and input the observation into a software that uploads them to a cloud and later into the computer network. The last step is conducted while securing the tunnel. The contractors will scan the exposed rocks prior to and after securing the tunnel. The collected data will then be available to the clients (personal communication, A. Al-Samarray, 2022).

The geological mapping software called Bever Control is where all the acquired data is uploaded. Software facilitates mapping in both 2D and 3D. Figure 2A shows a 3D model of the tunnel that can be used to locate joints and weaknesses zones. These can be transferred to 2D mapping where the strike and dip of these structures, as well as their density can be determined automatically (Figure 2B).

(A)



(B)

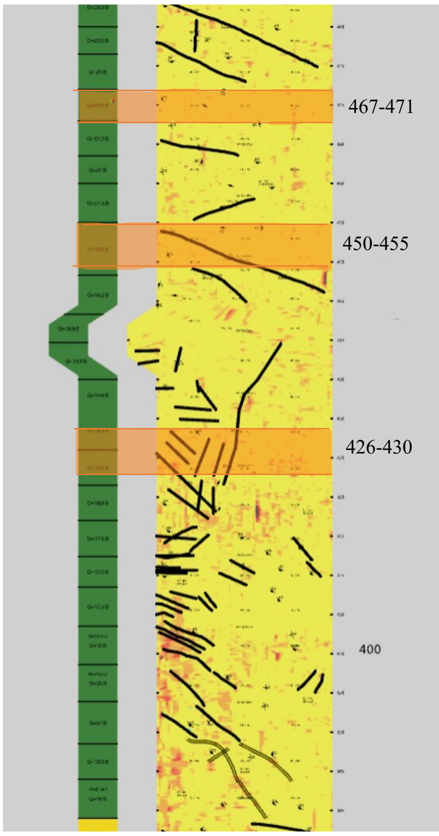


Figure 2: Screenshots of tunnel excavation progress from Bever Control. (A) 3D model of the tunnel. (B) 2D model of the tunnel (Provided by A. Al-Samarray, 2022).

Figure 2A shows a 3D model of the tunnel excavation progress. The orange markings represent the three localities visited in this thesis. Figure 2B shows a 2D model of the same length of the excavation as figure 2A. The values to its left are the Q-values, and the black lines represent the foliation. As in figure 2A, figure 2B is marked with orange markings that represent the visited localities, and the values on its right are the profile numbers. The profile number represent the distance from the exposed wall's start to the tunnel working face. The tunnel begins at profile number 300.

After all the data have been gathered from the three sources described previously, the information can be compiled into a report. Figure 3 depicts distance maps, geology, and rock security registration, all in one report. Similar to figure 2, the orange bands represent the localities visited in this thesis: The first visit to the tunnel was at profile number 425-430, the second visit at profile number 450-455, and the last visit at profile number 467-472.

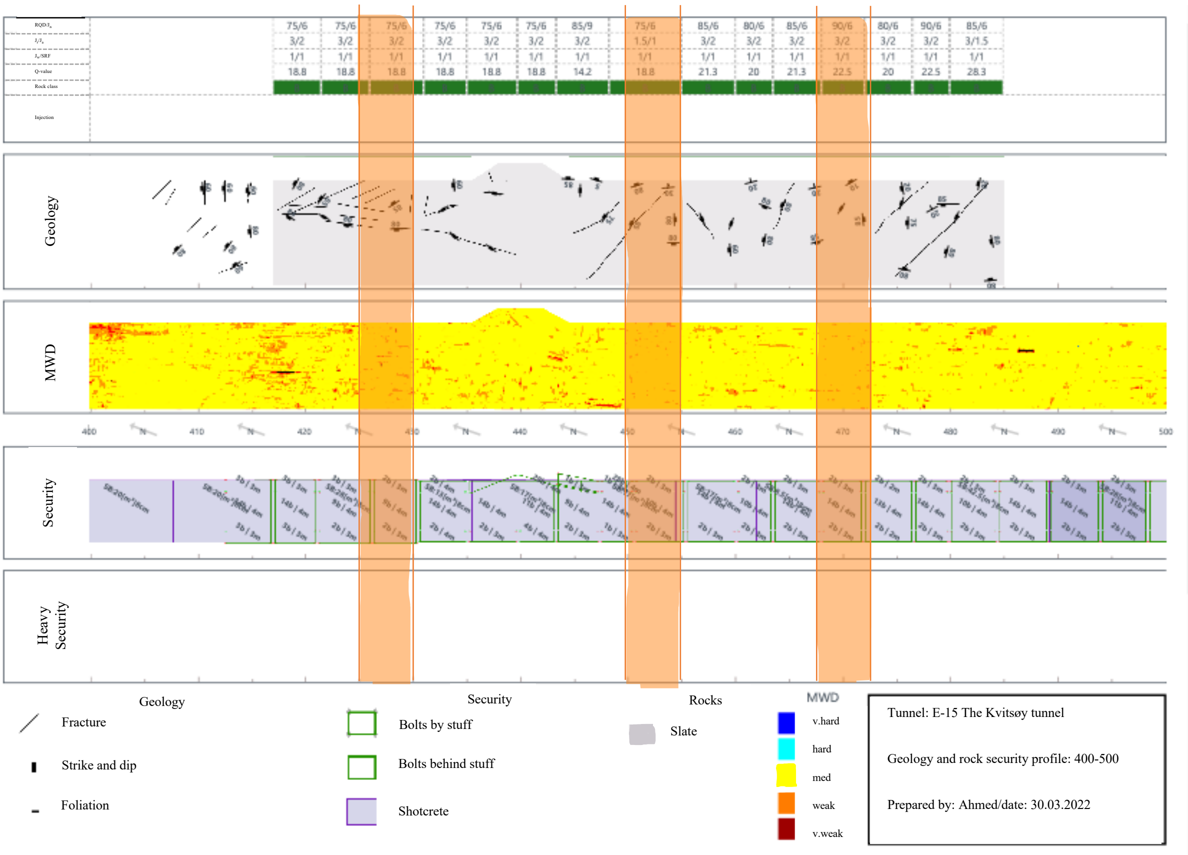


Figure 3: Geological final report of the tunnel transects visited in this thesis (Provided by A. Al-Samarray, 2022). The orange strips are the localities visited and scanned in this thesis.

The stability of the rock mass in a tunnel or rock chamber, may be determined by the Q-system proposed by Carton et al. (1974). High Q values indicate good stability, while low values mean poor stability. The Q-value is calculated from six parameters using this equation:

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

The six parameters are:

RQD = Rock Quality Designation
J_n = Joint set number
J_r = Joint roughness factor
J_a = Joint alteration and clay fillings
J_w = Joint water inflow or pressure
SRF = Stress Reduction Factor

In practical terms, to find out the information about the structure of the rock mass, one can use the quotient RQD / J_n. This is a crude measure of the block size. Information about roughness and the frictional characteristics of the filling materials is given by the quotient J_r / J_a. Lastly, the quotient J_w / SRF represents the ratio of these two stress parameters.

Chapter 3

Methodology

The methodology applied in this thesis is outlined in figure 4. The main steps consist of pre-field work to data collection, processing, and analysis.

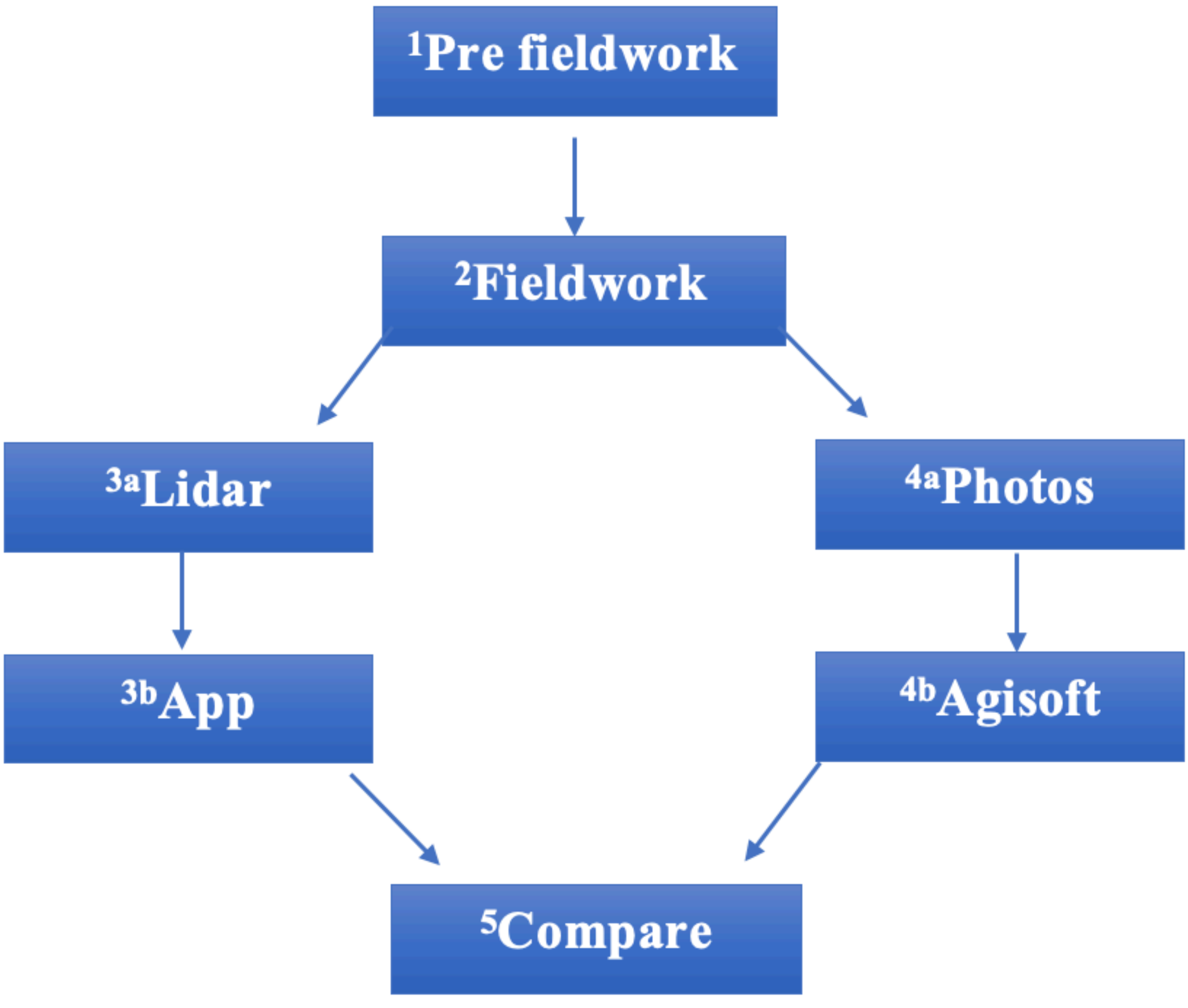


Figure 4: Workflow followed in this thesis. Left branch is the iPad-Lidar, and right branch is the photogrammetry.

3.1 Pre fieldwork

Before starting the fieldwork to collect the required data, it is important to have a fieldwork plan to be prepared and efficient. Firstly, it is important to be familiar with the equipment, and make sure that everything functions correctly. For example, when using an SLR camera, it is wise to check all the different settings for the type of work that will be performed. Secondly, when visiting a tunnel that is actively under construction, health and safety information must be acquired prior to entering the tunnel. Proper safety attire and supervision were required during the tunnel visit. To collect the most detailed pictures, the camera and tablet needed to be close to the exposed wall, and this was achieved by taking the pictures or scanning the face from the basket of a crane, which moved systematically around the face (Figure 5).

Figure 5: Photo showing safety attire and supervision and the required proximity to the rock wall face for using the terrestrial lidar scanner on the iPad Pro 2020 (Provided by A. Al-Samarray, 2022).

I conducted three visits in total, and the first two visits concerned testing the two different methods of collecting data. The third and final visit focus on testing both methods on the same exposed wall. The next section explains each visit more in depth.

3.2 Field work

The first visit in the tunnel consisted of bringing an SLR camera and a plan over the pattern of the crane to be as efficient as possible (Figure 6A). The most important part of the pattern is that it is consistent, and that the pictures are overlapping with each other. It is also important that the camera faces directly to the rock wall to minimize distortions. Figure 6B shows all the locations where the pictures were captured. During the first visit, neither the sides nor the roof were included in the photographs; therefore, these important features could not be included in the model.

(A)

(B)

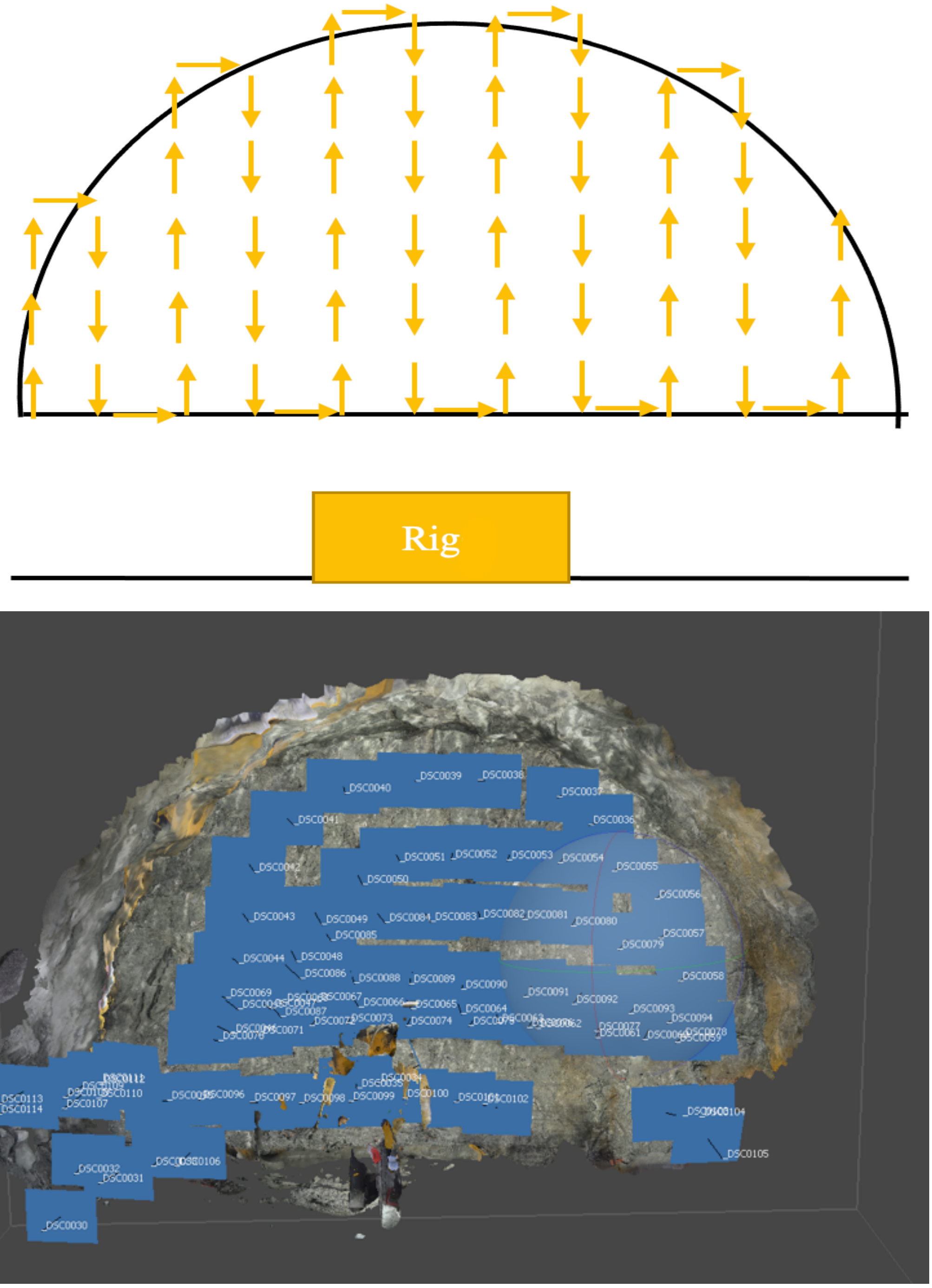


Figure 6: (A) Illustrates the crane pattern of the first visit. (B) Screenshot from the Agisoft Metashape program showing the locations of each captured photograph. Blue squares show the coverage of each photograph.

In the second visit, the iPad Pro 2020 was used to test the lidar scanner. Based on the model from the first visit, the crane pattern was improved to provide more data coverage (Figure 7A). With this new pattern plan, a much larger area would be covered. The lidar scanner worked as a continuous scan, meaning it was only needed to "film" the rock faces. The expanded crane pattern was deemed applicable for use in the third field visit.

The last visit focused on testing both the Nikon D5600 camera and the iPad Pro 2020. This way, a clear comparison of the two methods could be made since they both collected the same data. The pattern from the second trip showed positive impacts, so the visit was much like the last one. Considering the amount of experience gained by the third visit, the amount of time spent in each visit was about the same. Figure 7B shows all the locations of the photos the Nikon camera captured in the third visited locality.

(A)

(B)

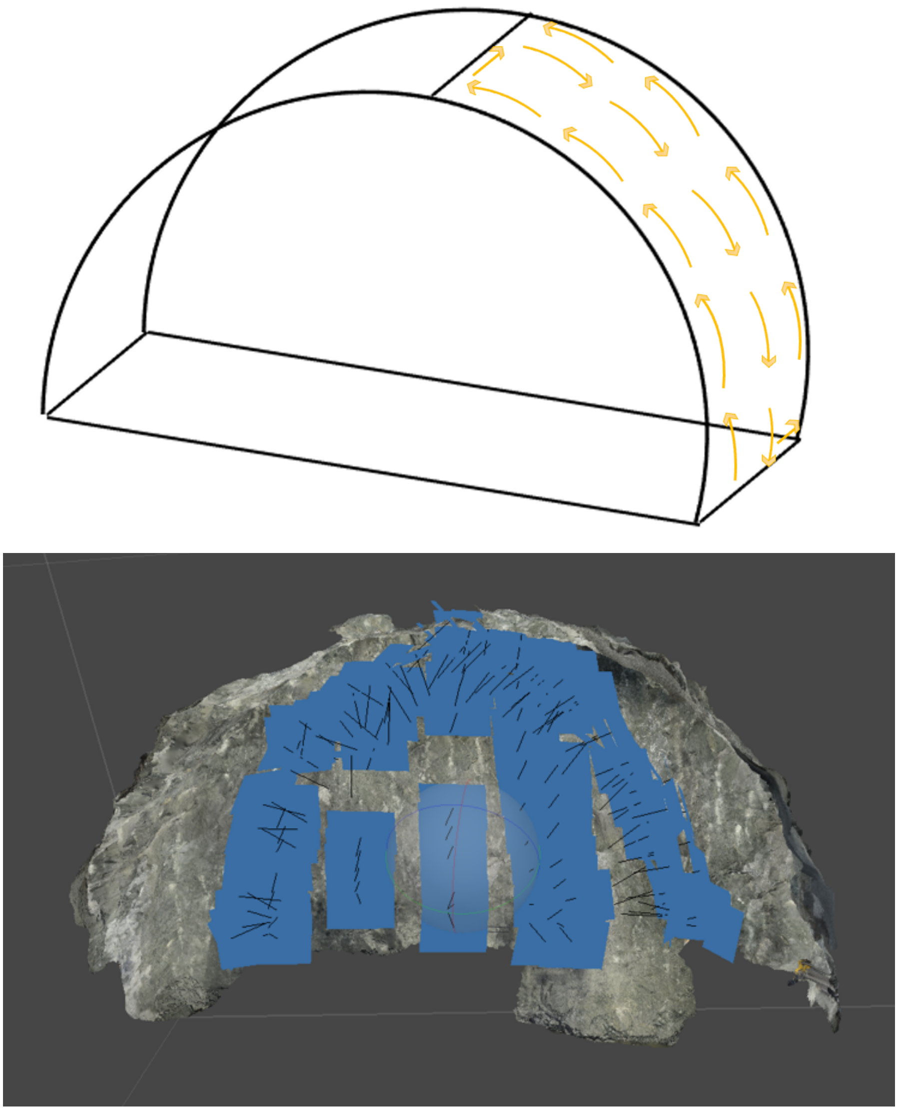


Figure 7: (A) Illustration of the new pattern of the crane in the second visit. The arrows represent the movement and applies on both sides. (B) Screenshot from the Agisoft Metashape program, showing the locations of each photograph for the third visited locality. Blue squares show the coverage.

3.3 Agisoft Metashape

The next step after collecting all the data was to upload and create the 3D models. For the construction of the 3D models from the photos by the SLR camera, all the pictures had to be uploaded to a photogrammetric software called Agisoft Metashape. This program provides tools such as aligning photos and building dense point clouds, mesh, and texture to combine all the photographs into 3D models. This is a very time-consuming process, especially for high quality models. The higher quality of the model has, the longer the processing time.

3.4 Lidar Scanner App

With the iPad Pro 2020, there was nothing to do other than press “done” after scanning the rock wall, and after two minutes, a model was created. From there, different filters could be applied, or the scale could be checked.

3.5 Comparison

The final part of the methodology was to compare the 3D models made. The comparison was easier with the models from the last field trip, because the other models were from different rock faces; therefore it was not possible to identify the same fractures or other geologic features.

Chapter 4

Case Study

Norway is a country with many of topographic changes and islands, making the connection of between places difficult. Luckily, there are ways to travel through mountains instead of over them and travel from island to island without a boat. Tunnel construction is the most important part of the infrastructure in Norway and is crucial for transportation.

The Norwegian Public Roads Administration is working on making the route between Kristiansand and Trondheim a continuous coastal highway route, with Rogfast as the first ferry replacement project. The tunnel is going to be the longest and deepest underwater tunnel in the world: 26,7 kilometers long and 392 meters deep.

The main tunnel will go from Mekjarvika in the south to Aarsvågen in the north. The main tunnel will be connecting to another tunnel leading to Kvitsøy, an island in-between the start and terminus of the Rogfast terminal (Figure 8) (Vegvesen, 2022).

Figure 8: Location of the tunnel with zoom in of working area in yellow box (Google Maps, 2022; provided by A. Al-Samarray, 2022).

In 2014, the Geological Survey of Norway (NGU) obtained information about the seafloor between Kvitsøy and Bokn, because of prior lacking data. Drill samples collected from a ship with oil well drilling equipment made it possible to construct a new, reliable model of the geological conditions between Kvitsøy and Bokn. The samples show that phyllite or schist are present on the seafloor. However, the tunnel will not run through these rock units, because they do not extend down to the level of the tunnel. Therefore, most of the tunnel will go through Precambrian granite and gneiss (Figure 9) (NGU, 2014).

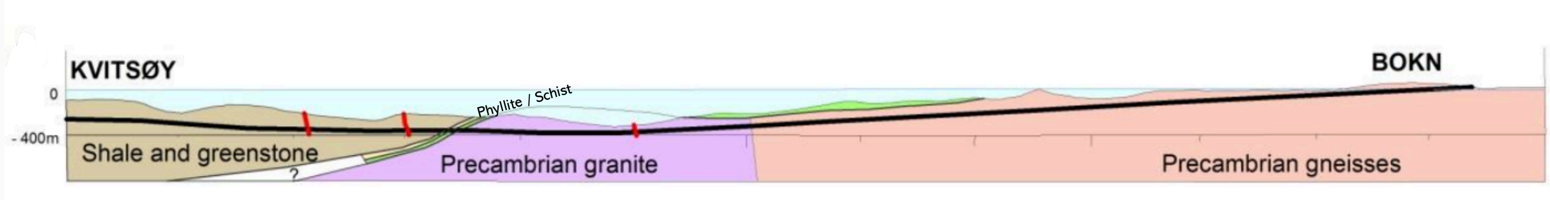


Figure 9: Section along the tunnel trace. The black line represents the tunnel trace, and the red lines represent the drilled cores (NGU, 2014).

Chapter 5

Results

5.1 Visit 1; Model 1: Nikon D5600 Camera

Approximately one hundred photographs were taken for the 3D model application (Figure 10). The setting used for the camera inside the tunnel was the outdoor focus setting. This means that the camera used a longer time to take the photographs because it had to focus on the entire small area, not just one object. In addition, the flash needed time to activate. The collection time was approximately 30 minutes.

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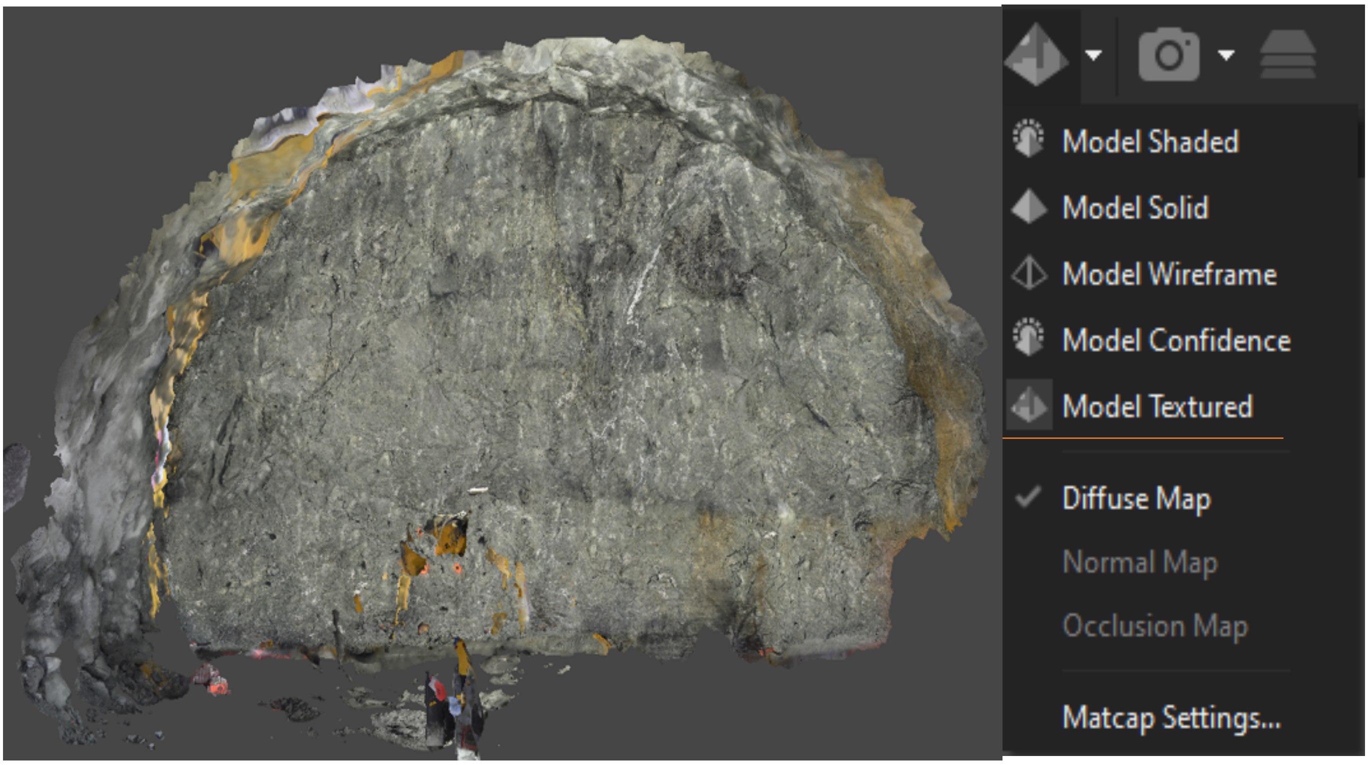

Figure 10: Model 1; "Model Textured" applied.

The Agisoft Metashape program comes with several filter applications. Figure 11A shows the smoothened filter, which adjusts the contrast and saturation of the model. Furthermore, Figure 11B shows the shape filter, which takes away the texture to get a more massive overview. Figure 11C shows the color filters, which can help identify fractures, joints, and other features.

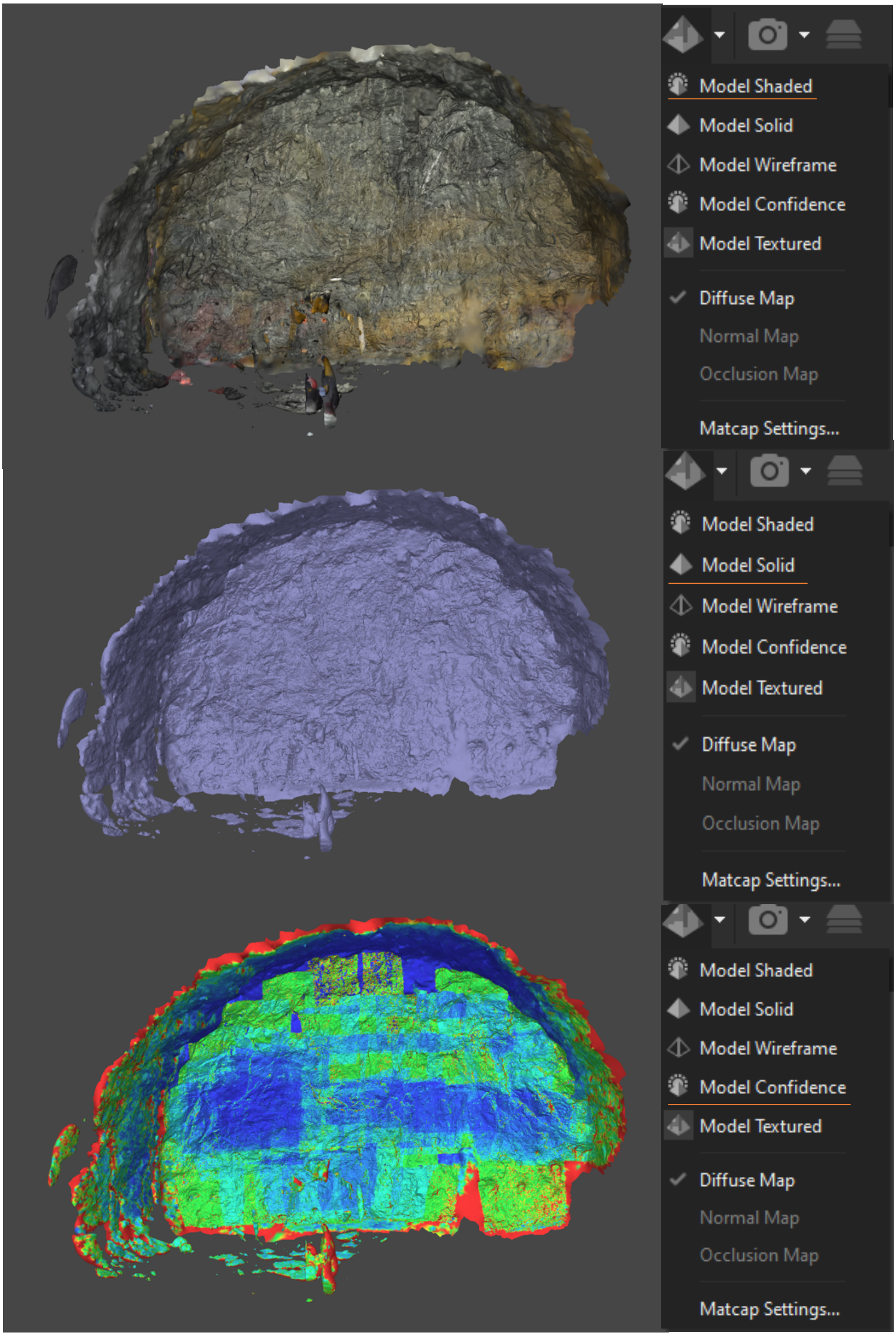

Figure 11 A, B, C: Model 1; A) Smoothened filter / "Model Shaded" applied, B) Shape without texture filter / "Model Solid" applied, C) Color filter / "Model Confidence" applied.

5.2 Visit 2; Model 2: iPad Pro 2020

Figure 12 shows the model created from the Lidar Scanner app (3D Scanner App) on the iPad Pro 2020. Each picture in figure 12 shows a different viewing angle – front-facing, bottom-up, from the right and from the left. This was possible because the data collection pattern was improved, as explained in the methodology. The Lidar Scanner app made this model approximately two minutes after the scanning was completed.

Much like the Agisoft Metashape program, the Lidar scanner app comes with different filters that can improve the visualization of the texture and fractures (Figure 13). Figure 13A uses photo-realistic representation of the rock face model. By using the grid and scale features, the size of the rock face model can be easily determined. Figure 13B uses a flat, non-textured filter where the overall surface faces are easily observed. Figure 13C shows the color filter, and the fractures are clearly visible.

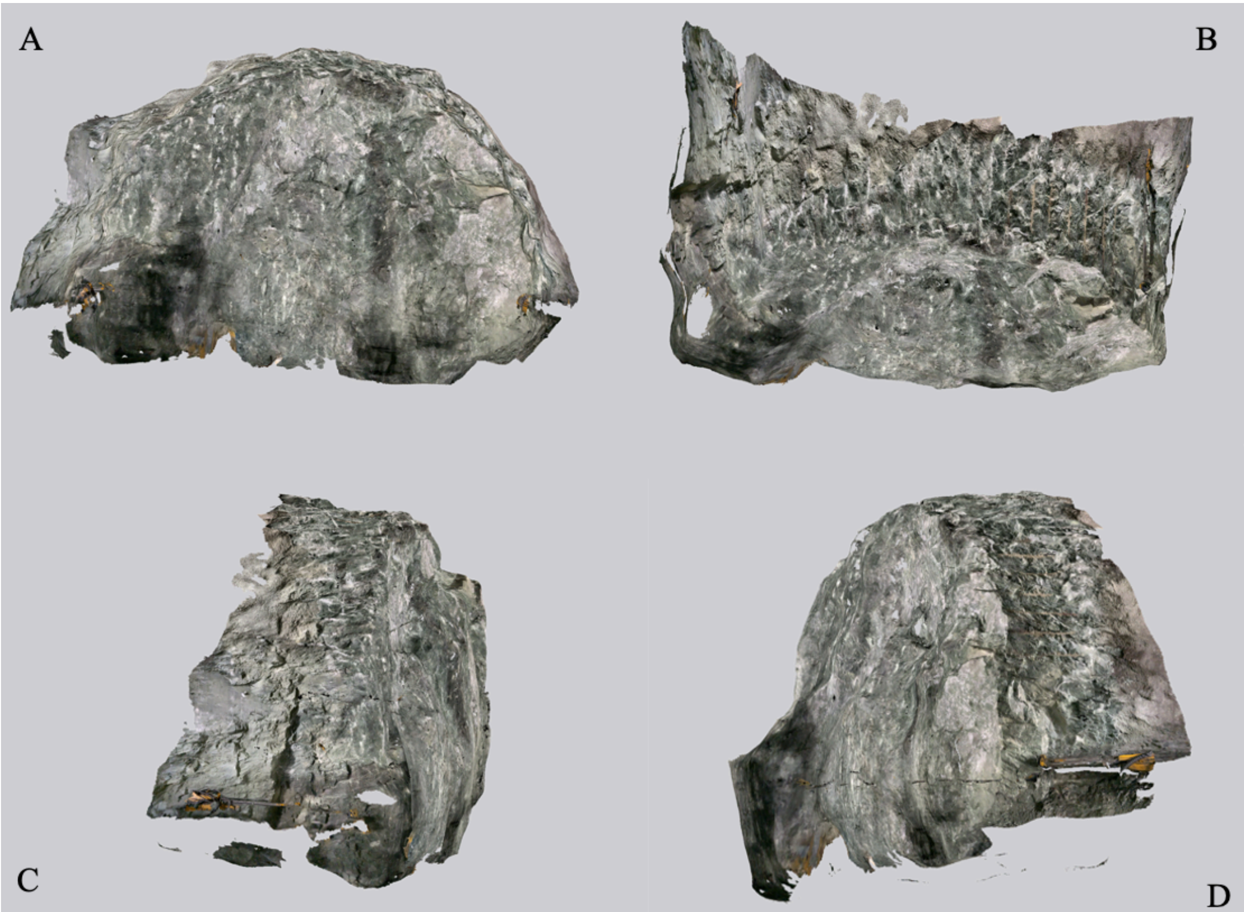

Figure 12: Model 2. Different viewing angles of the model. (A) Front-facing, (B) Bottom-up (floor-to-ceiling), (C) From the right side wall, and (D) From the left side wall.

(A)

(B)

(C)

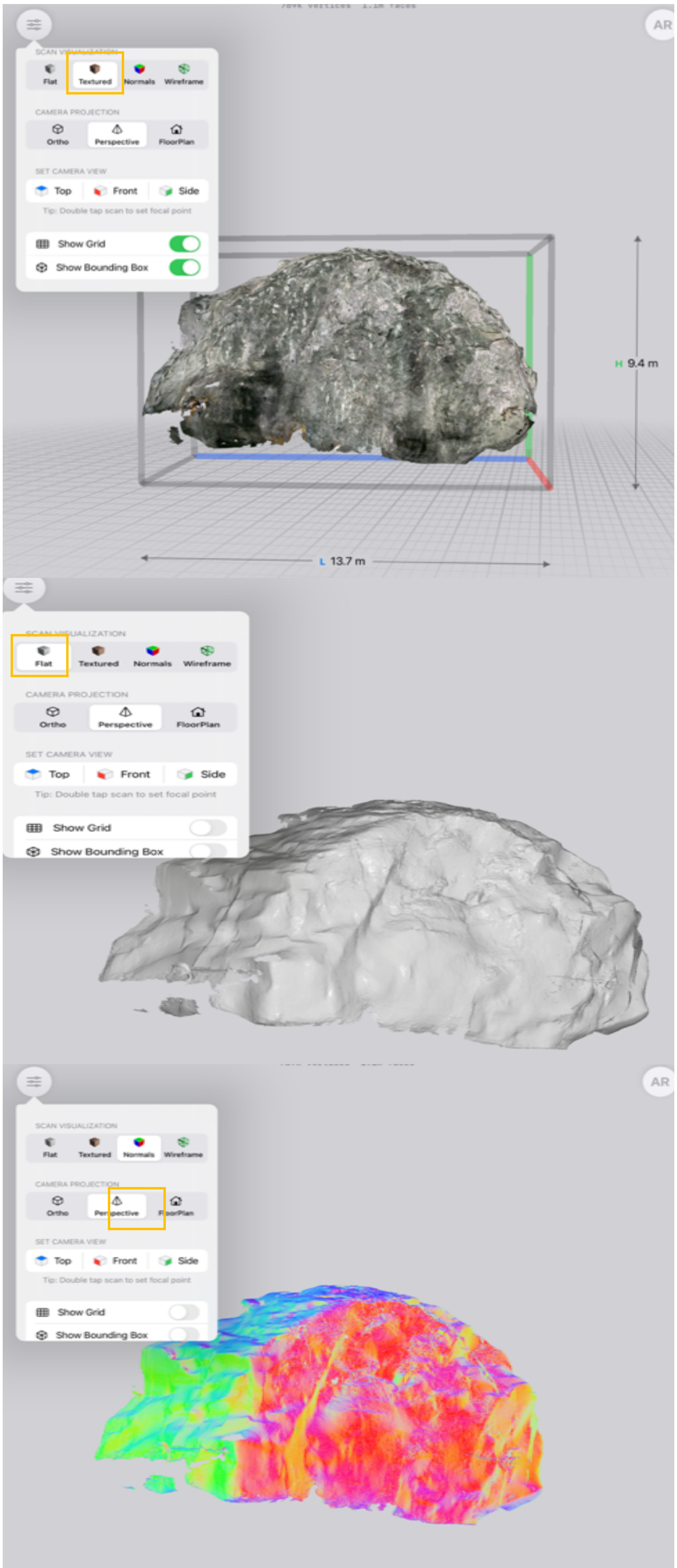

Figure 13: A) Textured filter together with grid to see the scale, B) Shape without texture filter / "Flat" application, C) Color filter / "Normal" application.

5.3 Visit 3; Model 3: Nikon D5600 Camera & Model 4: iPad Pro 2020

In order to make a more absolute comparison of the two methods, the last visit used both methods to collect data from the same rock face. By doing this, the new models would contain the same data and provide a clear data comparison. Even though this visit accomplished twice the work as the prior visits, the same amount of time was used as each of the first two visits.

Figure 14 displays the two models beside each other; model 3 is made from the Nikon D5600 Camera, and model 4 is made from the iPad Pro 2020. Due to the improved pattern change, the model 3 is more three-dimensional than model 1. The red box on the first picture marks a spot with poor lighting, marking the model darker. Model 4 is highly similar to model 2; however, there is a small error on the lower middle part marked in the yellow box where the app probably is trying to connect the model with the wrong pieces. The models are both included as screenshots and uploaded to Sketchfab (URL: https://sketchfab.com/hannaosthus)

Figure 15 represents the models with the different filters side by side. Figure 15A shows the solid / flat filters to observe the overall surface faces. Figure 15B shows the confidence / normal filters to identify fractures, joint or other geological features.

Figure 14: Comparison between Model 3 (camera) and Model 4 (iPad), which are the tunnel face at the third visited locality.

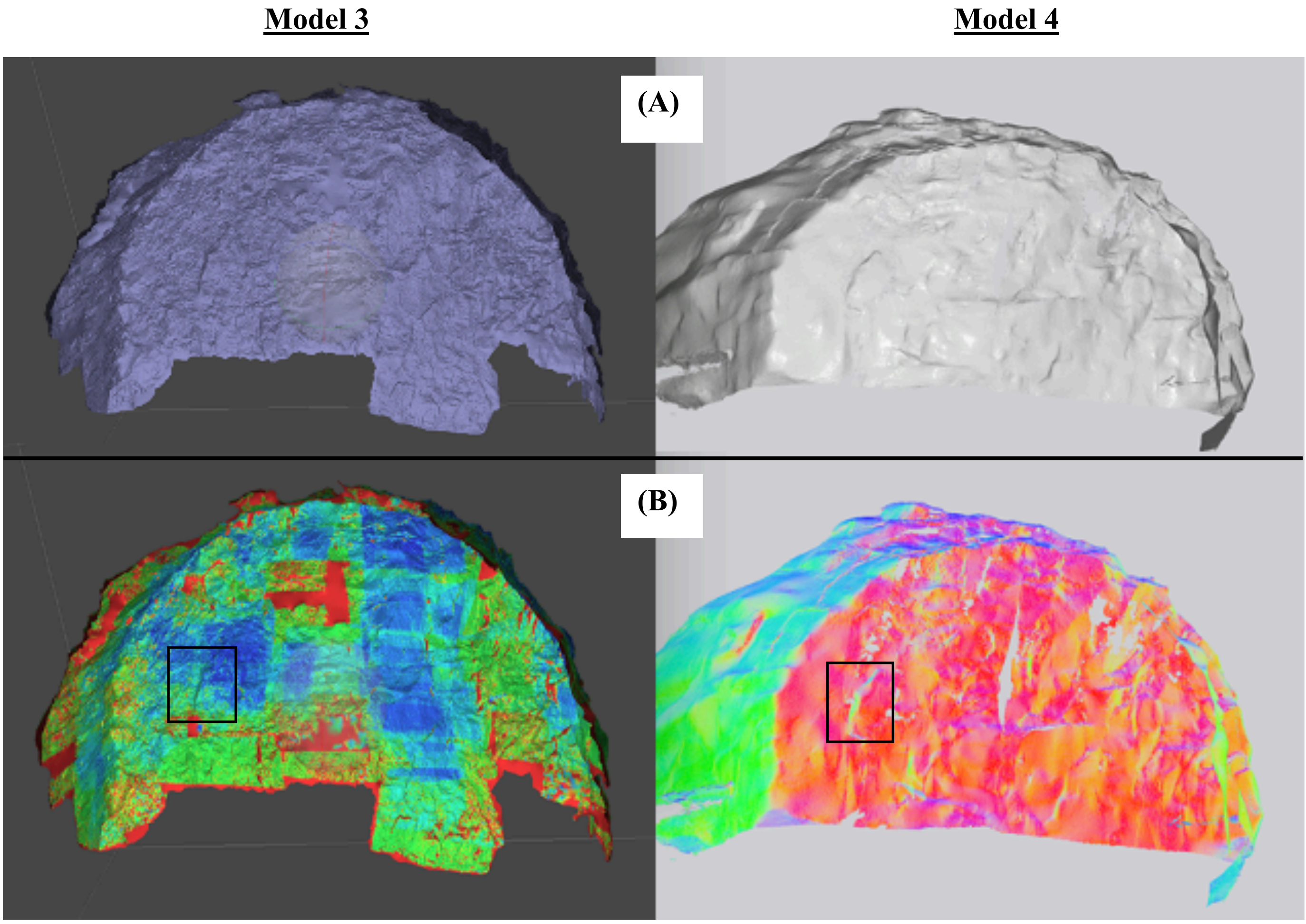

Figure 15: Model 3 and Model 4 comparison with filters; (A) Solid / Flat, (B) Confidence / Normal.

Chapter 6

Discussion

In view of testing the methods on two individual visits, and both of them in the same visit, there are several advantages and disadvantages that could indicate which method is most preferable.

First of all, the Nikon D5600 camera has a comfortable and stabile figure. The lens of the camera is of high quality, and the settings that come with the camera such as object-focus, and automatic outside / inside lighting, provide a higher degree of details in the photographs. Together with a photogrammetric program like Agisoft Metashape, one can easily import the photographs for 3D model applications. Learning the basics of the program is simple and logical; in addition to more advanced settings and editing options that may require more time to learn.

However, it is not a flawless method. Even though it comes with different settings, because of the motion of the crane and the irregularity of lighting, the camera needed some extra time to focus and capture photographs with the same quality across the rock face. One example of photographs with lower quality is shown in figure 14, marked in a red box. The camera needed more time to focus on this section due to of poor lighting at that height. Consequently, because of the time limit, the camera setting needed to be adjusted to lower quality, to reduce the focus time. A setting called burst mode was used taking continuous photographs in a quick succession with poorer quality. There is an obvious trade-off with the camera for high-resolution photographs and time.

As mentioned, the Agisoft Metashape program was used to generate the 3D models. Although the degree of difficulty is low, it is not a time efficient choice. The program uses a long time to piece all the photographs together, and afterwards it needs to smooth everything out. Much like the camera settings, if the goal is to make a high-quality model, the duration will extend as well. The time can vary, but an estimation is approximately one hour on a fairly small area (e.g., model 1).

Lastly, it is not possible to use an SLR camera simultaneously as charging. If the battery runs out and there is not a back – up battery, data collection must be delayed until the battery is recharged.

In comparison, the iPad is a more compact choice, with the lidar scanner, a camera, and the program all assembled in one unit. The iPad comes with a 12,9 inches large screen, enabling the user to more easily identify overlapping sections. With this device, there is no need to capture photographs, but simply to record as you move around; the app simultaneously collects photographs and lidar data. The Lidar Scanner app is exceptionally user-friendly, with a measurement application to collect the scale of the surface. Once the scanning is complete, the program will use a couple of minutes to process the data, before presenting the final 3D model. What's more, the iPad can be used while charging, meaning if a power bank is present one can simply continue to work while charging the device.

The iPad seems like a great choice, being compact and efficient. However, there are few settings and editing options in the app, which makes it harder to correct mistakes and fewer possibilities to be creative. Furthermore, the figure of the iPad is not easy to work with considering the touch screen and wearing gloves in the tunnel, as well as keeping it still while moving around in the crane.

To compare, both methods have shown exceptional results considering details and degree of difficulty. They both used approximately 30 minutes to collect all data and come with filter applications that can provide information about fractures and shape. Moreover, cost is an important factor, and the price of a good quality SLR camera and an iPad with a lidar scanner will vary in the price range of 7000 NOK to 10 000 NOK. Hence the price is relatively similar, and they are both a one-time expense.

The two methods have developed great high-quality models. By comparing the appearance of model 3 and model 4 in figure 14, one main difference is the greyscale. Model 4 shows a larger range of the greyscale with both lighter and darker areas compared to model 3. Model 3 does not have as large range of the greyscale which makes less contrast.

The filters of the models in figure 15 applies different for each model. There are differences in the texture for the solid / flat filters application in figure 15A. Model 3 has a compacted and lumpy texture. Model 4 has a texture that is reminiscing a footstep in mud; the textures are light and shiny, and the shine is the feature that makes the contrast in that model.

Figure 15B represent the confidence filter and normal filter application of the two models. The range differences in the greyscale may have caused the difference in the distribution of colors for the two models. Model 4 shows more of a smoothness of the colors on the plane surface, and other colors are filling the fractures or cracks that appear to mark the feature. Model 3 has less of that smoothness in the distribution of color. However, there are detected some similar fractures in both models, one example marked in the black boxes in figure 15B.

Overall, it is wise to include the usage of filters in 3D modelling, as they are able to view models from other perspectives and / or highlight information that could be hidden in a textured model.

Moreover, the models are not perfect. A problem with construction of models in geological areas is that areas vary in scale and obstacles. Because of the limited mobility of the crane and the time constraints, it is difficult to obtain every aspect in the models. If there was an extension in the time frame, perhaps a more complete model could be made.

As mentioned earlier, the lidar scanner collects and processes the data automatically. This means that the algorithms used to process the lidar scanning and photographs are unknown, and we must blindly trust the program. If there was a way of exporting the data to a point cloud and to another software that could further process it, there would be more room for editing and improving the preserved rock face of the models.

Table 1 represents a summary of the comparison between the two methods, and model 3 and model 4.

Table 1: Pros / Cons Summary.

	Camera	**iPad**
Figure / shape	Ergonomic	Required a stylus for use in construction sites
Stability	More stabile	Less stabile
Settings	More	Less / None
Must transfer to external program	Yes	No
Battery	Needs to be taken out	Can charge while using
Efficiency	Less efficient (hours)	More efficient (minutes)
Costs	10 000 NOK	10 000 NOK
Time collecting data	30 min	30 min
	Model 3	**Model 4**
Greyscale	Lower range	Higher range
Possible to use filters	Yes	Yes
Possible to identify cracks or fractures	Yes	Yes
Scale	No	Yes

Chapter 7

Conclusion

Starting this project, my hypothesis was that the Nikon camera would make better models, because it has much better quality of the lenses. However, other factors come into play considering ease of use, data processing, output models, efficiency, degree of difficulty, stability, and costs.

They are each good in their own way, but I would say the efficiency is the biggest difference between them. Therefore, in my opinion, if you want a good model that can be made in minutes comparing to hours, the iPad is the better choice for use in active tunnel excavation. Future work stemming from this study would be to compare a traditional TLS to the iPad TLS or to further process point cloud data from the iPad TLS for fracture and join extraction.

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