2022

How can Planet X improve its photogrammetry workflow in terms of efficiency and visual quality in producing 3D assets?

Graduation project with Planet X

Jason Hu – 470677

Creative Media and Game Technologies

SAXION HOGESCHOOL CMGT planet x

Abstract

In recent years the demand for entertainment has increased due to changing patterns and consumption habits of users globally. This demand requires many entertainment studios to produce more content which requires more 3D assets to match the demand while upholding the quality of its work. One of these companies with this problem is Planet X, a VFX/CGI studio in the Netherlands, looking for solutions to optimize their workflow to produce more content to match the growing demand. Planet X can utilize and improve its photogrammetry workflow to speed up its workflow and make high-quality assets to match the demand. In this thesis, insights into technologies, photogrammetry setups, and photogrammetry programs were researched and tested to form advice to create a workflow document and videos to help Planet X produce assets more efficiently. The result of this research and tests is an optimized workflow document that delivers a greater visual quality

Table of contents

Table of figures

List of tables

List of charts

1. Introduction

In recent years, the demand for 3D assets has been overwhelming for VFX/CGI artists, prompting new technologies to be developed. These technologies comprise Photogrammetry, virtual production sets, deepfakes, and Unreal Engine 5, which streamline and improve the workflow and workload of 3D artists.

Planet X is one of many companies to work in this industry and is looking into new possibilities to improve its efficiency in creating realistic 3D assets for production. A possible solution to this problem is photogrammetry.

1.1 Industry

The game and film industries have a combined market value of $238,4 Billion in 2022, with the gaming industry making up most of the value of $196,2 Billion (Wijman, 2022) and the film industry at $42,2 Billion (Market Dataforecast, 2022). It is estimated that both industries will continue to rise in value and demand in the upcoming years due to the increasing consumption of entertainment, COVID lockdowns around the world, and the normalization of working from home, which consequently changed the media consumption and spending habits of users as seen in figure 1 and 2 (Nielsen, 2020). It is estimated that the gaming industry will grow to a market value of $321 Billion in 2026 (Read, 2022) , and the film industry to $45,9 Billion.

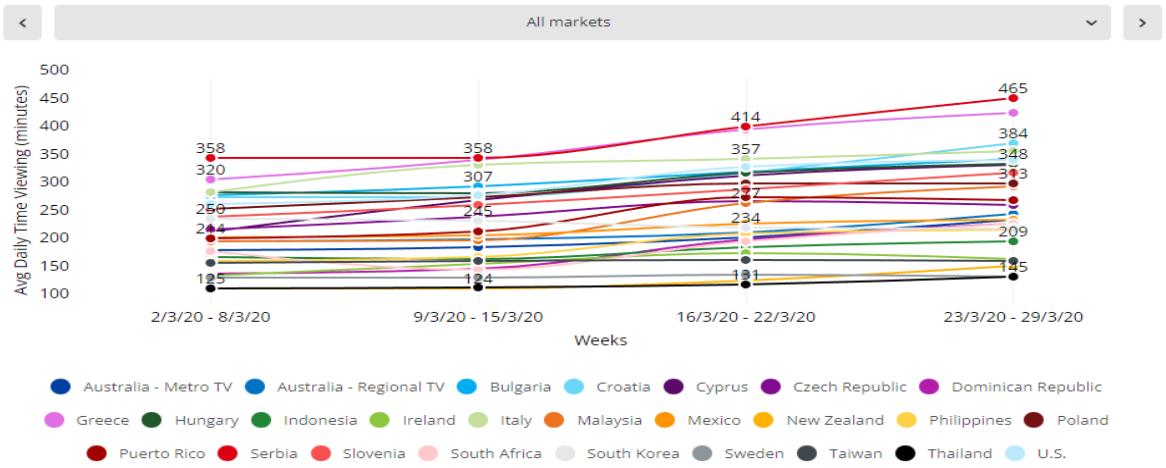


Figure 1 Increased gaming time of users

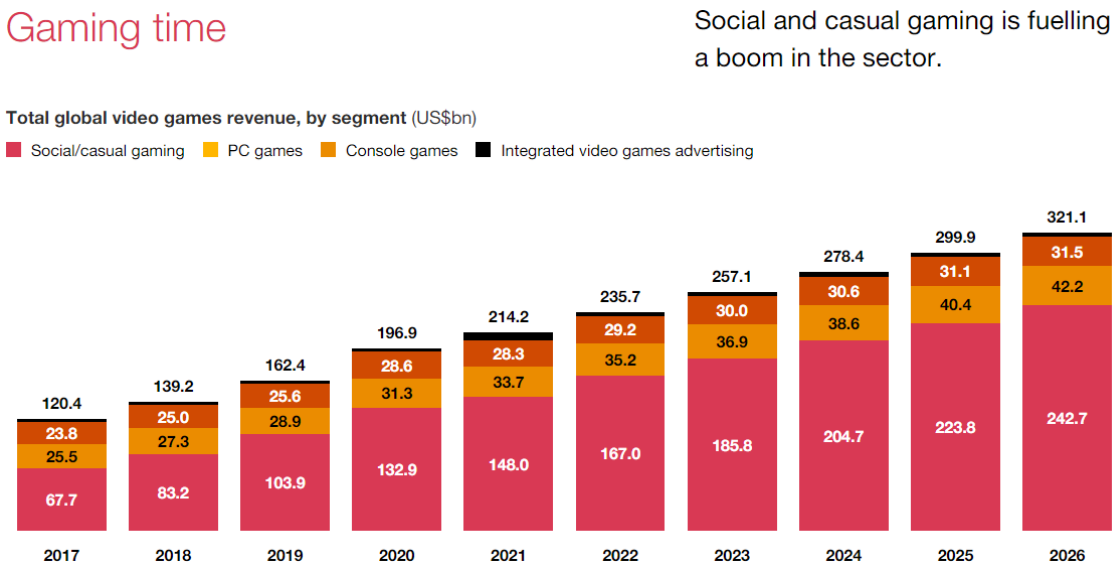


Figure 2 Global video games revenue

With the growing popularity and rise of the entertainment sector in mediums such as TV, films, games, apps, and theatre, the demand for 3D artists is at an all-time high, requiring artists to create a high amount of realistic 3D assets in a short amount of time (Wood, 2022). This issue can be observed in the current movie industry, where for the past ten years, many of the highest-grossing movies require large amounts of visual shots that need 3D assets (2010s in film, 2022). In 2021 and 2022 alone, the top-grossing movies Spider-Man No Way Home, Jurassic World Dominion, and Doctor Strange in the Multiverse of Madness, for the most part, consist of visual 3D shots, with Spiderman only having only 80 scenes without visual effects (Entertainment Desk, 2022) and Jurassic World having over 1500 visual effect shots which make up to two-thirds of the movie (Weiss, 2022). In recent years, the demand for 3D assets has been overwhelming for VFX/CGI artists, prompting new technologies to be developed, such as Photogrammetry, virtual production sets, deepfakes, and Unreal Engine 5, to streamline and improve the workflow and workload of 3D artists. Especially photogrammetry has been a rising technology that has become and standard practice in the film industry (Frazer, 2021). Photogrammetry is becoming more popular amongst game development studios with the recent release of Unreal Engine 5, which allows higher polygon models to run more efficiently on low-spec hardware. In the opposite spectrum, game engines such as Unreal Engine have been used in recent years for TV/film production to create virtual sets to save space and resources and offer the creatives flexibility and speed to keep up with the demand (Coldewey, 2020).

Planet X recognizes the rising demand for media entertainment in recent years and has spent time keeping up with the demand by utilizing photogrammetry. However, it lacks the workforce to further research to optimize the efficiency of its current photogrammetry workflow to take on more projects.

1.2 Description of the company

Planet X is a creative visual effects company founded in 2014 (Planet X, n.d.) and known for its visual work on film and TV projects such as Dirty Lines, Dragon Girl, Ares, and Hoogvliegers. The company is a leading visual effects studio in the Netherlands focusing on creating feature films and episodic productions emphasizing VFX/CGI. It strongly believes in the outstanding work that they deliver to consumers to be enjoyed worldwide. The company is located in Amsterdam and employs twenty-five specialists in the VFX department to work on their ongoing projects.

The company's portfolio comprises the following categories: VFX, CGI, title designs, character animations, colourization of footage, FX simulation, and virtual reality development. In addition, the company has recently been working on creating a virtual production set in conjunction with Unreal Engine as a better alternative to a greenscreen. A virtual set allows the company to better visualize and preplan its productions more efficiently for the production phase. Furthermore, the company also spends resources developing tools for creatives to aid with visualization for film/TV productions, with plans to commercialize the tools in the future (Planet X, n.d.).

The company strongly believes in staying up to date with the releases of new promising technologies that potentially improve the quality of their work. This is evident from the company's belief in encouraging a learning environment for its employees to benefit them and the company in future projects (Planet X, n.d.).

Due to the introduction of the Film Incentive that offers a 35% cash rebate on productions spent in the Netherlands (Filmfonds, n.d.), Planet X has progressively been more present in international film/TV productions, as seen with projects such as the Dragon Girl. The company aims to expand its international productions and projects to a wider audience and establish its name in the film/TV industry (Planet X, n.d.).

1.3 Company expansion

Planet X has been expanding its production with new tools to produce more high-quality content in recent years. However, the company lacks the resources to optimize its current workflow. One part of their existing workflow is photogrammetry. Photogrammetry is a method of creating realistic assets by automating the creation of models/textures by extracting that information from images or videos. Planet X integrated photogrammetry into its workflow to create more realistic 3D assets more e

Therefore, the company requested consultancy on improving the workflow to produce more visually realistic or efficient production assets by conducting research and testing.

1.4 Company vision

Planet X recognized the increasing demand for entertainment and focused its efforts on matching the demand. However, it wishes to expand further by improving or changing its existing workflow to produce visually more realistic 3D assets efficiently. The company hopes to have the improved workflow speed up production while maintaining or improving the quality of their work to undertake more productions to grow the company globally.

1.5 Assignment

Planet X tasked the researcher with this assignment to research photogrammetry workflows to improve efficiency or visual quality to create a workflow document and video course for internal use.

The visual improvement can be defined as such: More visual detail is observed in the asset created with photogrammetry, or more visual data is included, such as more polygons and higher texture resolution.

The efficiency mentioned above can be defined as such: improving the workflow to ease the user's workload or improve user experience.

Photogrammetry was chosen for this research because it is part of Planet X's workflow for film/TV productions. Improving Planet X photogrammetry workflow helps the company train new artists, produce assets more efficiently, or produce visually higher quality assets for the company to showcase their ability to create high-quality content.

2. Problem definition

Planet X recognizes the increasing demand for entertainment and has focused efforts to match the demand. However, it wishes to expand further by improving and optimizing its existing workflow to produce visually more realistic 3D assets efficiently. The company hopes to have the improved workflow speed up production while maintaining or improving the quality of their work.

Issue 1: The company is unfamiliar with current possibilities to improve visual quality or efficiency for photogrammetry.

Issue 2: The company currently uses the program Reality Capture, which is expensive for photogrammetry. Thus, the company wants to look for alternative programs that are inexpensive and deliver similar or better results than Reality Capture.

Issue 3: The company wants to further improve the visual aspect of photogrammetry assets to compete with its competitor but does not know what programs to utilize to achieve this.

3. Research question

Based on the issues presented, the following research question is formulated:

How can Planet X improve its photogrammetry workflow in terms of efficiency and visual quality in producing 3D assets?

3.1 Sub questions

Based on the main research question problems and other factors within this scope, the following sub-questions are defined:

The following sub-questions were determined to achieve the main objective:

- 1. What program is best used for photogrammetry to create realistic assets?
- 2. What setup is best to improve photogrammetry's visual quality or efficiency?
- 3. What program can be used to improve photogrammetry assets visually?

The research methodology and results will be presented per sub-question.

4.1 What program is best used for photogrammetry to create realistic assets?

4.1.1 Research methodology

To answer sub-question 1, secondary research was conducted on the following: what type of photogrammetry programs exist, what photogrammetry programs are used by professionals, and what tools/features are important to determine which photogrammetry programs are best?

The research was conducted by doing desk research on photogrammetry programs used by professionals, features/tools important for photogrammetry, and types of photogrammetry. The research was gathered by watching photogrammetry workflow videos, reading articles, and reading professional research.

4.1.2 Research results

4.1.2.1 What types of photogrammetry programs exist

The research from TOPS (n.d.) observed that photogrammetry is used in many industries, such as medicine, construction, nature preservation, historic preservation, and many more. Depending on the user's objectives, these industries use either aerial or close-range photogrammetry (TOPS Marketing, n.d.).

Aerial photogrammetry is primarily used for large-scale objects or terrain such as entire cities, mountains, and buildings. Aerial photogrammetry is also used for educational purposes, planning, and preservation purposes (BLM, 2008). For example, aerial photogrammetry is used in sectors such as construction to plan buildings or to measure large terrains.

Close-range photogrammetry is used for small to medium-scale objects and is more widely used in multiple industries. Close-range photogrammetry is used in the entertainment industry to efficiently produce realistic assets for games, film, and TV (PlanetX, 2022).

4.1.2.2 Photogrammetry programs used by professionals

The research is focused on close-range photogrammetry, as this is the type of photogrammetry Planet X chooses to use.

According to Übel (2022) and Sculpteo (2022) the following programs are best used for photogrammetry: Zephyr 3DF, Reality Capture, Agisoft Metashape, and Meshroom. Other programs on the list were primarily focused on aerial photogrammetry, which does not match the objective of this research.

Zephyr 3DF

3DF Zephyr is developed by 3DFLOW. Originally released as 3DF Zephyr Pro, a consumer-centered version, 3DF Zephyr Lite was soon released, and then a GIS and map-centric version, 3DF Zephyr Aerial. In 2017, 3DFLOW also released a free version that can process up to 50 images. However, as of 5.0, the Pro and Aerial versions have been discontinued and merged into a new full version (named 3DF Zephyr) (3DF Zephyr, 2022).

Reality Capture

Reality Capture is a photogrammetry program for making 3D models out of photos or laser checks without creases. The most widely recognized fields of its ongoing use are social legacy, full body filtering, gaming, reviewing, planning, special visualizations, and augmented reality. (RealityCapture, 2022) It highlights automatic image alignment, automatic calibration, calculating a polygon mesh, colouring, texturing, parallel projections, georeferencing, DSM, coordinate system conversion, simplification, scaling, filtration, smoothing, measurement, inspection, and various exports and imports. The program can be run under the order line, and a developer kit is accessible.

Agisoft Metashape
Agisoft Metashape is a program for a photogrammetry pipeline. The software has two versions, the Standard and Pro versions. The standard version is primarily used for interactive media tasks, while the Pro version is designed for authoring GIS content. The software is developed by Agisoft LLC located in St. Petersburg in Russia. Agisoft Metashape has been used in popular projects within the gaming industry, such as Cyberpunk 2077, Halo 4, Metal Gear Solid V, and Star Wars Battlefront (Metashape, 2021).

Meshroom
Meshroom is a photogrammetric computer vision framework that provides 3D reconstruction and camera tracking algorithms. It allows the creation of 3D textured models by analyzing a series of unordered images of a static scene captured by any type of camera, from professional cameras to smartphones. The library consists of modules for feature extraction, image matching, scale-invariant, camera calibration and localization, depth map estimation, meshing, and texturing. Unlike its competitors, the library is open source and freely available under the Mozilla Public License. It relies on standard and open-source file formats (Alembic, Wavefront .OBJ files) (AliceVision Meshroom, 2020)

4.1.2.3 Essential features/tools for photogrammetry

Multiple factors and principles define photogrammetry's visual results, meaning a lot of the visual quality depends on the quality of the dataset provided. However, the photogrammetry software influences how the data is processed. For example, photogrammetry programs that use RAW images are typically better than those that use JPEGs because RAW images contain more visual data than JPEGs (Baran, 2019).

This research was conducted by reviewing what aspects authors find important for photogrammetry programs.

Datem Systems International (Datem Systems International, 2021) proclaims that having the option to detect and store geological information in photogrammetry software is an important factor in deciding which photogrammetry program to use. This geological information aids the program in establishing a view of the camera positions that can be fine-tuned during the alignment process for an accurate alignment. Mapware (2020) agrees but also emphasizes the importance of user-friendliness, quoting, "The best photogrammetry software is straightforward and user-friendly, and does not require advanced technical knowledge" this user-friendliness comes from well-designed UI/UX aids the user in navigating and using the photogrammetry program without prior experience. Additionally, Mapware points out the importance of speed for photogrammetry, alignment accuracy, model size, and texture density and quality.

In the comparison and reviews of photogrammetry programs by Formlabs (Formlabs, n.d.), they rated the programs on their output quality, speed, features, user-friendliness, and price. These focus points are also mentioned in Datem's (2021) and Mapware's (2020) research.

Conclusion
The research and reviews indicated that features/tools do not directly improve the result for photogrammetry scans but instead aid with improving the quality of the user's dataset to produce a better photogrammetry scan. Based on the findings from the research, the best photogrammetry program for photogrammetry should be evaluated on its processing speed, user-friendliness, alignment accuracy, model size, texture density, and price. Additionally, having geological processing data is a nice addition but is not required as it is more useful for aerial photogrammetry (Datem Systems International, 2021).

4.1.3 Testing methodology

Based on the results of the desk research into photogrammetry programs, the following criteria have been established for testing: test and compare programs to each other in texel density, model size, the user experience of the researcher, processing speed, price, texture density and quality, model size, and visual quality to identify which program is the best choice for photogrammetry to answer sub-question 1.

Based on the results of the research methodology section, the following programs were selected to be tested: Zephyr 3DF, Reality Capture, Agisoft Metashape, and Meshroom.

The test was conducted by aligning and rendering with the same source files on the program's highest settings within the tested program with no external programs to give other programs an unfair advantage. The results were then compared to the criteria mentioned before to form a recommendation and integrate the best program into the photogrammetry workflow document/videos.

All processing and tests have been done on the same hardware listed in table 1, with similar conditions in temperature to avoid advantages for certain programs.

Table 1 Hardware components

Computer component	Part
GPU	NVIDIA GeForce RTX 3090
CPU	12th Gen Intel(R) Core(TM) i9-12900K
RAM	DDR5 4x16 64GB RAM from Acer
Motherboard	Stock Acer motherboard
Storage	NVME 1TB Samsung SSD
PSU	800W Gold stock Acer power supply

4.1.4 Testing results

4.1.4.1 Zephyr 3DF results

User experience

The UI/UX of Zephyr is solid, with clear icons and explanations when hovered upon. Zephyr follows a step-by-step approach to photogrammetry, starting from a sparse cloud towards a textured mesh that is easy to understand. However, A small downside is that some functions are not bound, requiring the user to constantly click the icons to perform the same action. The issue with functions not being bound can be fixed by an update that allows manual binding.

Rendering

Zephyr 3DF aligned 65 out of 65 images but could not align all 65 images at once. Instead, it required the user to split the image into two sets and adding the images afterward combined both datasets into one. The results of the rendering can be seen in figure 3. Aside from that issue, there were no problems during the workflow.

Figure 3 Render results of Zephyr 3DF

The result of Zephyr 3DF is decent, with the model polygon count being small for rendering at the highest visual settings. Additional results of the test can be found in table 2

Issues

As mentioned before, there are no binded shortcuts for important features, and Zephyr did not manage to align the dataset in one attempt, instead requiring the user to split the dataset in two and combine the datasets afterward.

4.1.4.2 Reality capture results

User experience

Reality capture UI/UX experience from a first-time user perspective is daunting. The overall clarity of workflow found in other programs is not present in Reality capture, but Reality capture attempted to solve this issue by presenting the user with an automatic pop-up that shows tutorials to help the user navigate and use Reality capture. However, the pop-up is not helpful enough as it lacks crucial information to navigate and utilize the program. A minor improvement would be adding more visual information in the form of icons or a more streamlined UI/UX.

Rendering

Reality Capture aligned 32 out of the 65 images, even when using data points and rendering the dataset separate did not solve the issue of poor alignment. However, this test is done on an older version of Reality capture V1.0.3 BETA which might have influenced the success rate of the alignment. The results of the rendering can be seen in figure 4.

Figure 4 Render results of Reality capture

The results are not optimal because of the older version of Reality Capture, but despite not having favourable conditions, Reality capture results are tied to other programs, if not better. Additional results of the test can be found in table 2.

Issues

Reality capture did not align all images, and the generated UVs are not ideal. The poor performance is because Reality capture is not given fair testing conditions. This unfairness is due to using an older version of the program compared to competitors with recent versions of their program. The researcher could not access Reality capture's more recent version due to the higher cost of subscribing to or buying Reality Capture than their competitors. If the test was done with a more recent version of Reality capture, the results might be more favourable to Reality capture.

4.1.4.3 Agisoft Metashape results

User experience

Agisoft Metashape has a well-designed UI/UX. If the user has prior experience in photogrammetry, the user can easily navigate Metashape without any tutorial. Furthermore, The program has well-designed visual icons to explain functions and a more in-depth explanation of what the function performs when hovered or selected at the bottom of the program.

Rendering

Agisoft Metashape aligned 65 out of the 65 images. However, Metashape could not render the dataset's original RAW file format, which required the dataset to be converted to JPEG. The results of the rendering can be seen in figure 5.

Figure 5 Render results of Agisoft Metashape

Additional results of the test can be found in table 2.

Issues

The only issue for Metashape is the lack of support for higher image file formats such as RAW.

4.1.4.4 Meshroom results

User experience

At first glance, Meshroom looks confusing due to its node-based structure. However, if the user is familiar with Blender or Substance Designer programs, this would make more sense workflow-wise. However, this approach to UI/UX is not user-friendly, making the process unnecessarily difficult.

Rendering

Meshroom aligned 65 out of the 65 images. However, some of the camera's rotation and location are incorrect, resulting in some faulty parts in the mesh. Another glaring issue is the incredibly long processing time compared to the other programs. The results of the rendering can be seen in figure 6.

Figure 6 Render results of Meshroom results

As seen above, the mesh is riddled with holes because Meshroom misaligned the pictures. Additional results of the test can be found in table 2.

Issues

The texture and model generation does not produce an asset ready for production. Additionally, the time it takes to render is marginally longer than its competitors, making it inferior to the other programs tested before in all aspects.

4.1.4.5 Additional Results

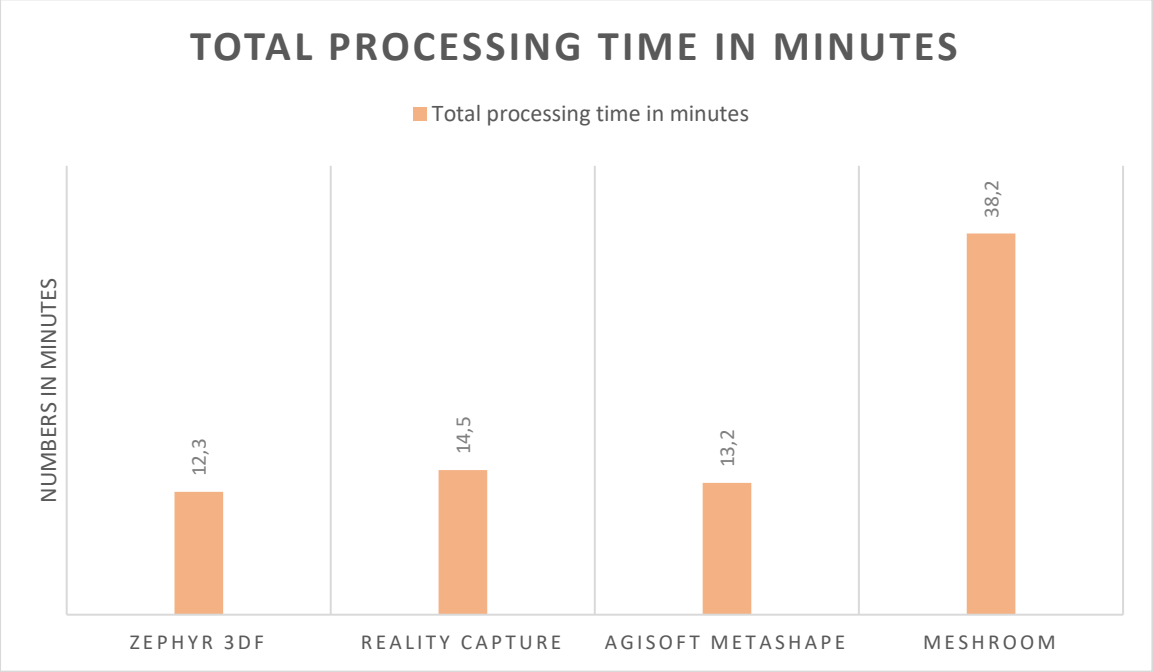
The texel density determines how large the texture is projected in the UV map and the model size shows how much visual data is inside the model. A higher texture density and model size value equals more visual data.

Table 2 Additional test results

Application	Texture map	Texel density	Model	Total price
Zephyr 3DF	The automatic UVs created by Zephyr is overall decent, but doing the textures manually and rebaking the textures would deliver a better result. As for the visual aspect, the textures are overall great, with some minor image artifacts around parts with icons/logos.	Map size 4096 333.9632	607.962 triangles	€149.00 One time purchase
Reality Capture	The texture map is generated in a singular map, and the UVs generated from Reality capture is not utilizing the texture map's full space. The only fix for this issue is manually UV-mapping the model. However, this issue is not present when rendered in multiple texture maps(UDIMS). Despite using less space within the texture map, the visual fidelity is similar to Zephyr 3DF.	Map size 4096 225.4247	10.907,802 triangles	$ 3.750 One time purchase
Agisoft Metashape	The texture map is UV-mapped correctly and uses the maximum amount of space within the map. As for the visual fidelity of the texture, the icons, logos, and text are sharper and more accurate than other texture maps.	Map size 4096 401.8156	2.164,484 triangles	$ 3.499 One time purchase
Meshroom	The texture maps generated by Meshroom are far from perfect. Meshroom provides enough space between UV but creates too many seams, empty spots within the texture map, and insufficient texture padding to avoid texture bleeding.	Map size 4096 271.1104	2.379,649 triangles	Free

Overall, the difference in render time between Zephyr, Reality capture, and Metashape is minuscule, and Meshroom's render time is the longest and would not be the most time-efficient program. The results of the processing time can be found in chart 1.

Chart 1 Processing time chart comparison



4.1.5 Conclusion

Zephyr 3DF is the fastest in generating the texture and model. However, Zephyr 3DF has the lowest number of polygons generated from the datasets but is visually similar to the higher poly models, as seen in figure 7. That means fewer resources and time are needed for Zephyr 3DF to produce comparable quality to its competitors, which makes it an overall better choice for photogrammetry.

Figure 7 Photogrammetry render comparison

However, when the goal is to render the utmost visual quality regarding models, Reality Capture is the best choice. If the goal is to generate the best texture maps, Agisoft Metashape is the best choice, with the second choice being Zephyr 3DF and Reality Capture as good alternatives. However, Zephyr 3DF is the best all-around program for photogrammetry because it delivers good results in all parameters with fewer resources. An overview of the strong points of each program can be found in table 3.

Table 3 Best photogrammetry program

1. Reality capture	Best application for the highest graphical fidelity model wise
2. Zephyr 3DF	Best overall application for general use
3. Agisoft Metashape	Best application for texture generation
4. Meshroom	Worst application out of all four applications

4.2 What setup best improves photogrammetry's visual quality or efficiency?

4.2.1 Research methodology

To answer sub-question 2, secondary research was done to understand what principles are required to make good photogrammetry scans before defining what setup and equipment can be used to improve the efficiency or the visual quality of photogrammetry assets. Additionally, it was important to understand which factors influence the results of photogrammetry scans and how others have tried to resolve these issues. These points were crucial to understanding what aspects of the setup and equipment need to be tested and compared. Furthermore, the definition of "the best setup" for photogrammetry might differ depending on the situation and what type of object is being photographed. Therefore this research is important to get a general idea of what equipment and setup should be tested and integrated into the workflow document to create efficiency or visual improvements for photogrammetry.

Research was conducted by doing desk research on principles for photogrammetry, factors that determine the quality of photogrammetry, equipment used for photogrammetry, and setups used for photogrammetry. The research was gathered by studying professional photogrammetry workflow videos, papers, articles, and interviews with Planet X. The information gained during research was used to create a testing methodology to answer sub-question 2.

4.2.2 Research results

4.2.2.1 Principles for creating good photogrammetry assets

According to Johnson (2021) , creating photogrammetry ideally includes

- No changes influence the stationary object. That means the object must stay consistent between shots when photographing the object. Changes resulting from movement, light, shadows, weather, or deformations inside the object cause inconsistencies that lead to a high chance of faulty scans because it makes it harder for photogrammetry programs to compare the object between images.
- Many angles of the object must be photographed to generate a complete scan.
- The object is illuminated even, which means the light is dull with no shadows or highlights around the object, so no light data is baked into the texture maps.
- A device that can capture crisp unblurry photographs to generate 3D assets.

According to Johnson (2021) it is important to photograph enough unblurry crisp photos with a large depth of field of the object with a static background meaning no changes are brought into the object or environment to keep consistency.

4.2.2.2 Factors that influence the quality of photogrammetry

As mentioned in section 4.2.2.1, certain factors influence the quality of a photogrammetry scan. These factors can be divided into consistency, light, overlap, and dataset

Consistency is key in all aspects of photogrammetry because consistency is directly tied to the quality of the photogrammetry assets. That is because photogrammetry programs produce assets by comparing photographs with each other to create an alignment and extract visual data to generate a 3D model and textures. Suppose this process is inconsistent because the lack of alignment caused by inconsistencies externally or internally will result in a lower-quality scan because fewer photographs are aligned, causing a smaller number of data that can be extracted (Clancy, 2020).

Lighting around the object is important to create a successful photogrammetry scan. The object must be perfectly illuminated with no shadows, colours, or intensity changes to bake an albedo map

with no light data*(a texture with no light information)*. This albedo map with no light data is needed to realistically project light on the object in 3D (Marqués, 2016).

Overlap is the amount by which one photograph includes the area covered by another photograph and is expressed as a percentage. This overlap is important for establishing a link between photographs and is crucial for the alignment process in photogrammetry because the overlap dictates how many photographs can be used to extract visual data from (Clancy, 2020).

Dataset refers to the number of photographs taken of the object. A larger number of photographs gives more leniency for failure. A larger dataset can either increase the amount of data extracted or provide a higher success rate for alignment in case some photos fail to align.

These factors influence the quality of photogrammetry scans by having programs or equipment that aid these factors improve the visual quality or efficiency of photogrammetry workflows.

4.2.2.3 Equipment used for photogrammetry

For professional photogrammetry, it is common to DSLR or mirrorless cameras. As for all other equipment, it varies between people. Research into workflows from multiple artists who use photogrammetry, such as Grzegorz Baran, Dylan Gorman, Gleb Alexandrov, Steve Lund(CG geek), and Clinton Jones(Ex-Corridor Digital) shows different methods and equipment used for photogrammetry. But, because Grzegorz Baran (Baran, 2019) has the most experience in photogrammetry and is a specialist, his video on photogrammetry equipment was used to choose the equipment. Grzegorz recommends a wide array of equipment for multiple types of photogrammetry scenarios. However, for this project's scope, a generally good choice for equipment based on the advice in Grzegorz's video would be a DLSR camera, polarization filter, tripod, colour checker, and a prime lens. Justin and Amber Johnson (Johnson, 2021) also recommend similar equipment for photogrammetry.

- DLSR camera: The DSLR camera captures a higher-resolution picture so more visual data can be extracted later in photogrammetry programs.
- Polarization filter: This filter can be placed on top of the camera lens to partially or fully remove the light and reflection of the subject matter.
- Prime lens: Is a lens with a fixed focal length. A prime lens has the best optical quality and creates a shallower depth of field in its images and footage, which is ideal for photogrammetry because a lower depth of field creates a sharper picture.
- Colour checker: A colour checker is a tool that can be placed in the scene when photographing to capture accurate colour information that can be used in post-production to create a colour profile to adjust the photographs to be colour accurate.
- Tripod: A tripod is a three-legged stand designed to support a camera. A tripod is used to stabilize the camera to help with capturing pictures without blur.

4.2.2.4 Setups used for photogrammetry

From desk research and after consulting with Planet X, it was determined that setups for photogrammetry could be divided into two categories for photogrammetry. The indoor studio setup used for small-scale objects results in great results seen in Grezgorz's tutorial (2021) on photogrammetry setup for indoors. And an outdoor setup for larger-scale or immoveable objects, as seen in the photogrammetry course of Gleb Alexandrov (Alexandrov, 2021). Other setups from 3D artists such as Clint Jones, Steve Lund, and Dylan Gorman follow a similar setup.

Although the definition of the best setup for photogrammetry highly depends on the user's subject matter and available tools, A few observations were made by analyzing the setups of multiple photogrammetry users, such as Gleb and Baran. Based on what is analyzed, a few principles were observed for identifying the best setup in certain scenarios.

- Large objects / immovable objects are typically photographed outdoors due to space, and small objects are shot indoors.
- If the user has space and funds to afford lights, then shooting indoors is ideal.
- Equipment used for photogrammetry needs to help the camera produce perfect-quality pictures for photogrammetry (perfect quality means high-quality unblurry photographs with no unevenness in the picture from factors such as light and movement).
- A DLSR/system camera system is used for professional quality photogrammetry scans, although other mobile cameras can be used if the user cannot afford a DLSR/system camera.

4.2.3 Testing methodology

Based on the previous research on equipment and setups, a testing methodology for sub-question 2 was created to determine if the equipment and tools are worth adding to a photogrammetry workflow.

This testing phase was conducted by testing the two setups and equipment examined in the research: A turntable setup where the camera is stationary and a handheld setup where the camera is moving.

The equipment used for the test was: a DSLR camera, polarization filter, prime lens, colour checker, tripod, and numerous other household tools.

These setups and equipment were tested on their alignment results, pros and cons, and the researcher's user experience. The setups were then expanded upon by creating iterations by changing/adding the equipment to improve the setups. The results are then compared to determine the best setup for photogrammetry and integrated into the workflow document and videos to give and advise the company.

4.2.4 Testing results

4.2.4.1 Turntable method

The researcher created a turntable with two serving plates used as a makeshift turntable, with 18 pictures taken while rotating the plates for 20 degrees at a time, as seen in figure 8.

Figure 8 Photogrammetry setup turntable

Testing equipment and environment

The camera used for this setup was the iPad Pro 2020, and the pictures were taken outside during peak sunlight hours with a roof screen diffusing the sunlight. The pictures were shot on the standard photo app delivered with the device with camera settings set to the default settings. Due to the restrictive nature of Apple software, certain fine-tuning parameters in the camera app were not accessible. However, there are workarounds with third-party apps, but the downside is that the app will not utilize 100% of the device's capability due to security restrictions.

Alignment results

3DF Zephyr correctly aligns 18 of the 18 images during the alignment process. However, the program confused the shadows with holes in the background because of the shadows in the crinkles. This issue could be resolved by having a darker environment or adding additional light sources to remove the shadows. Furthermore, due to the DIY nature of the spinning table, the object's placement was not 100% accurate, causing some camera angles in the program to slightly misalign.

User experience

The turntable setup was easy and fast because the camera stayed inert, allowing flexibility with camera settings only requiring the user to move the turntable slightly. The shooting process was straightforward. However, capturing the asset's top and bottom by rotating the object was troublesome. However, this is highly discouraged as it might misalign the object. Another possible solution would be moving the camera around those sides afterward, but this process is tedious and time-consuming.

Pros	Cons
Inexpensive setup	It does not capture the bottom and top sides practically
Consistent lighting conditions due to the rotating turntable	It would not work well with larger objects
Ideal camera settings	Requires a light source if not shot outside
Less physical activity/movement required	Limited time during the day to shoot

4.2.4.2 Turntable setup-controlled environment method

The second iteration of the turntable setup is an alteration of the first one. Instead of shooting a turntable setup outdoors with natural light, the turntable is moved indoors with additional tools such as a ring light and one softbox to create a more evenly lit light condition. Furthermore, a black backdrop was added to mask the background, and a turntable to rotate the object evenly. However, this came with higher financial costs compared to the initial setup. Table 4 is an overview of the equipment bought.

Table 4 Purchased equipment

Item	Usage
JBZ -Ring lamp met Statief https://bit.ly/35lORFH	The leading light will be used for most of the shots.
Donza - Achtergrond systeem ophanging https://bit.ly/3vD9OpZ	The backdrop masks the lighting and reflections
Repusel Draaiplateau Klein https://bit.ly/3IJJePN	The spin table is used to spin the object.
Studiolamp - 1 x Fotolamp - Fotografie - Softbox https://bit.ly/3CbwG1a	Secondary light with a diffuser can get more lighting if one light is insufficient.

With these tools, a small studio was created in one of the spare rooms in the researcher's house. Other cheaper alternatives for the backdrop were tested out and compared to the more expensive backdrop to compare the effectiveness of the costly backdrop.

Testing equipment/environment

The camera used for this setup was a Samsung fold 2, and the pictures were shot with the following camera settings: image format JPEG, ISO-500, F-stop 3,5, exposure time 1/80 seconds. The ring light was placed in the front of the object in combination with the softbox on the left side, and on the opposite side, a reflector reflected some of the light created from the softbox to light the left and right sides of the asset evenly. The camera was placed in front of the object with a tripod, and the process used in the prior setup was repeated.

Alignment results

During the first few attempts, all results ended up in failure. The program would either fail to align the data or misalign the location and rotation of the cameras. After numerous attempts to solve the issue, it turned out that the problem was that the program could not find enough data in the background to compare the alignment between pictures., as seen in figure 8. After trying multiple backdrops ranging from a black shirt, band-aid, and patterned bedcover to add more data to the background, it still failed. After numerous attempts, it turned out that using a printed noise texture, such as Perlin noise under the object, fixes the issue of not having all images recognized. Perlin noise worked well because of the texture's complexity, which made comparing points between images easier for the program. Out of the 37 pictures taken, 37 were aligned correctly after including the Perlin noise, as seen in figure 8.

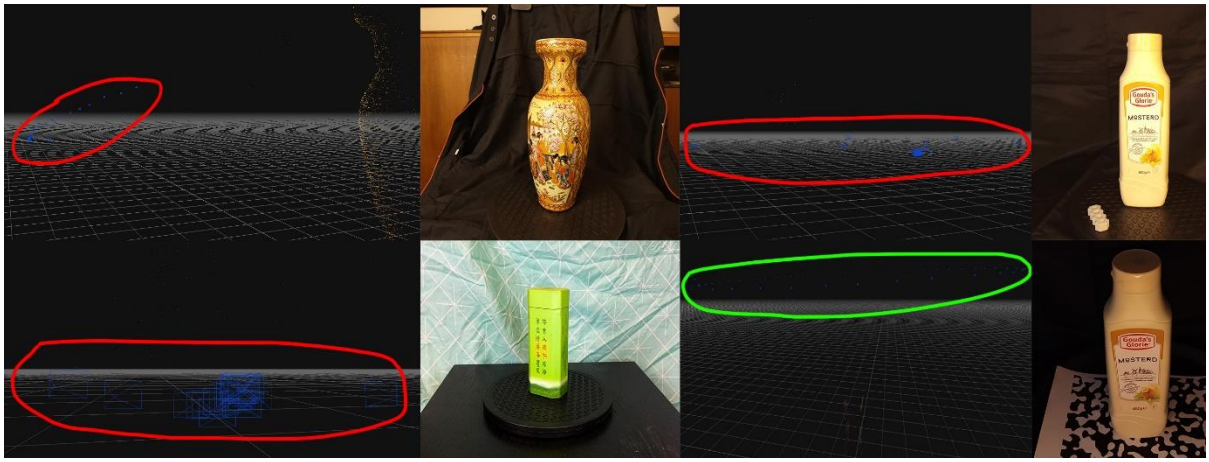


Figure 9 Turntable second attempt

User experience

The experience was almost identical to the prior setup but was slightly different due to the added tools for this setup. This method suffers from the same issues as the outdoors turntable setup but yields better visual results concerning the alignment and texture/model generation. One problem with indoor shooting is that it requires space. As seen in figure 9, an area of 4x4 meters was used for this test, which in the researcher's experience, was not enough to shoot practically.

Pros	**Cons**
Good camera alignment	Expensive setup
A perfect light condition that causes no shadows/visual artifacts in the generated asset	It would not work well with larger objects
Tripod allows for flexibility with camera settings	A decent amount of space is required to shoot practically

4.2.4.3 Turntable setup-controlled environment + DSLR camera method

The third iteration is identical to the one prior, except for the upgraded camera. The Canon EOS 250D was chosen for this setup because, at the time, the Canon EOS 250D was the best camera that Saxion could offer. For later scans, the researcher purchased a Cannon 90D due to the limited time the researcher was allowed to use Saxion's cameras.

Testing equipment and environment

The camera used for this setup was a Canon EOS 250D with a 50mm prime lens from Canon, and the pictures were shot with the following camera settings: image format RAW, ISO-100, F-stop 1,8, exposure time 1/60 seconds, and focal length 70mm. The picture quality of the new Canon camera was tested by photographing a glue bottle and compared, as seen in figure 10.

Figure 10 Canon EOS 250D / Samsung fold 2 camera comparison

Alignment results

3DF Zephyr correctly aligned 65 of the 65 images during the alignment, and due to the higher volume of details captured from the Canon EOS 250D, the rotation and location alignment of the cameras are better compared to Samsung Fold 2. Moreover, the number of points created is significantly more than in the previous iteration, leading to better visual quality during the texture generation process.

User experience

The user experience is identical to the previous setup.

Pros	Cons
An incredible amount of detail	Expensive
Better masking	It would not work well with larger objects
A perfect light condition that causes no shadows/visual artifacts in the generated asset	A decent amount of space is required to shoot practically
Tripod allows for flexibility with camera settings	

4.2.4.4 Handheld method outdoors

The researcher created a setup outdoors to shoot handheld using a table to hold the object, and then pictures are taken by moving around the object from multiple angles.

Testing equipment/environment

The camera used for this setup was a Samsung fold 2. The pictures were shot with the following camera settings: image format JPEG, ISO-200, F-stop 3,5, exposure time 1/80 seconds. The shooting location is in the backyard with a white table to raise the asset to a higher vocal point, as seen in figure 11.

Figure 11 Handheld shooting outdoors method

Alignment Results

3DF Zephyr correctly aligned 47 of the 54 images during the alignment process. Seven images failed to align due to the lack of visual pointers and overlap between images, making it complicated for the program to identify the position and rotation between images correctly.

The accuracy of the alignment is close to perfect, with some slight misalignments due to matching colours between the asset and an item in the background, but this can be fixed by adjusting the shooting angle or removing the item from the environment.

User experience

Shooting handheld feels like the simplest form of photogrammetry yet. It was a straightforward process and allowed for flexibility when shooting from certain angles around the asset. However, it gets physically tiring from constantly moving around and shifting from crouching to tiptoeing to capture all angles of the object.

Pros	Cons
Good/decent camera alignment	Unstable environment depending on light/weather conditions
Inexpensive	Physically tiresome
Flexible angles	Not optimal picture quality settings due to shooting handheld

4.2.4.5 Handheld indoors method

Shooting handheld indoors is comparable to shooting outdoors with the negatives of lighting/weather conditions fixed. In all aspects, shooting handheld indoors is superior to shooting outdoors due to the controlled environment and light sources. However, it requires a decent amount of space to photograph the object proficiently.

Testing equipment/environment

The camera used for this setup was a Samsung fold 2. The pictures were shot with the following camera settings: image format JPEG, ISO-1000, F-stop 2,5, exposure time 1/80 seconds. The shooting location is inside the researcher's restaurant, with lights coming from multiple spotlights from the ceiling and four spotlights on the right side of the asset. The platform is a 1x1 meter table with A3 Paper, as seen in figure 12.

Figure 12 Handheld shooting indoors method

Alignment

3DF Zephyr correctly aligned 50 of the 52 images during the alignment process. The alignment process is nearly flawless, with some minor position misalignments. Additionally, photo editing software could correct some minor image artifacts in the object for better alignment.

Experience

The shooting process is identical to shooting outdoors, and the physical aspect of shooting handheld still applies. However, shooting indoors in a controlled environment improves the asset's accuracy in colour and alignment. Furthermore, it is less prone to displacement from wind or movement from any other external forces.

Pros	Cons
Great alignment	Requires a decent amount of space indoors
A perfect light condition that causes no shadows/visual artifacts in the generated asset	Physically tiresome
Unaffected by conditions from shooting outdoors	Not optimal picture quality settings due to shooting handheld
Flexible angles	

4.2.4.6 Handheld method indoors + trackers

Rene from Planet X recommended adding trackers to the setup to align and accurately capture the object's scale. This method works by printing multiple trackers with unique symbols and placing them around the object to capture as many of the trackers visible while photographing the object. These trackers help the program identify the location, rotation, and scale between images, leading to better-quality scans.

Testing equipment/environment

The camera used for this setup was a Canon 90D with a 50mm prime lens from Canon. The pictures were shot with camera settings: image format RAW, ISO-200, F-stop 3,5, exposure time 1/80 seconds, and focal length 70mm. The object is shot indoors on a 1x1 meter table with natural light from the back and spotlights lighting the other parts of the model. As for the trackers, the textures are from Zephyr 3DF printed on paper and stuck on beer tap coasters, as seen in figure 13.

Figure 13 - DIY trackers

Alignment results

3DF Zephyr correctly aligned 94 of the 94 images. Inspecting the alignment, textures, and model, no faults or misaligned textures can be found. However, some small colours offset can be noticed in the textures, but this was caused by the natural light coming from the window in the scene.

User experience

In all aspects, the procedure is similar to the previous tests with shooting handheld, with the added distinction being that trackers are placed evenly in a circular shape around the object. The trackers are numbered from 1 to 10. It was important to place the pattern around the object correctly, starting from 1 and ending at 10. Aside from those requirements, the experience shooting was smooth, with no major differences worth mentioning. The setup with trackers can be seen in figure 14.

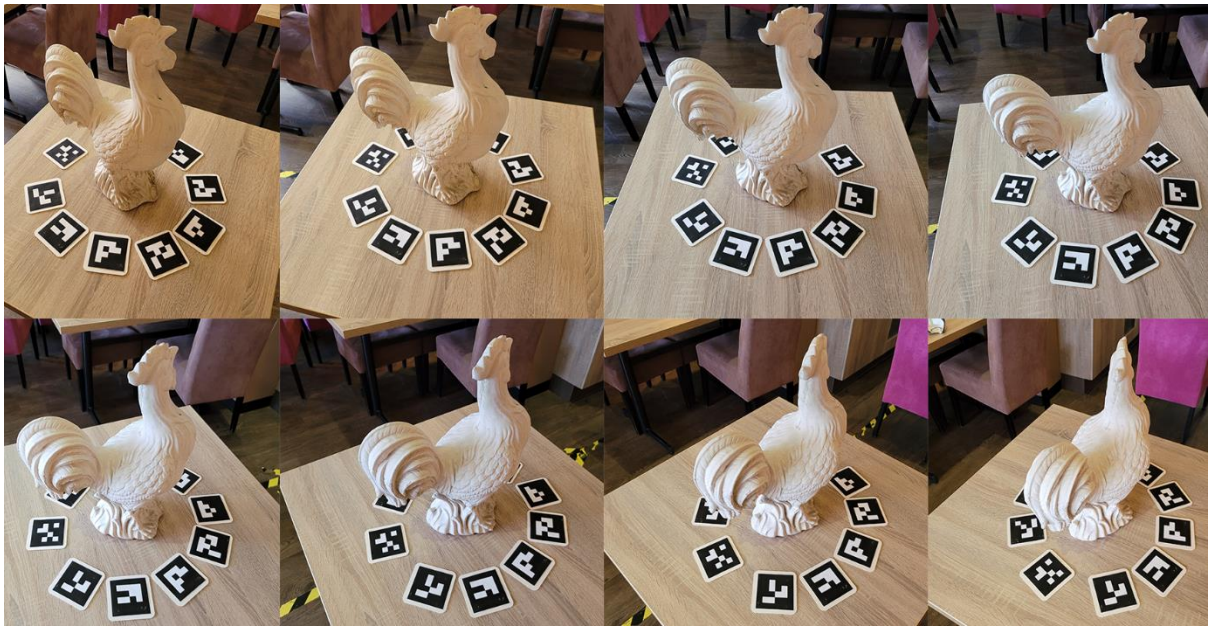


Figure 14 Shooting process with trackers

Pros	Cons
Great alignment	Requires more trackers depending on the size of the asset
Correct scale	Impossible to use with large assets such as buildings

4.2.5 Testing conclusion

Table 5 is an overview of the setups used with a short description of their usage and results.

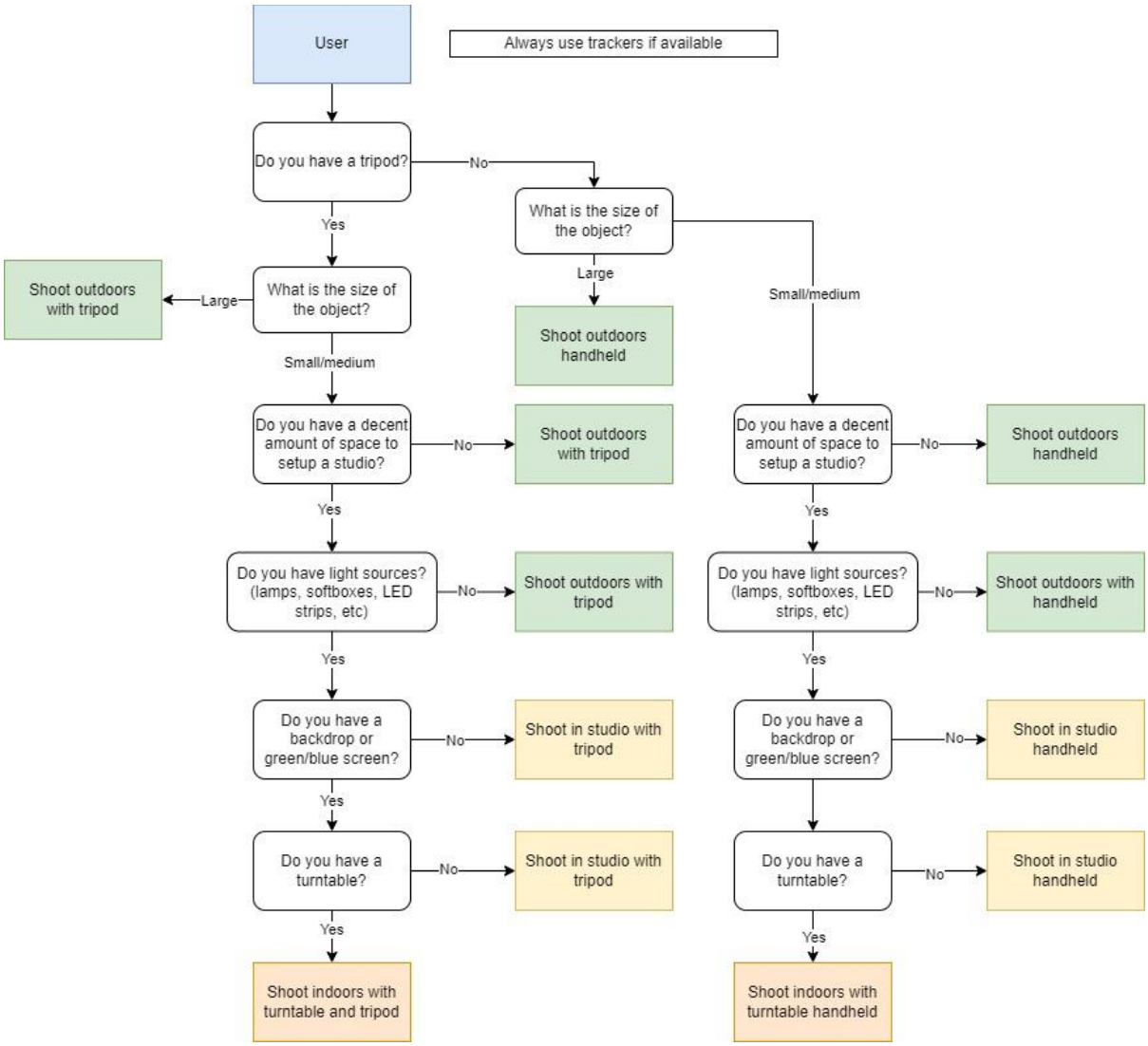
Table 5 Sub question 2 results

Setup	Results
5.1.4.1 Turntable method	The setup is great for users with fewer resources and is more suited for small to medium-sized assets. It creates decent results with little investment but is far from perfect when working with assets with more intricate shapes.
5.1.4.2 Turntable setup-controlled environment method	The setup is the best for shooting small to medium assets because the environments create ideal conditions for shooting good-quality photographs. It should be used if the user can afford it. This method avoids shadows/highlights and gives even lights that lead to flexibility to adjust camera settings due to the camera being non-moving.
5.1.4.3 Turntable setup-controlled environment + DSLR camera method	The setup results are identical to 5.1.4.2 but shooting with a DSLR camera yields superior visual results.
5.1.4.4 Handheld method outdoors	The setup is a great method when capturing medium to large assets. It is recommended to use a handheld method when trying to shoot assets that cannot be easily captured indoors, such as buildings, rocks, statues, and vehicles. Additionally, it is a great method for shooting objects quickly as it requires no preparation to start shooting but relies on the lighting/weather conditions during that time.
5.1.4.5 Handheld indoors method	The setup trumps shooting outdoors in all parts. If planned to shoot handheld, it is recommended to shoot indoors as it removes all the consequences of shooting outdoors, but this might not always be possible due to the amount of space required to photograph or the size of the asset. A good general rule of thumb is if the object fits indoors with enough space to photograph all angles, then shoot indoors.
5.1.4.6 Handheld method indoors + trackers	Shooting with trackers is recommended as it drastically improves the success rate for alignment, and the model is correctly scaled by comparing the size of the trackers with the asset. If possible, trackers should always be used.

In comparing all results, it cannot be concluded which setup is best for photogrammetry. All tests have positives and negatives. The best choice depends on the financial and environmental circumstances of the user. However, shooting handheld outdoors/indoors is generally recommended for low-resource users, and shooting indoors in a studio with a tripod is recommended for the opposite.

To better exemplify what method should be used depending on the user's circumstances, A flowchart created by the researcher based on the test findings can be seen in chart 2 and can be used to see which setup best suits the user.

Chart 2 Photogrammetry setup flowchart



Other factors can influence what method is better suited for the user, but for a general overview, the flowchart above will apply to most scenarios. Additionally, the user should always use trackers when possible to create a better alignment of pictures in post-production.

4.3 What program can be used to improve photogrammetry assets visually?

4.3.1 Research methodology

To answer sub-question 3, secondary research has been done to find methods to improve photogrammetry assets further. This research was conducted by doing desk research into the workflows of photogrammetry professionals and by looking into new technologies through conversations with Planet X.

4.3.2 Research results

4.3.2.1 Existing programs that improve photographs

Research into photogrammetry workflows shows that before and after the generation of photogrammetry, multiple programs are utilized to enhance the input and output of photogrammetry.

Photo editing programs

A common method to enhance the quality of photogrammetry seen in multiple workflows is using photo editing software to enhance colours, remove blur, sharpen images, reduce shadows, and more. This process is done to improve the visual quality of the texture map and help with the alignment process by removing or reducing unwanted parts inside the photograph, which can be observed in the workflow of William Faucher (Faucher, 2021).

William Faucher's (2021) photogrammetry workflow was studied to determine what photo editing software is best used for photogrammetry. In William's photogrammetry workflow, he uses Adobe lightroom to process photos but recommends alternatives such as Photoshop, Capture One, and Affinity Photo. Furthermore, William references Clint Jones workflow on photogrammetry as another good source of information which also uses Adobe lightroom as its choice for photo editing software.

Colour profiles

During the research on equipment, a colour-checker was recommended by Planet X as a tool that can visually improve the quality of photogrammetry scans. This visual improvement is achieved by taking photographs with a colour-checker, in which then a colour profile is created in a program as a preset that can be applied to pictures for colour-accurate colours (Alexandrov, 2021). The colour profile applied in the photographs leads to higher-quality texture maps because the colours will be more accurate to what is seen in real life.

Delight technology

To combat the issue mentioned in 4.2.2.2 of light data being baked in the texture map, research was conducted on possibilities to fix this issue without using the equipment but instead focusing on what users can use after the generation of the textures and models. This research found delighting technology, specifically Agisoft De-lighter, a tool recommended by professionals such as Ludovico Antonicelli (2017) for removing light data from textures. Agisoft de-lighter is a tool that removes cast shadows and ambient occlusion from 3D models by taking user input in the form of rough brush strokes marking lit and shadowed areas, and delighting those areas. The result is a texture map with no light data that can be used for production. A texture map without light data is superior because having existing light data in the texture map causes light from other sources to not accurately project light on the model (Agisoft, n.d.).

AI enhancement programs
Further research on programs that enhance photographs resulted in the discovery of AI technology that can upscale, denoise, and sharpen images by using artificial intelligence to interpret shapes and objects in images to re-render the images with better visual quality (Google Research Brain Team, 2021). By diving deeper into AI technology that improves images visually, it was found that all commercialized AI image enhancement programs utilize datasets from numerous databases such as Set5, Set14, BSD100, and Urban100 (Paper with code, n.d.). These databases were used to create countless commercialized AI photo enhancers available.

Based on the list of best AI photo editor software from Joe Taylor (Taylor, n.d.) all AI programs are subscription-based, one-time purchases, or pay-per-edit. However, only one-time purchased programs are viable for this project's scope.

Cross-referencing lists and recommendations on AI image enhancers from Joey Taylor (Taylor, n.d.), Rosa Salia (Salia, 2021), and Anabel DFlux (DFlux, 2022) it was observed that Topaz labs is recommended as one of the best programs for AI enhancement if not the best.

4.3.2.2 Existing programs that improve models
In interviews with Planet X (PlanetX, 2022) is established that there is no real way to optimize the models to be more efficient aside from reducing the number of polygons. However, reducing the number of polygons removes data from the model, which in theory, means losing visual quality. Planet X has expressed that optimizing the models is an impossible task without reducing the number of polygons thus recommended that the researcher instead includes standard 3D mesh optimization methods as an optional choice in the workflow document.

4.3.3 Testing methodology
Desk research was conducted to gather insight into which programs could improve the visual quality of photogrammetry assets by analyzing the workflows of professionals and researching new technologies by following news in the creative sector.

Primary research was conducted to test if the programs found during the desk research improve photogrammetry assets visually and are worth adding to the photogrammetry workflow document/videos.

The test was conducted using the programs and comparing the result to the original to determine if the program has further visually improved the photogrammetry asset.

4.3.4 Testing results

Based on the research in the research methodology section of sub-question 3, several programs were found and chosen to test if the programs can be integrated into a photogrammetry workflow to improve the quality of photogrammetry assets further visually. Below the results of the test are presented.

4.3.4.1 Photo editing programs

The photographs were edited in Lightroom with basic noise reduction and sharpening. As seen in figure 15. It can be observed that the edited version of the picture has more detail compared to the original.

Figure 15 Photo editing program results

The original and edited photographs are aligned in Zephyr 3DF, and both datasets successfully aligned 65 of the 65 images.

Figure 16 Photo editing program results zoom in

After the alignment, the model and texture were generated, and it can be seen that the edited photographs resulted in a superior scan, as seen in figure 16. The edited version has more readable text and better-defined symbols and details.

Conclusion

Photo editing program does influence the quality of scan of photogrammetry. The program aids with reducing noise and sharpening details within the model/texture. Using photo editing programs does not change or affect the alignment process, so photo editing should always be utilized as it has no downsides when used reasonably.

4.3.2.2 Colour profiles

A few datasets were altered with colour-profile and compared. It can be observed that the colour profile slightly changes the colours to be more accurate to what was observed in real life.

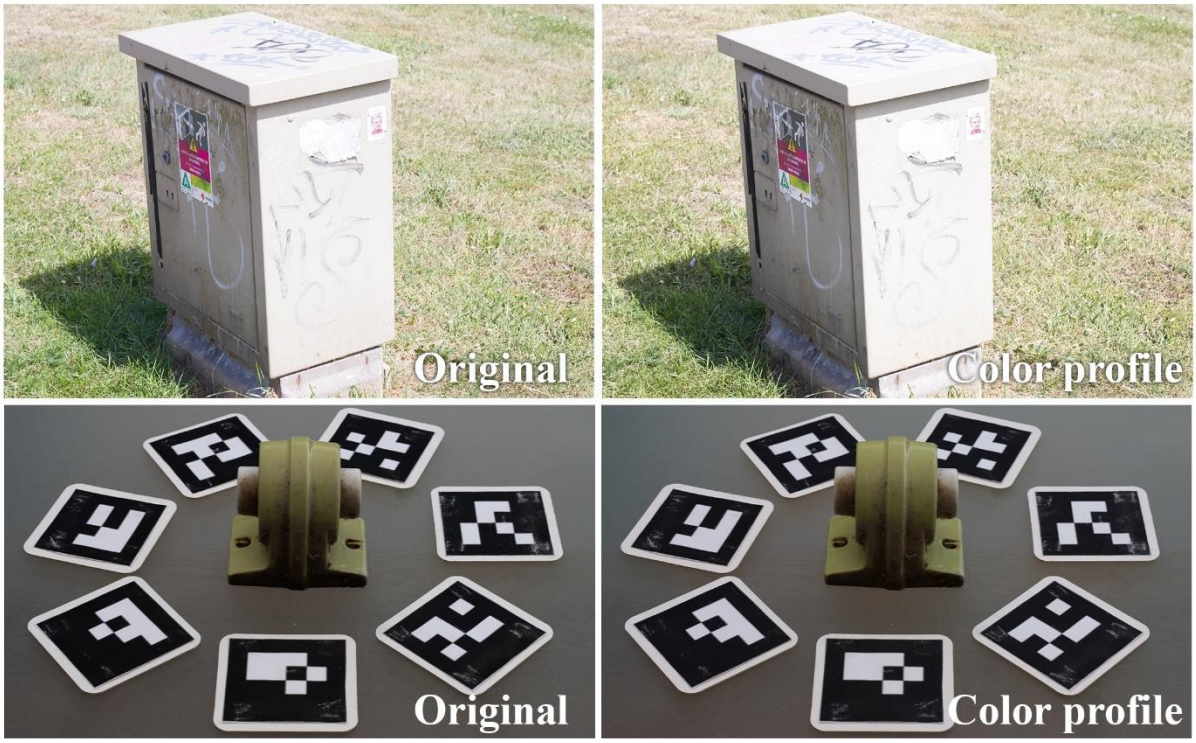


Figure 17 Colour profile results

Although hardly noticeable, it results in better colour accuracy, as seen in figure 17.

4.3.4.3 AI technology

Upscale technology is a technology that enhances pictures or videos with AI. This technology can be used to denoise, sharpen or upscale the input, meaning that a low-quality image can be improved into a high-quality picture. Texture maps generated from the user's photogrammetry software can be further enhanced by utilizing upscale technology. This technology is especially handy when sharpening symbols, icons, and text. The researcher chose to use Topaz labs for this process as Topaz is a one-time purchase recommended by the research results (Topaz Labs, n.d.).

Three tests were conducted to test out the AI technology. Topaz AI was used with the recommended settings set by the AI. The 3D generation was done in Zephyr 3DF with default settings, and the image output was set to 7680x7680 for all three tests.

Test one upscaled images

For the first test, all images in the dataset were upscaled before the alignment and then aligned with Zephyr 3DF. This caused the program to not correctly position the cameras, as shown in figure 18, which was no issue before the upscaling.

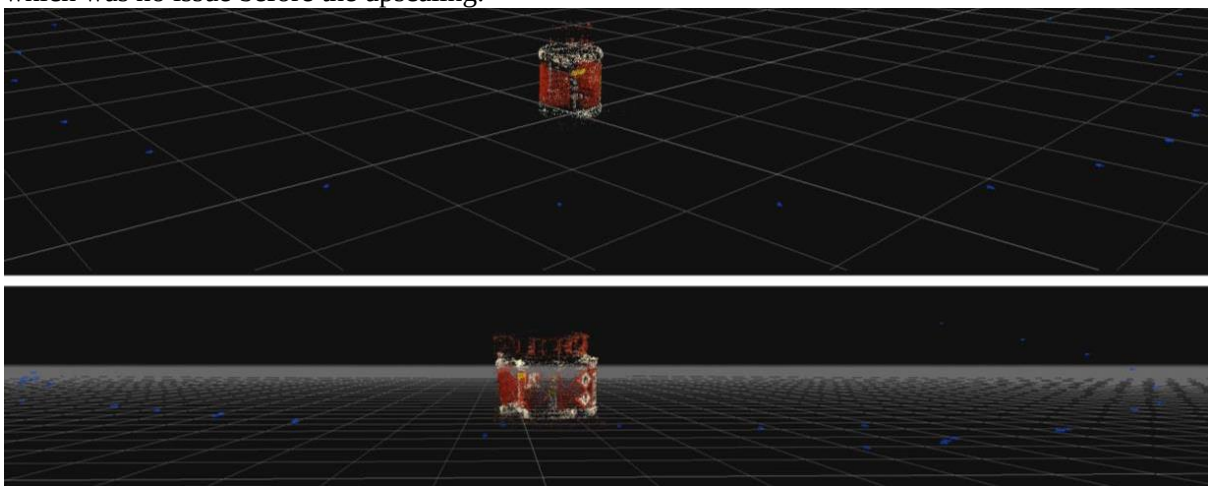


Figure 18 - AI test alignment

The failed camera position is due to the visual artifacts created by upscale AI. That is because photogrammetry programs analyze the background for positional data and compare that to other images. Furthermore, the AI adjusts each image differently, causing inconsistencies between images and ultimately failing the alignment process. After some adjustments to only sharpen the model's textures, a successful scan was made, as seen in figure 19.

Figure 19 AI test one sharpen comparison

A noticeable difference can be seen between the pictures, especially in the visibility of the text in figure 19. However, the upscaled model has a few artifacts due to the sharpening effect. This issue could be solved by manually correcting them, but it would not be ideal workflow-wise.

Test two upscaled texture map
Only the generated textured maps for the second test will be upscaled for the second test shown in figure 20.

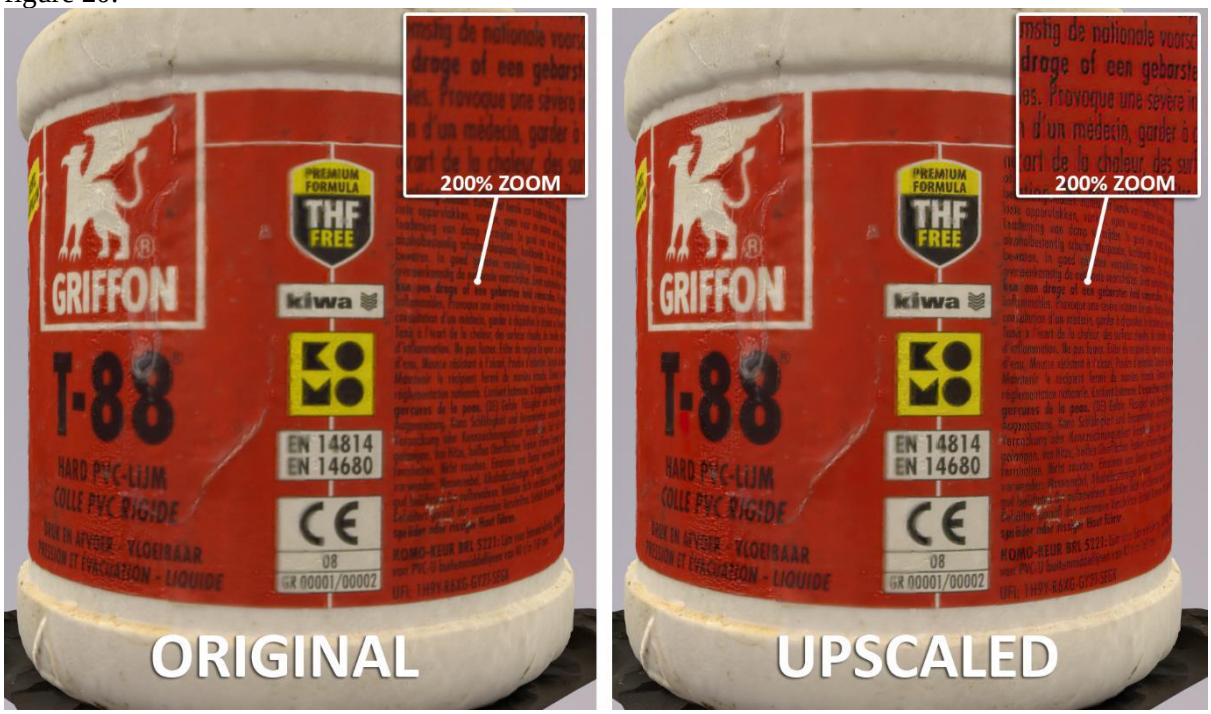


Figure 20 - AI test two comparison

When upscaling the albedo texture map, less noise/grain is created while enhancing the text, logos, and icons. Nevertheless, some small artifacts still require manual input to fix.

Test three upscaled images + texture map
The source images and generated texture maps were upscaled for the third test, as seen in figure 21.

Figure 21 - AI test three comparison

The third test does not seem to visually improve the texture map aside from adding more noise and grain to the asset. Therefore, it can be concluded that using upscale technology on the whole dataset is not recommended as it only degrades the visual quality of the texture map.

Conclusion

Upscale technology improves the texture's visual fidelity, but only when used with limited amounts. As seen in test three, overusing the technology causes noise and artifacts. The best method to utilize AI technology is after the texture generation. It is more time-efficient, avoids miscalculating the camera position/rotation during the alignment process, and avoids additional noise/grain.

4.3.4.4 Delight technology

The researcher used the built-in de-lighter from Metashape to remove most of the over/under-lit areas to start the delighting process, as shown in figure 22.

Figure 22 - Built-in Delight Metashape

After cleaning much of the lighting issues using the built-in tools from Metashape, Delight is then used to paint over the troublesome spots in the texture map and then proceed to re-export the texture map with the changes shown in figure 23.

Figure 23 - Agisoft Delighter

From a rendered perspective in figure 24, the difference is more noticeable. As shown below, the left rooster shows the model is the original, and the right is the adjusted version using Metashape and Delight to remove highlights and shadows.

Figure 24 - Before and after delighting

Delight Conclusion
Although Metashape and Delight did a fine job removing shadows and highlighting, it is not perfect. There are flaws in this process, primarily that using Metashape's built-in de-lighter can cause image artifacts inside the texture, such as blurring details, noisy artifacts, and uneven colouring. Moreover, when combined with the standalone Delight application, it can cause even more image imperfections, resulting in a worse result than the original problem. Therefore, the delighting aspect should only be used lightly or as a last resort. Suppose the scanned object has a faulty texture map due to shadows and highlights, then Delight software should be used to polish it. However, it is always better to fix the lighting issues with lights instead of programs, but this offers some leniency when working with fewer resources.

4.3.5 Testing conclusion

The new programs and technologies found during the research phase were tested to be useful for photogrammetry. All programs and technologies should be integrated into a photogrammetry workflow if the user wants to achieve the utmost visual quality within photogrammetry assets.

4.4 Products testing

To answer the main question, a workflow document and videos were created to encompass the knowledge gained based on the research and results from the sub-questions. A draft version of the workflow document and videos was created to receive feedback on the clarity of the products to provide a good product before giving it to the company. This feedback was essential to improve the workflow document to be understandable for experienced and beginning photogrammetry users.

4.4.1 Product test methodology

The draft workflow documents and videos on photogrammetry were given to three individuals who varied in the knowledge of creative programs to follow and produce a photogrammetry asset. The three individuals were given the workflow document, videos, programs, and a dataset of pictures of a rooster statue. The testers were asked to follow the document and videos to produce a photogrammetry model with the tools. In addition, the testers were allowed to use the internet for aid to google certain terms used by 3D artists. Furthermore, the researcher is on a call with all testers overlooking their screens but is not allowed to interfere with the process, nor can the overseer communicate any information that might aid the tester. However, the researcher can ask questions during and after the test to understand what the tester thinks during certain parts of the process.

The goal of the test is to determine if the workflow document and videos are clear for new users and if they can follow along to create an end product that can be used for production. The test also provides the researcher feedback and input to improve the workflow document/video guides on its clarity and quality. Furthermore, additional feedback was received by attending multiple meetings with the company during the project.

4.4.2 Testers

The created draft workflow documents and video guides on photogrammetry were given to the following three induvial that vary in skill:

Ruben Beugelink: Ruben is a graduate of Rijn Ijssel with a bachelor's degree in AAV (audio, animation, visuals). He has limited experience with 3D mentioning that he only used Cinema4D for two weeks during a course at Rijn Ijssel. Ruben is very familiar with creative applications, heavily uses Premiere Pro and Photoshop for daily life, and does photography as a hobby.

Randal Vakkers: Randal is a network maintenance worker for a Russian company with a degree in international business. He has no experience regarding 3D but does understand certain aspects of game development due to his interest in games. Although Randal did not study for a creative degree, he regularly uses creative programs such as Premiere Pro, Photoshop, and after effects as a hobby.

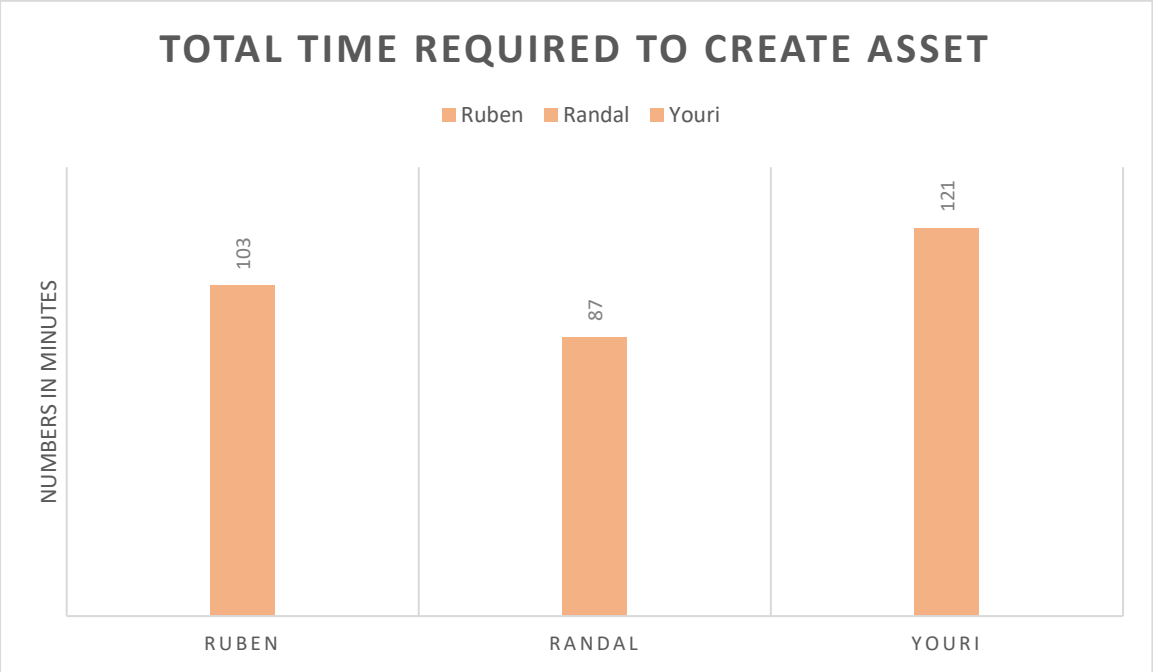
Youri van Mullem: Youri is a student at Hogeschool Maastricht studying politics. He has no experience with 3D and is not that familiar with technology in general. Youri has little experience with Premiere Pro due to certain school projects at Hogeschool Maastricht.

These individuals were chosen to test the workflow document/videos to gain insight into user needs and the product's clarity. Planet X employees were not chosen to do this test because of their existing knowledge of photogrammetry and 3D, which provides the tester with an unfair advantage.

4.4.3 Product test results

All three testers successfully created models and textures of the rooster. Although the rendered models and textures varied in quality, all were passable for production. All testers took around 1 to 2 hours to finish the asset render, as shown in chart 3. The time was calculated excluding render/processing time as the three individuals have different PC hardware, which colludes with the results.

Chart 3 Time required for testers to finish 3D asset



The testers communicated that the inclusion of pictures greatly helped during the process, but having additional pictures to guide the testers step by step would have been more helpful. During the tests, the testers solved this issue by looking at the videos to see exactly where and when they needed to perform a certain action.

Figure 25 shows the rendered results of the testers. The assets produced are useable for production. Ruben's render is considered the best of the three testers because Ruben had more experience with Adobe Lightroom and spent more time editing the pictures.

Figure 25 Testers render results

4.4.4 Testers feedback

After the testers concluded the test, the following feedback was given:

- The testers mentioned that although they could easily follow along during the photogrammetry process with the document and videos, they did not understand what each tool or action does and mentioned that it would be interesting to learn/understand what each step does.
- The testers recommended adding more voiceovers to the videos for clarity and immersion. They must switch back and forth from document to video to fully understand the workflow process.
- The testers find the inclusion of visual examples helpful and would like to see more of these examples within the product. The testers also noted that the workflow document should include more steps for navigation to make it easier to find and perform certain actions.
- The testers want the workflow document to include more pictures instead of written instructions, as visual guidance is more helpful to the readers.

4.4.5 Workflow comparison

One last test was conducted inside the same environment and parameters with the workflow document of Planet X, which also can be found in appendix II. Because Planet X uses expensive equipment inaccessible to the testers, the same dataset used for the researcher's test was provided. The result of this test is shown in figure 26.

Figure 26 Testers render results Planet X workflow document

- The testers noted that the early stages of the document follow a similar approach to the workflow document created by the researcher but lack steps making the overall process difficult to follow.
- The testers noted a lack of explanation of important features that help with polishing the 3D models, for example, masking.
- The testers mentioned that the lack of video guidance makes the overall process hard to understand. They prefer to have the workflow document in video format as it is easier to follow.
- The testers mentioned that there is a lack of additional tools to fix imperfections in the photogrammetry workflow document from Planet X.

It was observed that light is incorrectly displayed on the models created with Planet X workflow because the light data was baked in the textures and not cleaned up afterward.

The researcher's and Planet X's workflow in figures 25 and 26 were compared, and it can be seen that the researcher's workflow creates a better photogrammetry asset useable for production. Furthermore, the input and feedback of the testers determined that the researcher's workflow document offers solutions to problems for the tester and includes better guidance with more visual depictions and videos.

4.4.6 Conclusion

According to the testers, the researcher's document and videos are clearer to the testers compared to the workflow document from Planet X and produce better results for productions. All the feedback the testers provided was considered and included in the end product. The biggest need for the testers is more visual guidance for program navigation and more explanation of certain actions/tools. Testers prefer the researcher's workflow document and videos to Planet X's as it contains additional steps and information to create a higher quality product and has better visual guidance in the form of videos and more image depictions.

With the given feedback from the testers, the following changes were made to the products:

- Step-based instructions were added to the workflow document with images.
- More voiceovers were added / voiceovers were rewritten and re-recorded for better clarity
- Visual animations and explanations were added.
- Additional images and steps were included in the workflow document for better clarity and guidance.

The feedback and changes were applied to the product and then given to the company for approval and input. The company expressed satisfaction with the product and communicated that no further changes are required to the product. The final approved workflow document and videos can be found in appendix I and appendix II, respectively.

4.5 Conclusion & discussion

Overviewing the results from the conducted test, a variety of information regarding photogrammetry can be concluded. Based on the results of the research, the following can be concluded:

The best overall photogrammetry program to score is Zephyr 3DF. That is because Zephyr 3DF is inexpensive compared to competitors and delivers, on average better results in all tested categories. It can be argued that Reality Capture has marginally better visual results than Zephyr 3DF but is significantly more expensive than Zephyr 3DF, which is $149 compared to the $3750. It would be a better use of funds to invest the money that would have been spent on a license of Reality capture in equipment for photogrammetry.

The best overall setup for photogrammetry highly depends on the financial budget and priorities of the user. However, shooting handheld with trackers is observed to offer the overall best results for most scenarios. But investing in a photogrammetry studio is the best choice if the objective is to create the highest visual quality photogrammetry assets.

Additional programs such as photo editing programs, de-lighter technologies, colour profiles, and AI technology should be utilized in a photogrammetry workflow, as these programs visually improve the photogrammetry assets.

Planet X was satisfied and surprised as the final product exceeded their expectation. The researcher asked if any changes should be made to the products, but the company stated that the products were good and required no additional adjustments.

4.6 Recommendation

As the project concluded, recommendations were given to the company based on the findings of this research.

Planet X should consider switching to Zephyr 3DF for photogrammetry instead of Reality Capture. That is because Zephyr 3DF is cheaper compared to Reality Capture and offers a better user experience for the user with clearer UI/UX and features that aid with efficiency/visual improvement to the photogrammetry workflow. Furthermore, the visual output of Zephyr 3DF compared to Reality Capture is visually close to identical. Although if the company wants the utmost visual quality, Reality Capture is currently the best. But I'd recommend saving the funds that would have been spent on Reality Capture to buy Zephyr 3DF and invest the remaining funds in equipment and other programs to enhance the assets further visually.

Programs that further visually improve photogrammetry assets, such as Adobe Lightroom, colour profiles, Topaz studios, and Agisoft de-lighter should be included in Planet X's photogrammetry workflow to create higher visual photogrammetry assets.

If Planet X has the funds to create a photogrammetry studio, they should consider creating one. That way, the studio can provide a space for its employees to photograph objects for photogrammetry scans indoors when the conditions outside are not favourable for photogrammetry. Utilizing a studio setup for photogrammetry also creates the best environment for creating high-quality photogrammetry scans.

In April, Unreal Engine 5 was released. The release of UE5 comes with new technologies, such as nanites and lumens, that greatly benefit photogrammetry assets. The company should consider further researching UE5 for its production as it might help its future production with photogrammetry.

4.7 Reflection

What went well: The depth of the research conducted went well. I managed to answer all sub-questions and delivered a product that can be quoted as "exceeded the expectations of the company," thus a successful end to the project. And the knowledge obtained during these six months has greatly added value to me as a 3D artist.

Obstacles and challenges: I underestimated how difficult and time-consuming it is to create educational content. Writing scripts, proofreading, voiceover, audio clean-up, creating graphics, and editing is time-consuming. It also requires the host to communicate well, a skill I lack, making the overall process a more difficult experience. Furthermore, the bar was set too high, creating a stressful environment of overworking, which influenced my mental health.

Looking back at the research question and comparing it to Planet X workflow document, it would have been better to narrow the research question to focus on one part of the photogrammetry process. Attempting to cover the full process in only six months was an unreasonable goal that caused a lot of issues along the way.

Acquired knowledge: I have learned much about utilizing photogrammetry to produce realistic assets that can be used for film/TV and game projects. I believe I have increased my odds of breaking into either industry as a 3D artist. Especially during my last talk with the company and assessment of the company, I am confident in the acquired skill.

Reflection Methodology: During the early stages of the research methodology, a lot of knowledge was obtained from multiple sources, which led to various tools, equipment, and programs being used for testing. While these tests are helpful, it would have been better to focus on quality instead of quantity to give a deeper insight into truly important factors for photogrammetry.

The test conducted could have been more universally even. For example, during sub-question two, tests with setups were conducted, but the dataset captured varied in size between setups requiring some setups to be in unfavourable conditions, which might influence the ranking of setups.

In the tests for sub-question one, an older version of Reality capture was compared to other photogrammetry programs. This difference would affect the results. If the recent version of Reality capture was used, then perhaps the judgment for Reality capture could have been more favourable.

In the product test, the researcher interrupted the testers to ask questions about their experiences, but it would have been better for the tester and researcher to ask questions afterward as it was distracting for the testers to keep answering questions while focused on the tests.

References

2010s in film. (2022, June 25). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/2010s_in_film

3DF Zephyr. (2022, May 5). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/3DF_Zephyr

Agisoft. (n.d.). *Agisoft Texture De-Lighter - general workflow*. Retrieved from Agisoft helpdesk: https://agisoft.freshdesk.com/support/solutions/articles/31000158376-agisoft-texture-de-lighter-general-workflow#Export-%C2%A0

Alexandrov, G. (2021, December). *Photogrammetry Course: Photoreal 3d With Blender And Reality Capture*. Retrieved from Blender Market: https://blendermarket.com/products/photogrammetry-course

AliceVision Meshroom. (2020, December 5). Retrieved from Wikipedia: https://wikitia.com/wiki/AliceVision_Meshroom

Antonicelli, L. (2017). *De-Lighting Strategies*. Retrieved from Art station: https://www.artstation.com/artwork/wbKZw

Baran, G. (2019, October 27). *Photogrammetry Equipment by Grzegorz Baran*. Retrieved from Youtube: https://www.youtube.com/watch?v=fapgOO39Dh8&t=152s

Baran, G. (2021, June 10). *Photogrammetry Setup for Indoor 3D Prop Scanning*. Retrieved from Youtube: https://www.youtube.com/watch?v=REA3XNgUMJg

BLM. (2008). *Aerial and Close-Range Photogrammetric Technology*. Retrieved from BLM: https://www.blm.gov/sites/blm.gov/files/documents/files/Library_BLMTechnicalNote428_0.pdf

Brown, A. H. (2016, August 12). *Star Wars: Battlefront and the Art of Photogrammetry*. Retrieved from Youtube: https://www.youtube.com/watch?v=U_WaqCBp9zo

Clancy, K. M. (2020, January 2). *Using Photogrammetry to Create a Realistic 3D Anatomy Learning Aid with Unity Game Engine*. Retrieved from Springer Link: https://link.springer.com/chapter/10.1007/978-3-030-31904-5_7

Coldewey, D. (2020, February 20). *How 'The Mandalorian' and ILM invisibly reinvented film and TV production*. Retrieved from Tech Crunch: https://techcrunch.com/2020/02/20/how-the-mandalorian-and-ilm-invisibly-reinvented-film-and-tv-production/

Datem Systems International. (2021, August 20). *KEY FEATURES IN MODERN PHOTOGRAMMETRIC*. Retrieved from Datem : https://www.datem.com/key-features-in-modern-photogrammetric-software/

DFlux, A. (2022, June 24). *Best AI Photo Editor Software in 2022*. Retrieved from Photo Workout: https://www.photoworkout.com/best-ai-photo-editor/

Entertainment Desk. (2022, March 19). *Spider-Man No Way Home: Did you spot these 'invisible' VFX in Tom Holland's Marvel film?* Retrieved from Indian Express: https://indianexpress.com/article/entertainment/hollywood/spider-man-no-way-home-did-you-spot-these-invisible-effects-in-the-tom-holland-film-7826663/#:~:text=He%20elaborated%20on%20the%20'invisible,it%20were%20all%20created%20digitally.

Faucher, W. (2021, December 18). *RealityCapture to UE5 - Workflow Tutorial*. Retrieved from Youtube: https://www.youtube.com/watch?v=WrCOhes1Zgg

Filmfonds. (n.d.). *About the film fund*. Retrieved from FIlmfonds: https://www.filmfonds.nl/nl/page/2902/take-the-netherlands

Formlabs. (n.d.). *Photogrammetry: Step-by-Step Guide and Software Comparison*. Retrieved from Formlabs: https://formlabs.com/eu/blog/photogrammetry-guide-and-software-comparison/

Frazer, B. (2021, June 14). *The Future of Filmmaking: Cinematography in the Age of Photogrammetry*. Retrieved from Frame.IO Insider: https://blog.frame.io/2021/06/14/photogrammetry-future-of-filmmaking/

Google Research Brain Team. (2021, July 16). *High Fidelity Image Generation Using Diffusion Models*. Retrieved from Google AI blog: https://ai.googleblog.com/2021/07/high-fidelity-image-generation-using.html

Hawkins, M. (n.d.). *3D photogrammetry: turning photographs into 3D models*. Retrieved from Canon: https://www.canon-europe.com/pro/stories/3d-photogrammetry/

Johnson, J. J. (2021, August 11). *Photogrammetry for a Virtual Reality Nature Scene*. Retrieved from ACM Digital Library: https://dl.acm.org/doi/abs/10.1145/3450549.3464416

Mapware. (2020, September 11). *5 Features to Expect from the Best Photogrammetry Software*. Retrieved from Mapware: https://mapware.com/blog/5-features-to-expect-from-the-best-photogrammetry-software/

Market Dataforecast. (2022, January). *Motion Picture Industry Market Research Report - Segmentation by Genre (Action, Comedy, Drama, Fantasy, Horror, Romance, and Others); By Demography (Children and Adults); By Dimension (2D and 3D & above) - Demand Analysis & Opportunity Outlook 2022 - 2027*. Retrieved from Market Dataforecast: https://www.marketdataforecast.com/market-reports/motion-picture-industry-market

Marqués, N. F. (2016, September 30). *Tutorial: Lighting in Photogrammetry*. Retrieved from Sketchfab: https://sketchfab.com/blogs/community/lighting-in-photogrammetry/

Metashape. (2021, April 29). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Metashape

Nielsen. (2020, June). *COVID-19: Tracking the Impact on Media Consumption*. Retrieved from https://www.nielsen.com/insights/2020/covid-19-tracking-the-impact-on-media-consumption/

Paper with code. (n.d.). *Image Super-Resolution*. Retrieved from Paper with code: https://paperswithcode.com/task/image-super-resolution

Planet X. (n.d.). *Planet X projects*. Retrieved from Planet X: https://www.planetx.nl/projects

Planet X. (n.d.). *The Studio*. Retrieved from Planet X: https://www.planetx.nl/about/the-studio

PlanetX. (2022, February). Photogrammetry workflows & possible improvements. (J. Hu, Interviewer)

Read, S. (2022, June 28). *Gaming is booming and is expected to keep growing. This chart tells you all you need to know*. Retrieved from Weforum: https://www.weforum.org/agenda/2022/07/gaming-pandemic-lockdowns-pwc-growth/#:~:text=The%20expansion%20is%20expected%20to,exceed%20%24320%20billion%20by%202026.

RealityCapture. (2022, March 13). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/RealityCapture

Salia, R. (2021, March 2). *Top 15 AI Image Upscaler for 2022 | Make Images Professional with AI Upscaling*. Retrieved from ToptenAI: https://topten.ai/image-upscalers-review/#1_Upscale_Image_with_-_Topaz_Gigapixel_AI

Sculpteo. (2022). *Best photogrammetry software in 2022*. Retrieved from Sculpteo: https://www.sculpteo.com/en/3d-learning-hub/3d-printing-software/photogrammetry-software/

Taylor, J. (n.d.). *13 Best AI Photo Editor Software in 2022 (Compared & Reviewed!)*. Retrieved from Expert Photography: https://expertphotography.com/best-ai-photo-editor-software/

Topaz Labs. (n.d.). *Products*. Retrieved from Topaz Labs: https://www.topazlabs.com/shop

TOPS Marketing. (n.d.). *WHAT IS PHOTOGRAMMETRY?* Retrieved from Takeoffpros: https://www.takeoffpros.com/2020/06/16/what-is-photogrammetry/

Übel, M. v. (2022, September 9). *20+ Best Photogrammetry Software of 2022 (Some are Free)*. Retrieved from All3DP: https://all3dp.com/1/best-photogrammetry-software/

Weiss, J. (2022, August 15). *GO INSIDE THE PRACTICAL DINO-EFFECTS OF 'JURASSIC WORLD DOMINION' IN EXCLUSIVE BEHIND THE SCENES CLIP*. Retrieved from SYFY: https://www.syfy.com/syfy-wire/jurassic-world-dominion-home-release-exclusive-clip#:~:text=%22My%20producer%20and%20I%20%E2%80%A6%20had,effects%20shots%20in%20this%20film.

Wijman, T. (2022, June 26). *The Games Market Will Show Strong Resilience in 2022, Growing by 2.1% to Reach $196.8 Billion* . Retrieved from Newzoo.

Wood, L. (2022, June 21). *Global Animation & VFX Market Report 2022-2026 - Evolution of VFX, AR and VR Technologies is Dramatically Changing the Creation and Consumption of Films, Videos and Games.* Retrieved from Businesswire: https://www.businesswire.com/news/home/20220621005600/en/Global-Animation-VFX-Market-Report-2022-2026---Evolution-of-VFX-AR-and-VR-Technologies-is-Dramatically-Changing-the-Creation-and-Consumption-of-Films-Videos-and-Games---ResearchAndMarkets.com

Appendices

Appendix I: Videos

Video 1: https://youtu.be/wPasSFqiRaM - General knowledge of photogrammetry
Video 2: https://youtu.be/7Z7vmfIKhck - How to shoot photos for photogrammetry
Video 3: https://youtu.be/V4m-Opk3TWQ - Editing the photos for photogrammetry
Video 4: https://youtu.be/BJdj3hzJv7E - Creating the 3D models, texture, and UVs
Video 5: https://youtu.be/IUlHpoZms4U - Texture map clean-up
Video 6: https://youtu.be/y0T0f6dXzKA - Correcting pivot and making model ready for UE5

Appendix II: Workflow documents

Workflow document:
https://drive.google.com/file/d/14hjMvmCDnUUwRD8cK6bDJ98vSa9_-L_R/view?usp=sharing
Planet X workflow document:
https://drive.google.com/file/d/1S5lsupOKWR3NebpFrSBRmSw_8LYS6YQ5/view?usp=sharing

Appendix III: 3D models

3D models render:
https://drive.google.com/drive/folders/12j_HXGRFFgjvEPu29b5hWNvd2duvXx99?usp=sharing