

Graduation Report

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Glossary

NeRFs- a technique that generates 3D representations of a real-life objects or scenes extracted from 2D images or videos, using advanced machine learning.

Base mesh- a simple 3D model that has proper topology and is used as a starting point for sculpting or wrapping.

UV map- flat surface representation of a 3D model, made so that textures can be applied.

Topology- it is the flow of the faces that form the geometry of the 3D model

VR- Virtual Reality

3D- Three-dimensional

2D- Two-dimensional

LiDAR (Light Detection and Ranging)- optical technology that uses a laser to calculate depth

Deep Learning- a type of machine learning based on artificial neural networks in which multiple layers of processing are used to extract progressively higher level features from data.

.obj- geometry definition file format that represents 3D geometry alone- the position of each vertex, the UV position of each texture coordinate, vertex normal, and the faces that make each polygon.

JSON (JavaScript Object Notation)- standard text-based format for representing structured data based on JavaScript object syntax.

Colmap- general-purpose, end-to-end image-based 3D reconstruction pipeline with a graphical and command-line interface. It is used to reconstruct ordered or unordered image collections.

Hi-fi- High Fidelity

Retopology- a step in the 3D modeling process where an object's mesh is modified in a certain way with special tools in order to recreate a cleaner topology, while maintaining the same physical appearance.

UI/UX- User Interface / User Experience

API (Application Programming Interface)- it refers to any software with a distinct function. It is a way of two or more computer software to communicate with each other using requests and responses.

CUDA- a Nvidia toolkit, that provides everything needed to develop GPU-accelerated applications.

CPU- Central Processing Unit

GPU- Graphics Processing Unit

Command Prompt- the input field in a text-based user interface screen for an operating system or program. It is designed to elicit an action.

Python- a computer programming language often used to build tools or software, automate tasks, and conduct data analysis. It is a general-purpose language, meant to create a variety of different programs.

Abstract

The digitalization of humans through 3D scans is a fascinating process that allows people to recreate hyper-realistic individuals virtually and use them in many ways. In order to properly digitalize a human for production purposes, the 3D scan must be generated efficiently and in a quick manner, yet still give a good quality of resolution. Afterwards it must undergo a process of wrapping a custom 3D mesh which will inherit the shape of the 3D scan. It is a complex process that requires a lot of expertise and research in order to come up with a fast and efficient workflow. The paper discusses the most used 3D scanning methods, their working processes, and best methods of wrapping a 3D scan. Moreover, all the theoretical findings and attempts to rank the methods and software are described. Each different approach is discussed, their advantages and disadvantages when using them for a specific purpose and results are compared and discussed. Ultimately, the paper discusses the concluded workflow and best methods for 3D scan reconstruction and wrapping.

1. Introduction

Three-Dimensional (3D) scanning is a relatively new technology that is rapidly expanding in the field of computer graphics and is being applied to a wide range of industries (Artec 3D, 2019). Nowadays, the necessity of 3D scans is growing fast as technology transitions into a more digital world.

Companies all over the world are developing applications and platforms to immerse users in a digital world that functions just like ours. They have the possibility of buying clothing and other items, playing games and exploring, and most importantly, meeting with each other and communicating. By developing a stronger internet presence, people want to be able to personalize and customize their avatars, which serve as their digital doubles.

Usually, a digital double should look like its user, which means that the best way to achieve this is through 3D scanning. However, most users are inexperienced in the field of 3D scans. This is the process of scanning a real-life object with a specific application or scan, and optimize it so it can be used properly in a digital environment. In order to transfer the object, you need to wrap a good 3D mesh around the 3D scan which is literally transferring the topology, or the geometric edge distribution and structure, on top of the scan so that the new mesh can contain the detail of the scan and have usable topology for animations, for instance.

New technologies arise to help achieve the consumption level and aid companies achieve better results, thus satisfying the clients. There is a technology that is making its way as the industry-standard: NeRFs, or neural radiance fields (Karagiannakos, 2022), are a fully connected neural network that can generate novel views of complex 3D scenes based on a partial set of 2D images. It is based on photogrammetry principle, but it operates through code. It is a method of capturing and reconstructing real-life objects that is growing and improving by the day, and is worth exploring, as it can give spectacular results, save time and effort, and ease the requirements for a client. Nonetheless, this process still requires time, technical knowledge, and expertise, which assumably not every user has.

Reblika B.V. is a company that offers such expertise as their main focus are digital avatars. Reblika offers a service that is called OmiFace. It is a feature-specific technology that creates believable facial expressions. In other words, it is a service that is dedicated to treat 3D scans (Goos Online B.V, n.d.). All the clients must do is send over their own scanned face or other scan data to Reblika and the rest will be taken care of by wrapping the 3D scan in a specific software, called R3DS Wrap3. This process ensures that the client does not need to worry about the technical knowledge like creating blendshapes, which are expressive facial animations. Rather, the company wants to let the user focus on the customization and personalization of their avatar.

However, Reblika has their own shortcomings, as their workflow of treating 3D scans still has room for improvement. Their goal is to develop an efficient workflow that will guarantee scalability of the service and the possibility to reach new markets outside of the Netherlands. As stated by Mao Lin Liao, the CEO of Reblika, the market in the Netherlands for 3D scans is not strong enough compared to the other markets. Thus, this makes growth of the 3D scan services slow and inefficient. One of the criteria for success would be to reduce the number of images that have to be taken by the client, in order to make their experience easier. (Interview, 2023)

1.1 The Company

Reblika is a company founded in 2019, and is based in Rotterdam. Reblika prides itself on its digital characters, which are usually part of advertisements, games, avatars, or implemented in the Metaverse. (Goos Online B.V, n.d.) The company consists of a multidisciplinary team of around 50 people, most people working as the internal team, although there are some freelancers. Through the use of 3D scanning, Reblika wants to remove the need for users to worry about the technical part of the process.

1.2 The Clients

The list of clients for Reblika includes both large and small businesses, like Marvel, Adidas, Disney, Roberto Cavalli, Coca-Cola, and many more. In addition, they worked together on projects with Rita Ora, the Old Spice TVC, and other artists (Goos Online B.V, n.d.).

Reblika's market strategy is to provide customers with answers relating the digital fashion era. Reblika offers technical assistance including rigging and grooming in addition to scanning actors in 3D for usage in production. This saves the brand's and retailers' physical fitting costs in the early stages.

Reblika also creates digital doubles that are computer-generated characters, carefully polished for maximized appeal in looks. In other words, they strive for excellent visual quality to elicit an emotional response from the audience, through storytelling. They use Photogrammetry to achieve maximum realism and identical appeal to the real-life model. Currently, the clients are the ones who are taking pictures of themselves and uploading it in a software to generate the 3D scan. However, not always the results are great or even usable for the company, which leads to time loss. From this rises another issue, that is the time it takes an artist to prepare a production-ready mesh.

1.3 Problem Analysis

The primary problem is that it takes too much time for a single artist to produce a wrapped model from a 3D scan, consisting of the ready mesh. **The approximate calculation of preparing a production ready wrapped mesh is 7 hours.** This results in time and labor costs. Not to mention, long-term consequences could be that the demand of the service by clients might grow overtime. Big quantities will significantly slow down the workflow if it's not modified. Another long-term problem is also that reaching new markets might be difficult as the workflow does not seem fully efficient. As of now, clients find taking overlapping pictures, that are acceptable for a scan somewhat complex and unintuitive. (Interview, 2023)

There are steps that slow down the process. When it comes to scans, the company wants to know what number of images are enough to create a scan that is good to work with. The less the client must do in terms of taking images, the better, as they might not be aware of the technical requirements. Another thing is that the more unnecessary detail there is the heavier the file gets, which slows down the work. Another issue that exists is the inconsistency of software, as most of the artists have their own way of producing wrapped mesh, meaning they use different software.

1.4 Current Workflow

The current way of achieving a production-ready scan is as follows:

1. The company receives scans done by a desktop software or mobile application, that might not have been cleaned.
2. An artist retrieves the scan and wraps it in R3DS Wrap3.
3. They clean it from artifacts and unsmooth areas within R3DS Wrap3, or in another software.
4. They export the new mesh and try to bring most of the characteristics back in a sculpting/modeling software like Maya or ZBrush.

1.4.1 R3DS Wrap3 Software

R3DS Wrap3 is a software that allows the user to process 3D-scan data. As stated, when working with a large set of similar objects like human scans Wrap3 makes it possible to take an existing base mesh and non-rigidly fit it to each scan. It allows the user to create the desired result on a clean base topology on top of the target topology, which is usually unusable for production. R3DS Wrap3 is node-graph based and allows to reuse the manner of wrapping throughout multiple scans.

Also, there are nodes that allow the users to work undestructively and also python is slowly being implemented in order to give people the opportunity to control each process easier. (Welcome to Wrap 3, n.d.)

R3DS Wrap3 is widely used for human scans, primarily organic matter. One of the very convenient advantages is that it comes with detailed documentation, allowing for better understanding and building a good strategy for optimized wrapping.

2. The Research Question

How can the company's current workflow for treating 3D scans be improved, so that an artist can be able to produce more scans, resulting in less time and labor costs and a more standardized and optimized workflow?

The following sub-questions arise:

1. What tools and devices make a good 3D scan and how can it be further optimized?
2. What number of images are enough to generate a good scan to work with?
3. How to work on a 3D scan in a clean way to preserve the detail and speed up the process?
4. How can the workflow be adjusted?

2.1 Sub-Questions

The first and second sub-questions are required to estimate how can the scan be improved in quality before entering the production phase and generate a clear understanding of the needs to treat it in a clean and non-destructive way. Furthermore, it can provide the clients with a better understanding of the requirements for a scan and has the potential to speed up the process greatly.

The third question is tightly related to the production and clean-up processes when working with 3D scans. It highlights the most common challenges when working with multiple scans and how they can be solved.

The fourth question can give an overview of the features available that can be used to solve the main issues, or can pinpoint potential future features based on the findings of question 1. The current features will be tested and analyzed to discover possibilities for workflow improvement.

2.2 The Scope

This report will focus on the technical and visual prerequisites and recent features in the field of 3D scanning and 3D wrapping. Multiple software will be tested in order to compare time and labor costs. Also, prices of each software will be taken into account. Testing hypothesis with each software will provide knowledge if new pipeline should be proposed. The research that will be carried out aims to investigate for ways or improve the current way of digitalizing humans in regard to the company's workflow.

The findings must identify either a method that is efficient, meaning that its faster than the current one if possible, or produce a variation of the current one, that still covers the primal need of the company-speed and efficiency.

It will be tested by the student at first and when a there is a better result it can be tested by an artist from the company. By assembling such option, it will inevitably result in reduced costs and overall be a consistent and optimized workflow that the artists from the company can use in order to produce 3D scans more efficiently and faster. The prototype will be created by most likely using multiple software, based on the research results. The prototype will be used for demonstration purposes and will not serve as a final version.

Paid software will be tested by using the trial versions, but will not be tested further after the expiration of the trial, especially if the results are not satisfactory. Free software will be tested and if results are acceptable, further experiments will be carried out.

2.3 Indicators of Success

For a task to be successful a positive change must be indicated in the institution's performance and/or behavior change. The goal is to improve on the current workflow for 3D scanning so that it will be efficient and faster than the current one as seen in Table 1. For this purpose it is needed to define each option by using the S.M.A.R.T. methodology.

Table 1. Main Objective

Objective 1	Improve the current workflow
Specific	To improve the current workflow for 3D scanning by adding additional value to it, to make it faster and more efficient for the company to use by the end of the Graduation internship.
Measurable	If the workflow has improved, it should be able to be measured by comparing the time for producing a 3D wrap before and after the changes applied.
Achievable	Researching for functions that can help reduce the time and improve the results in the current software used.
Relevant	It is aligned with the company's goals, considering the fact that this is one of the services they offer and need fast and good results.

Time-bound	The period for execution is 5 months, which is doable, considering the fact that most of the technical knowledge required for 3D scanning is already applied.
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2.4 Methodology

This thesis will primarily use quantitative data, such as texts, videos, manuals, in order to understand the concepts, define options and investigate for possibilities. However, quantitative data will also be analyzed in the form of experiments.

3. Theory

3.1 3D scanners and their specifications

3D scanning is a technology for analyzing and creating high-precision 3D models of real-world objects. (Artec 3D, 2019) The list of uses for 3D scans varies from manufacturing to healthcare and VR, and even forensics. Performing quality control of mechanical parts, designing customized prosthetic devices, creating visual effects for movies, developing characters for games and fashion industry- all of these projects have 3D models of physical objects in their core through scanning. This technology is more powerful than ever, and business all over the world are embracing its' versatility to boost the productivity, eliminate costs, and overall improve on quality and efficiency.

The 3D scanner takes multiple snapshots of an object as seen in Figure 1. The more there are, the cleaner shape it will be able to construct. It is also very important to have natural lighting, since the more shadowed areas might appear with artifacts that are never ideal, considering the fact that this technology triangulates the end result. Overall, the cleaner the object while scanning, the less need for cleanup it will need, once imported in a 3D software.

There are several physical principals of capturing real-life data and digitalizing it. They are classified as follows:

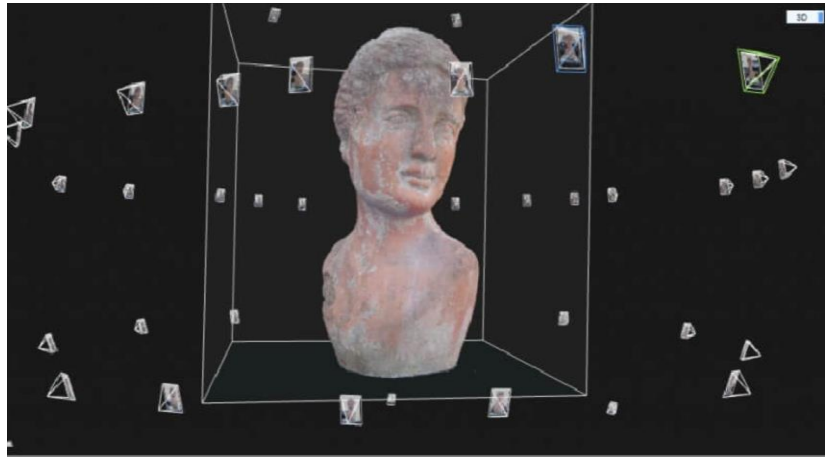


Fig. 1 - Photogrammetry Projection

1. **Laser triangulation 3D scanning technology:** In this category, the scanner projects a laser beam on a surface and measures the deformation of the laser. It is a very interesting process. It measures the distance between the camera and the laser, and the angle between the laser and the scanner in order to calculate the distance between the scanner and the object.
2. **Structured light 3D scanning technology:** This involves projecting structured patterns of light on an object and acquire a surface shape by measuring the light pattern's deformation.
3. **Laser pulse 3D scanning technology:** This process collects geometrical information by evaluating the time a laser beam takes to travel between its emission and reception.
4. **Photogrammetric technology:** It is known as a 3D scan from photography. It reconstructs an object from 2D to 3D and has specific computational geometrical algorithms for the task.
5. **Contact-based 3D scanning technology:** This requires contact between the probe and the object, where the probe is moved firmly over the surface to acquire data.

Nowadays, the most popular 3D scanning method is the laser triangulation method. (Quality Magazine, 2021) It can create a very precise scans, which are up to millions of polygons. Overall, the level of detail

is preserved greatly. However, sometimes these scanners don't always work on transparent or reflective surfaces. (Lievendag, 2019)

Next most used method is the photogrammetric one. As mentioned above, it uses a software to bundle multiple 2D images together and develop a three-dimensional data set. It is used with an optical 3D scanning system. It is most commonly seen on smartphones, as the user is allowed to perform photogrammetry with a handheld digital camera. Essentially, this makes it a cheap option, which is still precise and can scan objects from human hands and smaller, to buildings and stadiums.

Another new promising way of digitalizing objects is called NeRF. Same as photogrammetry, it most commonly uses images from a smartphone.

3.2 Photogrammetry 3D Scan and Neural Radiance Fields

This section is meant to compare the two most chosen options for 3D scanning and analyze their uses, specifications, and most importantly- strengths, weaknesses, and affordability. Although laser scanning being the best option, it will be discussed in Appendix I as it will not be tested.

3.2.1 Photogrammetry

As stated in 3DSCANEXPERT (Lievendag, 2019), photogrammetry scans are easily accessible for consumers and small businesses, they are the ones that will be used for generating the scans for this research. It is an affordable technology as it does not require new equipment to be up-to-date and provides better visual representation of textures.

Photogrammetry is based on the processing of images. The processing algorithms are being continuously developed. Photogrammetric theories can count on a long history of developments for over a century. Intensive research has been conducted for the last 20 years for the automation of information extraction from digital images, based on image analysis methods. (Baltsavias, 1999)

Some software that will be tested on an iPhone use the LiDAR sensor that is available to iOS devices. It stands for Light Detection and Ranging. It allows a device to scan the environment and thus calculate distances to objects. It is really similar to laser scanning, as it uses tiny invisible lasers. This process helps improve shots as it produces sharper images, especially when shooting under moderate lighting conditions, which is ideal for photogrammetry. (iCulture, 2022)

3.2.2 Neural Radiance Fields (NeRFs)

Neural radiance fields (NeRFs) slowly become one of the most interesting topics in the world of Deep Learning. A neural radiance field is a fully-connected neural network that can generate novel views of complex 3D scenes, based on a partial set of 2D images. It is trained to use a rendering loss to produce input views of a scene. It works by a similar manner to photogrammetry. It takes input images representing a scene and interpolates between them to render one complete scene. NeRF is a highly effective way to generate images for synthetic data, which is any type of information manufactured artificially.

A NeRF network is trained to map directly from viewing direction and spatial location to opacity and color, using volume rendering to render new views. (Lawton, 2023) Nevertheless, these neural networks can be costly to train and evaluate. However, as this technology is growing immensely, there are a lot of algorithms that help improve the performance dramatically. New versatile inputs are developed that permit the use of a smaller scale network without sacrificing quality. (Instant Neural Graphics, n.d.) This technology is most commonly used to generate 3D models of objects, including humans, as well as for

rendering 3D scenes for video games and for virtual and augmented reality environments in the metaverse. One of the aspects of NeRFs is that they can also capture reflective information better than photogrammetry, so later the material does not require effects using secondary processes. (Neural Radiance Field, 2023)

3.3 Tools Needed for a 3D Scan

If aiming for photogrammetry and/or training NeRFs, almost every phone nowadays is capable of constructing a well-detailed 3D scan. The first below, Table 3, will present strengths and weaknesses of the three methods.

The second table, Table 4, will present each tool that is used for each different method, including laser scanning for comparison reason, showing their prices, affordability, and specifications. It is essential to note that only two brands phones will be compared for the photogrammetry section, as they are the ones that are most picked, stated in 2023 survey by OBERLO (Lin, n.d.), meaning most users already own one. The two most picked models phones are used in the table as a different survey, done by Tom's Guide, states them as 2023 best used smartphones. (Pritchard, 2023)

Table 2. Photogrammetry and NeRFs strengths and weaknesses

Photogrammetry	NeRFs
Strengths	Strengths
<ul style="list-style-type: none"> Significantly cheaper equipment Most improvements are on the software side so no need to buy new equipment to keep up with progress Better visual representation of textures Most software are free and do not require additional purchases 	<ul style="list-style-type: none"> Cheaper equipment Software is free and is intuitive and user-friendly (Mobile) Training NeRFs gives almost photo-realistic results when enough images are provided Does very accurate representation on reflective / transparent surfaces Mobile app is free and does not require additional purchases
Weaknesses	Weaknesses
<ul style="list-style-type: none"> Accuracy is lower than laser scanners over large surface, as the process is guided by a user Less automated process allows for more user errors, results sometimes depend greatly on the expertise of the operator More time spent on site Errors when dealing with reflective / transparent surfaces 	<ul style="list-style-type: none"> Desktop version cannot export native formats such as: .obj .gltf .usdz Requires mobile application in order to export a format that is compatible with a 3D software Requires a lot of images in order to generate accurate representation It takes a lot of time to render or train the NeRF

Table 3. 3D scanning tools comparison

Purpose	Tool, Specifications and Price	Supports good scanning software	Affordability
Laser Scanning	<p>Artec Leo 3D Scanner</p> <ul style="list-style-type: none"> 3D point accuracy: up to 0.1 mm; 3D resolution: up to 0.2 mm; 3D accuracy over distance: up to 0.1 mm + 0.3 mm/m Recommended PC Requirements: Intel Core i7 or i9, 64+ GB RAM, NVIDIA GPU with 8+ GB VRAM, CUDA 6.0+ Battery: Built-in battery Battery life: 4 Hours (approx.) Price: \$34,800 	Artec Leo 3D Scanner: Supports powerful Artec Studio software but it is paid extra. Nevertheless, very precise and professional	Artec Leo 3D Scanner: Expensive and limited for users, as not every user needs one in a long-term scenario
	<p>Revopoint Mini 3D Scanner</p> <ul style="list-style-type: none"> 3D point accuracy: up to 0.05 mm; 3D resolution frame accuracy: up to 0.1 mm; Resolution: 0.1 mm Recommended PC Requirements: Intel Core i7 or i9, 64+ GB RAM, NVIDIA GPU with 8+ GB VRAM, CUDA 6.0+ Battery: Built-in battery Battery life: 2-4 Hours (approx.) Price: \$799 	Revopoint Mini 3D Scanner: Software is not beginner-friendly and might also not be suitable for professional use, has problems with smaller objects, takes too long to construct	Revopoint Mini 3D Scanner: Inexpensive and easy to use, however not every user has one, or needs one in a long-term scenario
Photogrammetry and NeRF	<p>iPhone 13</p> <ul style="list-style-type: none"> Display: 6.1- inch OLED CPU: A15 Bionic Rear Camera: 12MP wide (f/1.6); 12MP ultrawide (f/2.4) Battery life: 10 Hours (approx.) Price: €1,029 	iPhone 13: Supports every app available for use in the AppStore	iPhone 13: Affordable and desired by a lot of people, a lot already own one
	<p>Samsung Galaxy S22</p> <ul style="list-style-type: none"> Display: 6.1- inch AMOLED CPU: Snapdragon 8 Gen 1 Rear Camera: 50MP wide (f/1.8); 12MP ultrawide (f/2.2); 10MP telephoto (f/2.4) with 3x optical zoom Battery life: 8 Hours (approx.) Price: €579 	Samsung Galaxy S22: Supports every app available for use in the Google Play Store	Samsung Galaxy S22: Very affordable and desired by a lot of people, a lot already own one

3.4 Photogrammetry and NeRF software used by professionals

A research done by Manufactur3D (Manufactur3d, 2023) and Artec3D (Artec, n.d.) presents which software are best for close-range 3D scanning. They are as follows: Reality Capture and 3DF Zephyr. These software are mostly free and are focused on close-range photogrammetry. Two more will be included to that list, and thus tested, since it is required by the company- Polycam for photogrammetry, Luma AI, which generates NeRFs, and the lastly Nerfstudio, which also generates nerfs through the use of algorithms powered by Python scripting. More information can be found in Appendix I.

Reality Capture- Reality Capture is a photogrammetry software for making 3D models out of photos or laser checks without cases. It allows the creation of ultra-realistic 3D models from a set of images and/or laser scans.

3DF Zephyr- 3DF Zephyr is developed by 3DFLOW and is also a professional software for 3D scan creation. Currently, the previous versions were discontinued and a new, merged version was released (Zephyr 3DF). (Wikipedia contributors, 2022)

Polycam- Polycam is the leading 3D capture application for iPhone and iPad. It creates high-quality 3D models from photos with any iPhone and rapidly generates scans of spaces with the LiDAR sensor. (App store, 2020)

Luma AI- Luma is a new way to create incredible lifelike 3D with AI using your iPhone. (App store, 2022) It captures three-dimensional images using a technology known as Neural Radiance Fields (NeRF).

Nerfstudio- Nerfstudio provides a simple API that allows for a simplified end-to-end process of creating, training, and visualizing NeRFs. As this technology is still evolving, it is mostly intended for hard-surface objects, which have a clearly defined shapes.

3.6 Alternative Software Capable of Wrapping

Depending on the type of 3d scan, the level of detail required, the desired output format, and the available budget there are multiple software programs that have its own strengths and weaknesses. Below will be listed a few of the available options that can use custom topology, other than Wrap3:

1. **Zbrush Zwrap Plug-in-** ZBrush is the leading industry standard digital sculpting software. It combines 3D/2D modeling and sculpting, texturing and painting. What makes this software is the capability of producing high-resolution models which are used in movies, games, and animations. These hi-fi resolution models can have sculpted on medium to high-frequency details that were traditionally painted with bump maps.(ZBrush, n.d.) Overall, this software is leading the industry sculpting-wise, because it has a ton of options to edit and add more detail and realism to the sculpt, which inevitably leads to the creation of the desired result.
2. **Autodesk Mudbox-** A 3D sculpting and painting software that offers tools for creating custom topology on 3D scan.(Autodesk Mudbox, n.d.) The difference here is that this method does not wrap a base mesh around the scan but instead extracts a high-detailed displacement map from

the scan which is placed by adding subdivisions.

3. **Houdini**- Houdini is a software application fully adapted for procedural generation purposes and has a lot of procedural tools. It is widely used for producing complex reflections, animations and particle systems but is best known for the creation of VFX in film and television. It is node-based, so every action is stored in a node. They are wired into networks which define a certain recipe for the project, which can be tweaked to refine the outcomes and can always create similar, yet unique results throughout different projects. (Wikipedia contributors, 2023) In terms of wrapping, Houdini has the necessary tools to create a workflow for wrapping 3D scans.

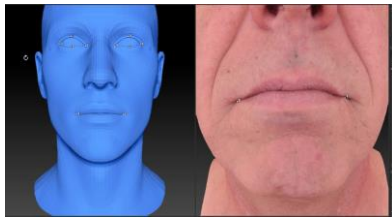


Fig. 3 - ZBrush Zwrap

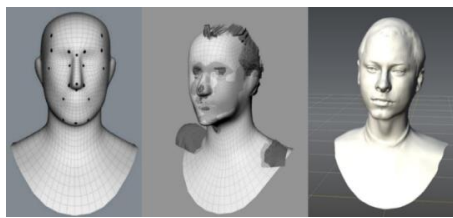


Fig. 4 - Mudbox Wrapping



Fig. 5 - Houdini nodes

4. Testing Methodology

In order to answer the sub-questions the student will propose a new workflow and conduct test in order to validate and justify the choices. Based on the results from the desk research, the first aspect that will be tested are the photogrammetry and NeRF programs in order to define which one is the best choice for creating a scan. Several aspects will be taken into account when analyzing results, such as: price of software (if applicable), polycount, level of detail, processing speed, texture quality, visual fidelity, and user journey within each software.

The following software will be tested in order to answer sub-question 1: 3DF Zephyr, Reality Capture, Polycam, Luma AI, and Nerfstudio.

Table 4. Hardware specs and components- PC

Acer Predator Helios 300 specs and components	Part
GPU	NVIDIA GTX 1060 6GB
CPU	Intel(R) Core(TM) i7-8750H CPU @ 2.20GHz 2.21 GHz
RAM	16 GB DDR4 3200 MHz from Acer
Motherboard	Default Stock Acer Motherboard
Storage	2TB M.2 (2280) Single-Sided SSD ; PCIe NVMe Gen 5 ; 6,600 MB/s Read, 5,000 MB/s Write
PSU	ADP-180MB K Input: 100-240V, 50-60Hz Output: 19.5V

Table 5. Hardware specs and components- Phone

iPhone 11 specs and components	Part
CPU and GPU	A13 Bionic chip 6-core CPU with 2 performance and 4 efficiency cores (4GB RAM) 4-core GPU 8-core neural Engine
Camera	Dual 12MP Ultra-wide and Wide cameras Ultra-wide: f/2.4 aperture and 120 degrees field of view Wide: f/1.8 aperture Image formats captured: HEIC and JPEG
Storage	128 GB
LiDAR Sensor Scanner	Not available, as it is exclusive to Pro models only

The tests were conducted by aligning and reconstructing with the same datasets with medium quantity of forty-three images and each software was tested with the highest possible settings. The results were analyzed and compared in order to extract the necessary conclusion. The same devices were used to capture and process the images. For specifications and components of capturing device check Table 7. and for processing device check Table 6.

5. Test outputs

5.1 First testing batch- Shoe object

5.1.1 3DF Zephyr output

Generation

3DF Zephyr aligned all 43 out of 43 input images. The result can be seen below in Figure 6.



Fig. 6 - 3DF Zephyr Textured Mesh Results

The results are really clean and the level of detail is impressive. The polycount is small, considering it is rendered with a dense sparse cloud and a detailed textured mesh. There is a small piece of surface where the model was captured but that is easily cleanable within the software.

More information can be found in Table 7.

Problems encountered

There were no issues encountered.

5.1.2 Reality Capture output

Generation

Reality Capture successfully aligned 43 out of 43 images. The result can be seen below in Figure 7.



Fig. 7 - Reality Capture Mesh Results

The results, although having some issues, are still pretty decent. The texture quality and details are great. The polycount is high, considering the scale and overall shape of the object. Nonetheless, these settings are adjustable.

More information can be found in Table 7.

Problems encountered

There are some issues when it comes to the shape, for instance the toe cap has an artifact, due to Reality Capture not being able to capture this area properly. Additionally, it requires quite some cleanup because of the white surface underneath.

5.1.3 Polycam output

Generation

43 images were captured that were not completely identical with the main dataset. Yet, the application was able to reconstruct the object. The result can be seen below in Figure 8.



Fig. 8 - Polycam Mesh Results

The results are decent, although it should be cleaned-up. The texture detail is also captured really well and the mesh has no major artifacts.

More information can be found in Table 7.

Problems encountered

As seen, there are some issues with the surface area.

5.1.4 Luma AI output

Generation

The result can be seen below in Figure 9.



Fig. 9 - Luma AI Mesh Results

The results are decent, although the textures are not as detailed as in other software. The white surface area is still a bit captured, but overall the mesh is mostly in a good condition.

More information can be found in Table 7.

Problems encountered

Unlike Polycam, Luma AI requires a lot of images in order to capture the object properly. This is reasonable, as it does not only tries to reconstruct the object but also the background around it. Downside is that this can be considered as a disadvantage. Also, there is a whole in the object which can be cleaned in later on but technically is not ideal.

5.1.5 Nerfstudio output

Generation

The whole dataset of 43 images was aligned. The reconstruction process took quite some time, which is reasonable considering that it is reconstructing the whole scene. The end result was exported as a sparse cloud and later imported in a different software, called Meshlab, where a mesh was extracted from the cloud. The result can be seen below in Figure 10.



Fig. 10 - Nerfstudio Mesh Results

The reconstruction was successful, although it can be seen that the result is pretty rough and it would need a lot of cleaning. However, keeping in mind the needs of the company, which are to use the minimal quantity of photos, which will be discussed in the following test, and the fact that nerfstudio uses machine learning to interpolate, this is still a promising result. It is definitely a method that can be explored further.

More information can be found in Table 7.

Problems encountered

As mentioned, if one is not a programmer, the workflow might a bit finicky. There were quite some issues encountered. One that took most time fixing was a compiling error with the Colmap, where the path for a certain file, called vocab_tree was not well specified, which led to extra lines of code to specify. Another issue was installing a proper version of CUDA. Having one that is not compatible with one of the algorithms, that “builds wheels” so that the Colmap can start extracting the necessary information, can cause issues.

Nevertheless, once the setup is created and the Nerfstudio environment is created, it is pretty much pasting a few lines of code to reconstruct. Of course, the current pipeline can be improved further by code, which is something to be looked into.

Table 6. Additional information regarding the first testing batch

Software	Texture Map	Polycount	Level of Detail	Total price	Time taken to reconstruct
3DF Zephyr	Automatic UVs are decent, not great, which is expected as it is an automatic process. The visual fidelity of the textures is great and most importantly- really detailed and realistic.	170,438 triangles	Texture map: 4096	Free version available Whole package one-time purchase: €4,200	7-12 minutes
Reality Capture	Automatic UVs are decent. The visual fidelity of the textures are pretty great and realistic.	1,412,453 triangles	Texture map: 4096	One-time purchase: €3,395	10 minutes
Polycam	Automatic UVs are decent. The visual fidelity is great and realistic.	99,999 triangles	Texture map: 4096	Price per month: €79,99	7-10 minutes
Luma AI	Automatic UVs are decent. The visual fidelity of the textures is decent, the quality good, it is realistic, although there are some issues.	149,918 triangles	Texture map: 4096	Free	15-20 minutes
Nerfstudio	Meshlab does not create an automatic UV set, but rather colored vertexes, which is not ideal. Overall	369,229 triangles	Texture map: N/A	Free	5 hours

	quality of the textures is low and not very realistic.				
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Fig. 11 - 3DF Zephyr Textured Mesh Results



Fig. 12 - Reality Capture Mesh Results



Fig. 13 - Polycam Mesh Results



Fig. 14 - Luma AI Mesh Results



Fig. 15 - Nerfstudio Mesh Results

5.1.6 Conclusion

To conclude the first testing, the program that performed best when it comes to time and visual output was 3DF Zephyr. Another advantage is that while the model has the lowest polycount, as seen in Table 8, there are no artifacts or issues, which is more than acceptable. Also, the visual fidelity of the textures is extremely good, which is yet another advantage of the software.

When it comes to photogrammetry, Nerfstudio is going to be tested further as requested by the company. It has potential to contribute to a better workflow through the use of code. As of now, it is definitely not a great quality mesh and textures but the tools are free and can be an addition to the workflow.

Taking into account the concluded software, the following tests will be carried out in the following software/platform: 3DF Zephyr, Nerfstudio.

The obvious choice, being 3DF Zephyr, will be tested further as it is a free software and it got the best results out of the other software.

Nerfstudio and NeRFs in general will be explored further by the request of the company. They are also free tools and can be a promising addition to the workflow.

5.2 Second testing batch- Human object

For this test 14 images were used in order to estimate if this quantity dataset was enough to produce a useful mesh. Main tests were done in 3DF Zephyr and Nerfstudio. To justify, 3DF Zephyr was the software that gave the best results compared to the rest and it is a free tool. The ones that are paid will not be further tested. Nerfstudio is also free, and the company requested that it's tested further and hopefully improved.

In addition, an alternative method was found and tested. It is called Instant NGP, which is a Nvidia product and it is a free way of generating NeRFs instantly without having to wait a couple of hours. The performance and the result is strongly dependent on the computer's components, which is troublesome when it comes to the current testing machine. (360Rumors, 2023)

Nonetheless, the method can be adjusted in a way that is applicable to a new workflow.

More information can be found in Table 8.

5.2.1 3DF Zephyr output

Generation

The second test in Zephyr went smoothly. 3DF Zephyr aligned all 14 out of 14 images. The results were stunning considering the small quantity dataset. Result can be seen below in Figure 16.



Fig. 16- Human Scan 3DF Zephyr Results

As mentioned, the results are of great quality considering the small dataset, which was something that had to be tested as it was required by the company. When it comes to artefacts, there are some places that can be cleaned up. However, the mesh is not ideal for wrapping as it lost a lot of cavity detail.

Problems encountered

There is one little issue that is somewhat visible- the forehead is a bit concaved inwards due to shadows.

5.2.2 Nerfstudio output

Generation

The second test in Nerfstudio was faster due to using smaller dataset. However, the results were not great when it comes to visuals. Implementing extra lines of code to increase the number of sampling and overall improve the quality did not work.

Nerfstudio successfully aligned all 14 images. However, it can be clearly seen that the mesh is not ideal even after optimizing the point cloud. Result can be seen below in Figure 17.



Fig. 17- Human Scan Nerfstudio Results

After testing new lines of code, the result remained to be blobby and having a really bad surface. The issue is still unknown and after researching online for a possible solution, it was found that most of the times the results look like the subject of this test. The issue might be due to the software being unable to reconstruct organic shapes well, as it is mostly intended for hard-surface objects. Another issue is that it does not preserve detail in the texture and is unable to generate UVs or a texture map in general.

Problems encountered

The result takes less time to generate, yet still too long. The mesh is not clean and it would be really troublesome to clean-up without losing the definitions of the shapes, thus losing the personality of the model.

5.2.3 Instant NGP output

Generation

Instant NGP successfully aligned all the images after generating them from a video. In total, it extracted 109 frames from the video, which is a value that can be adjusted according to the length of the video. In general, it is recommended shorter videos to have a higher quantity of images, while longer videos should have less images extracted. This is measured by adjusting the frame value within the code. The higher the number is, more images will be extracted and the lower the number- less will be extracted. After extracting the images, a line of code must be run to estimate their position in space and create the necessary JSON file. Later both the JSON file and the images are inserted in Instant NGP and the NeRF starts training. Usually, depending on the RAM, it takes between 1-4 minutes to train it fully. The more optimized the point cloud, meaning having less unnecessary objects around the model, the better result will come out. The current result can be seen below in Figure 18.



Fig. 18- Human Scan Instant NGP Results

The mesh's surface is still a bit jiggered and has some artifacts, such as holes. However, as it can be seen, the result is looking better than Nerfstudio and it took a lot less time to be reconstructed. It is safe to assume that a little more work and a stronger computer could make the mesh usable for a wrapping software. The result is fast to reconstruct and it requires just a simple video, which makes it ideal for the situation of the company and the clients.

Problems encountered

The most challenging part of this process was to install the necessary libraries and link the API to the Command prompt properly so I can run the Python scripts. Then some compiling errors had to be figured out in the code before generating the JSON file with the camera positions. There was an error related to the Colmap, which was caused due to an incorrect version of the Colmap. After resolving this issue, the toughest process was to figure out Instant NGP and try to extract the best possible result without having it crash due to insufficient CPU memory.

Table 7. Additional information regarding the second testing batch

Software	Texture Map	Polycount	Level of Detail	Total price	Time taken to reconstruct
3DF Zephyr	Automatic UVs are decent, not great, which is expected as it is an automatic process. The visual fidelity of the textures is really impressive, same as the last time. Mesh quality could be improved further by cropping the images and allow the software to	251,552 triangles	Texture map: 4096	Free version available Whole package one-time purchase: €4,200	5-8 minutes

	focus on reconstructing the face.				
Nerfstudio	No automatic UVs, mesh quality is bad.	259,998 triangles	Texture map: N/A	Free	2 hours
Instant NGP	No automatic UVs. Mesh quality is not great, yet still readable and contains the main shape without having a lot of artifacts.	819,560 triangles	Texture map: N/A	Free	5-9 minutes



Fig. 19 - Human Scan 3DF Zephyr Results

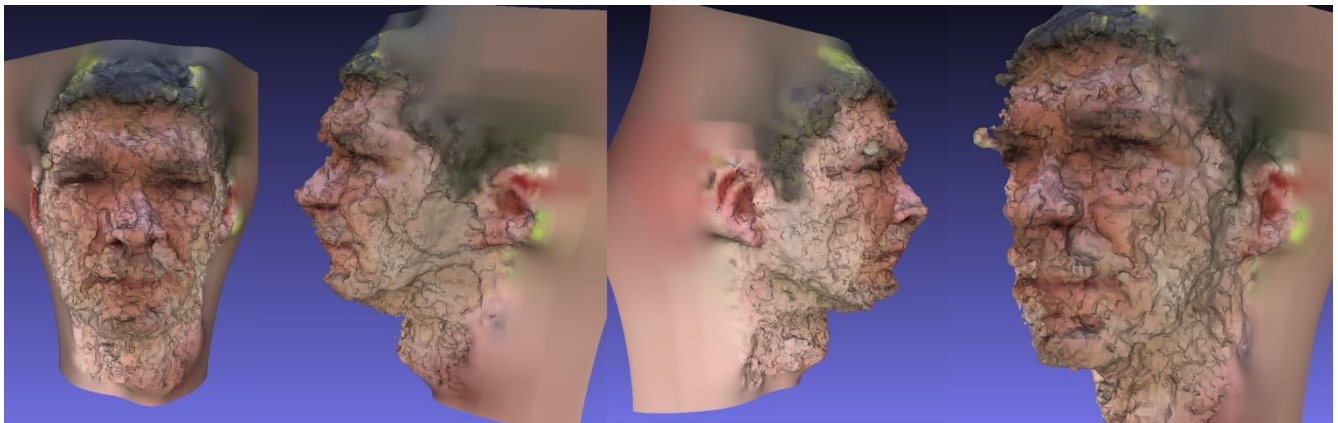


Fig. 20 - Human Scan Nerfstudio Results



Fig. 21 - Human Scan Instant NGP Results

5.2.4 Conclusion

To conclude the second testing, this batch was tested to try out a different feature of Nerfstudio- the Instant NGP platform, which is able to generate NeRFs from a video and do so in a fast manner. In addition, 3DF Zephyr was tested with a significantly smaller dataset than the first testing, in order to see if the result will be acceptable.

The dataset itself was of a human, as the company is primarily treating human scans. Future tests will only be conducted on humans, so that the results can be relevant and estimate the actual best software for the creation of human scans.

As seen in the results, 3DF Zephyr is the software that did the cleanest job when it comes to mesh and texture quality. Nerfstudio is not able to reconstruct accurate or even usable results, which means that it will not be tested any further.

When it comes to Instant NGP, the results were better than Nerfstudio, one downside is that the quality of the outcome depends almost entirely on the specifications of the computer. This makes further testing nearly irrelevant as the current testing computer is not capable of reconstructing better results. This would mean that testing the platform any further is not meaningful. Nevertheless, the algorithm for extracting images from a video can be applied to a workflow, as it is an easy method for the client to deal with.

5.3 Third testing batch- Human object

The third test was conducted in order to estimate the minimal quantity of images needed to reconstruct a useful scan. The process was done to answer sub-question 2.

There were several datasets, which contained different quantity of images. One had 5 images, the next contained 8, third had 10 and the final one had 12. The low quantity images were requested by the company. The lower the number, the less effort for the clients.

As proven from the previous test batch, the results from 14 images is of great fidelity. This test is intended to show what number can create a scan that can fit within several requirements:

1. Mesh is detailed, does not contain artifacts, and is not jiggered
2. Texture map is detailed and does not contain artifacts
3. The polycount is not high
4. The total reconstruction time does not take more than 10 minutes

The software that was used for this test was only 3DF Zephyr. As mentioned in the previous conclusion, it is the software that gives really good results, even with a small dataset and will be recommended for a workflow.

More information can be found in Table 9.

5.3.1 Output with dataset of 5 images

Generation

By using this small dataset of images, the software was unable to reconstruct any point cloud at all. There is not enough data for it to build marker points and be able to find similar angles. Further processes such as generating a mesh are unfeasible.

5.3.2 Output with dataset of 8 images

Generation

This dataset was able to align all 8 out of 8 images. The results, however, are not satisfactory. It can be clearly seen in Figure 22 below, some important parts of the mesh, such as the nose area, mouth, and the eye area, were not reconstructed at all. This means that this quantity is still not good enough to produce a usable mesh.



Fig. 22 - Human Scan 8 images result

5.3.3 Output with dataset of 10 images

Generation

3DF Zephyr was able to align all 10 out of 10 images of this dataset. This time it was able to reconstruct the nose area, which is still not perfect. However there are other more bothering issues. The left side of the face is really jiggered and is it simply unusable. There is still no detail in the eye or mouth area, which is not ideal when wrapping. Overall, this amount of images is also not ideal. Results can be seen in Figure 23 below.



Fig. 23 - Human Scan 10 images result

5.3.4 Output with dataset of 12 images

Generation

3DF Zephyr aligned 12 out of 12 images. However, there is not a lot of improvement. Left side is still in a bad condition, as well as mouth and eye area. In conclusion, this amount of images is also not ideal. Results can be seen in Figure 24 below.



Fig. 24 - Human Scan 12 images result

Table 8. Additional information regarding the third testing batch

Software	Test Quantity	Texture Map	Polycount	Level of Detail	Time taken to reconstruct
3DF Zephyr	5 images	N/O	N/O	N/O	N/O
	8 images	Texture map is detailed	175,235 triangles	Texture map: 4096	3 minutes
	10 images	Texture map is detailed	195,000 triangles	Texture map: 4096	4 minutes

	12 images	Texture map is detailed	210,122 triangles	Texture map: 4096	5-6 minutes
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Fig. 25 - Human Scan 8 images result



Fig. 26 - Human Scan 10 images result



Fig. 27 - Human Scan 12 images result

5.3.5 Conclusion

To conclude the third testing batch, 3DF Zephyr requires a lot more photos to produce a usable mesh. The first test produced no outcome as the software was unable to capture any relative points from that small dataset.

The second test was successful with aligning images, however the mesh is not useful, which goes for all the other tests. Simply put, smaller quantity of images does not work properly in a photogrammetry software, as it does not support interpolation.

Minimal requirement would be at least 40 images, or the maximum amount of 50 images allowed in the software, which are a close-up. This will ensure that the software will focus on reconstructing properly just the face and will not focus on other areas that are unnecessary. Another ideal adjustment is to increase contrast and have a less cluttered background. This will also help the software focus on the essential parts of the object.

5.4 Fourth testing batch- Human subject

By utilizing some photogrammetry theories, this test was conducted to enhance the outcomes of the prior one. Two actions were done that were intended to significantly differ the result from the prior experiment:

- a video was used, which made close-up shots easier and also this method cannot lose any frames, thus contributing to a clean reconstruction
 - extracting images from a video is an easy process and it happens fast, thus is efficient
 - it was optional, but the image dataset was altered in an external software, called Lightroom (see Appendix I for further details). The image was slightly flattened to help bring some of the shapes out and thus help the reconstruction.
- More information can be found in Table 10.

5.4.1 3DF Zephyr output

Generation

The software successfully aligned 50 out of 50 images. This time the result is significantly better and it can be seen that the steps taken beforehand really improved the reconstruction. The close-up shots allow the software to focus on that area without reconstructing objects that are unnecessary, such as jackets or anything from the background. The mesh is acceptable for the wrapping process. See Figure 28.

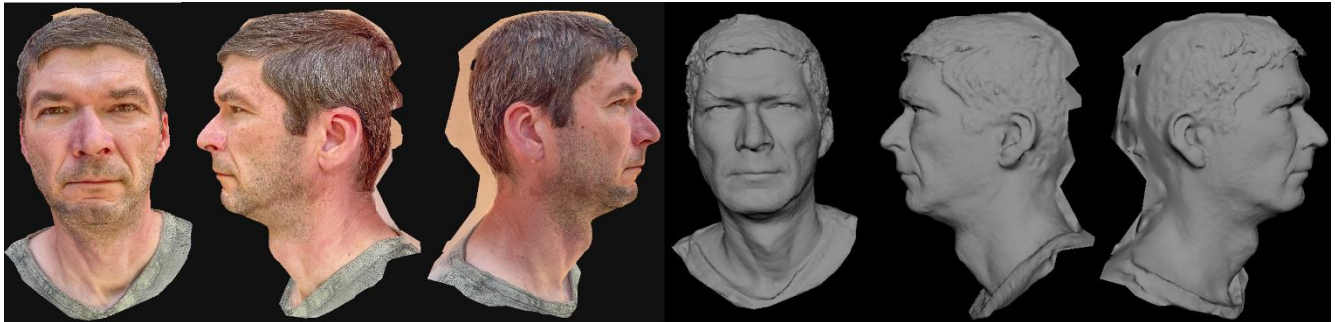


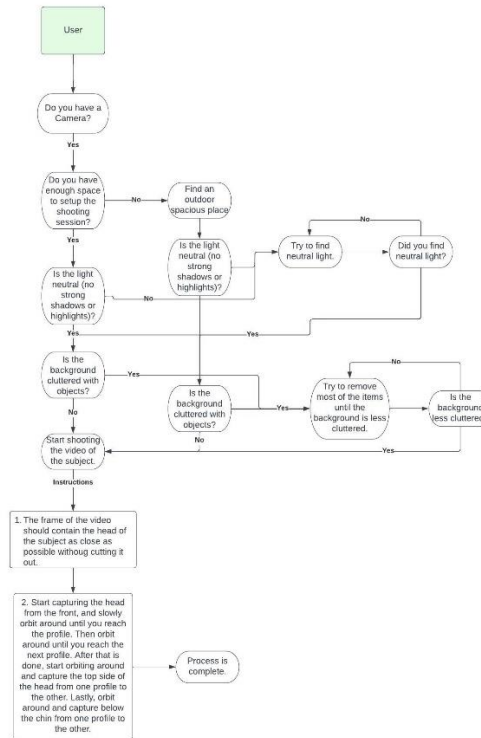
Fig. 28- Human scan output after improvements

Table 9. Additional information regarding the fourth test

Software	3DF Zephyr
Mesh Quality	Clean mesh and all features and characteristics are captured
Texture Map	Texture map is very detailed and have automatic UVs
Polycount	74,372 triangles
Level of Detail	Texture map: 4096
Time Taken per process	<ul style="list-style-type: none"> • Frame extraction: 15 minutes • Frame editing: 4-5 minutes • Reconstruction: 10 minutes

Based on the knowledge obtained a short user journey chart was developed, which contains the steps needed for a video capturing session. In addition, a visual user guide was created, in order to make the instructions when capturing more comprehensible. Please see Chart 1 and Figure 29 below.

Chart 1. User journey chart



5.4.2 Conclusion

To conclude, the results of this process were successful, and the 3D scan is treatable for the wrapping process. The changes of the process, such as taking a close-up video, extracting images from it, and editing the images so they become flatter really enhanced the result. It is a method that takes a bit more time than the previous processes, but the results are clean and useable. In addition, the time it takes is acceptable, and the method of extracting images from a video is one that can be easily explained to clients and is not technical, thus saving time and easing the client's task.

When it comes to technical results, the mesh is not heavy, as it has very low triangles quantity, compared to other meshes, which will have a positive effect when wrapping. Some heavy meshes, containing millions of triangles sometimes slow down the wrapping software and that can be bothersome. The texture map is extremely detailed and the automatic UVs are acceptable.

5.5 Fifth test- Wrapping the Scan

This test was conducted in order to answer sub-questions 3 and 4. Different software for wrapping had to be tested in order to estimate average time needed for an artist to wrap a scan. By doing so, each process will reveal what could be slowing down the workflow and if it can be improved.

The scan that was used for wrapping was the very final scan, created in 3DF Zephyr. To justify, 3DF Zephyr gives the best and fastest results so far, based on the input dataset of 50 images which is the maximum amount allowed in the software.

As mentioned in 1.4 the current workflow uses R3DS Wrap3, which is a wrapping software specifically for scans. As discussed in 3.6 there are also alternative wrapping methods/software that could be a way to speed up the process.

This test's purpose was to practice all the different software, figure out the ones that were unfamiliar, and look for steps that might be confusing and unnecessary. The tested software were as follows: Houdini, ZBrush, Autodesk Mudbox, and R3DS Wrap3.

Two versions were created with each software that allows point-based feature selection, meaning pasting points to define the deforming areas. Only Mudbox was not point-based, but rather copying detail in a displacement map.

For more information regarding the tests please see Appendix III.

Houdini Wrapping

As seen below, the first mesh contains the target topology and the second (yellow) mesh contains the target shape. This test was done with **less points** being placed.

See Figure 29 below.

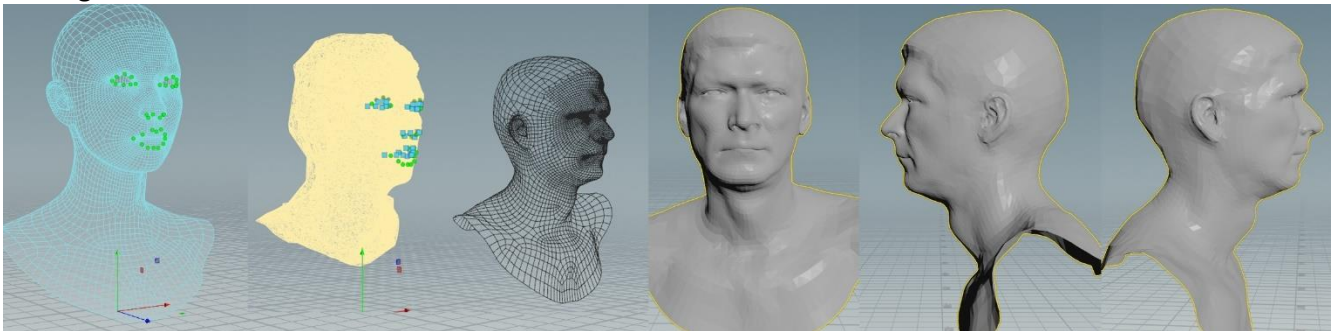


Figure 29. Wrapped model with less points- Houdini

The wrapping process lost a lot of the definitive shape of the lips, eyes, and nose. This would mean that the point cloud is not enough and the model would need a lot of clean-up in a sculpting software, for instance.

A second try was initiated, where **more points** were added in order to see if this will improve the result. See Figure 30 below.

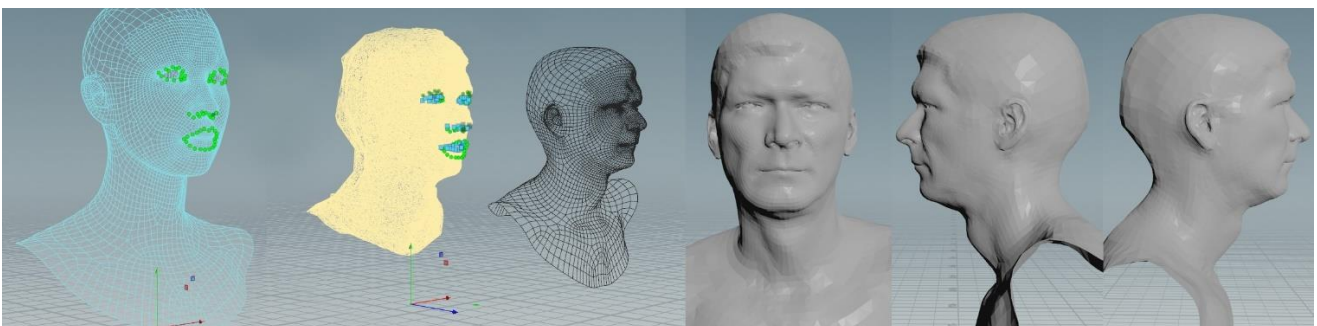


Figure 30. Wrapped model with more points- Houdini

The result had an obvious improvement on the mouth and nose area, however, the eye area was still not up to standard.

Wrapping

Same as in Houdini, two wraps were created. First wrap was done with **less target points**. As mentioned, the process in ZBrush is similar to the R3DS Wrap3 one. See figure 31 below.

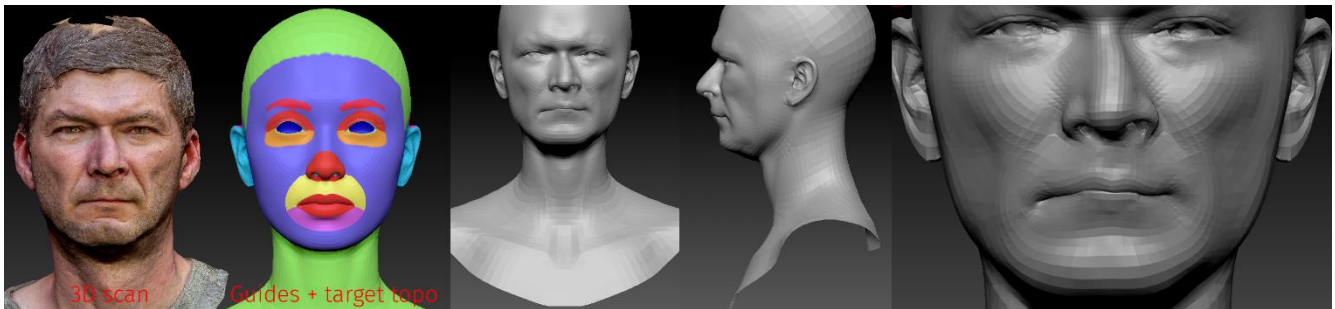


Figure 31. Wrapped model with less points- ZBrush

As it can be seen, the result is not perfect and there is some features missing in the mouth and eye area mostly.

By adding **more target points**, the wrap should be better. See Figure 32 below.



Figure 32. Wrapped model with more points- ZBrush

Although not perfect, the result is a lot more accurate to the scan than the previous result, having less points. See below after adding Morph target in Figure 33.

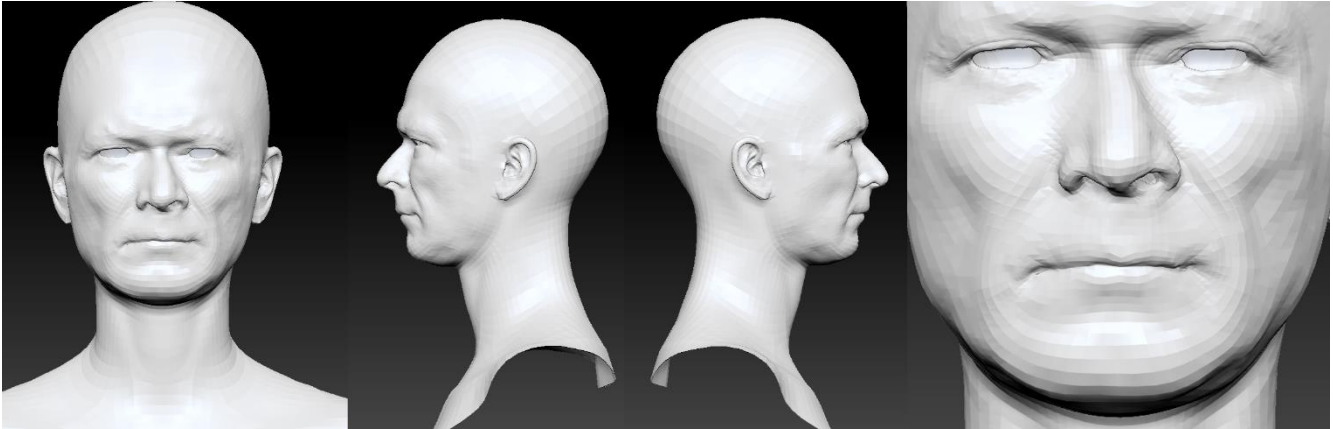


Figure 33. Wrapped model after Morph target- ZBrush

Mudbox Extraction

When it comes to topology transfer, Mudbox's way is to extract a displacement map. See Figure 34 below.



Figure 34. Projected detail- Mudbox

As it can be seen, this method is not ideal for the current situation, because it causes too many issues that are hard to fix.

R3DS Wrap3 Wrapping

Two wraps were created in order to estimate the proper number of points needed. First one is the one created with **less target points**. In contrast with other software, R3DS Wrap3 really allows one to be precise and it is really easy to work when you set it up. In Figure 35 is the result of the first wrap with less points.

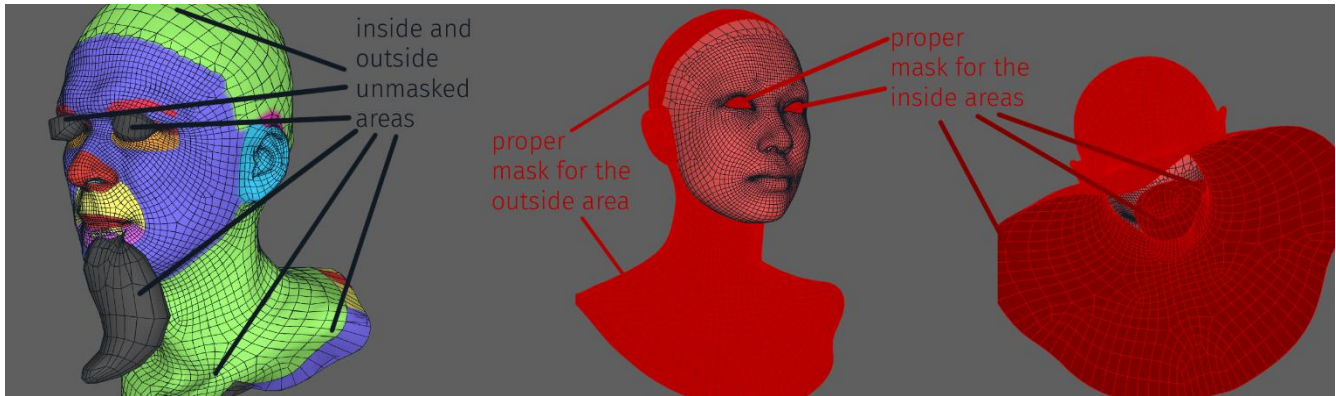


Figure 35. Result of wrapping without a mask and proper mask displayed

As it can be seen, the result is not ideal and that is because a mask hasn't been set up, and R3DS Wrap3 is really demanding when it comes to masking. See results after masking in Figure 36 below.

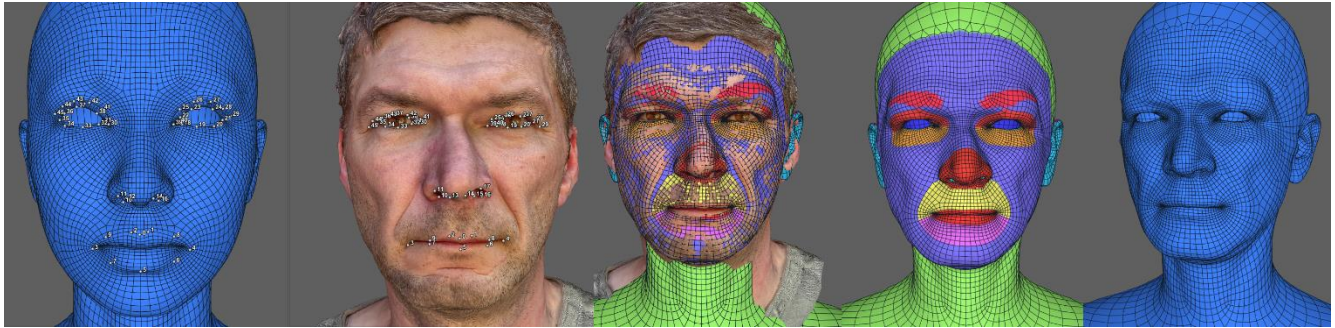


Figure 36. Wrapped model with less points- R3DS Wrap3

Same procedure was applied, same masking and aligning method, but this time **more target points** were added, which took a little more time, but they really defined important features. See results in Figure 37.

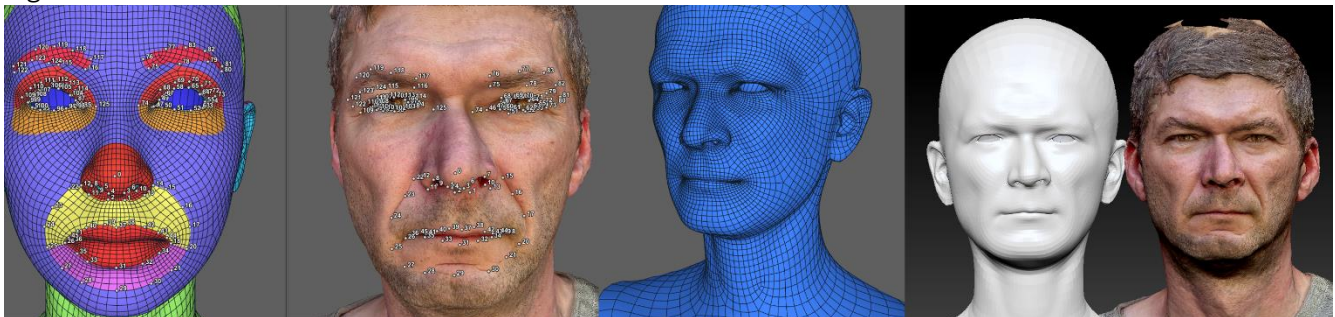


Figure 37. Wrapped model with more points- R3DS Wrap3

Overall, both methods worked better than other software because the advantages and tools of R3DS Wrap3 are more and make the workflow easier and faster. In general, Adding more points really helped define the important guidelines, but less points also could capture the features and the model is looking a lot more accurate to the scan than in other software.

5.5.8 Conclusion

The software that gives the best outcome and requires minimum clean-up afterwards was R3DS Wrap3. It is a flexible workflow that allows easy control over the meshes, is capable of capturing the details and has all the necessary functions for wrapping, unlike other software that lack some useful ones. Also, the result's appeal is closest to the 3D scan.

To summarize, best option is to use the current workflow of the company when it comes to wrapping, but change the 3D scan capturing method.

5.6 Sixth test- Testing Workflow

This test was carried out in order to validate if the workflow really is efficient and can be done quickly. To estimate improvement, the whole process must be finished under the previously stated 7 hours. As demonstrated in previous tests, the process cannot be automated, as it still requires a human input. Nonetheless, the necessary time and technical knowledge can be reduced so that the production time of a scan is shortened.

As seen in previous tests, the best result comes from 3DF Zephyr for scan extraction and R3DS Wrap3 in terms of wrapping. In this test the whole process was measured, from extracting frames to a video to a production-ready mesh.

Process

The model was not the same male model, instead a female model, in order to validate the results with a different characteristics. A 35-second video was taken out of which 55 frames were extracted. The unnecessary 5 overlapping frames were deleted. After that the images were placed in 3DF Zephyr and generated the 3D scan.

The next step was to place the scan in R3DS Wrap3 and do the wrapping process. After a little clean-up when the scan was ready the model was placed in ZBrush and the shapes were tweaked a bit in order to define some characteristics like wrinkles. The result can be seen below in Figure 38.



Figure 38. Production-ready model

This model was successfully done by following the workflow and no problems were encountered. More technical information about the time taken to finish each procedure can be seen in Table 11.

5.7 Image extraction improvement through custom script

Installing and dealing with Instant NGP so that one can use the image extraction function seemed too unnecessary and somewhat time-consuming. In order to remove the need for it a custom script was created which made the whole workflow a lot easier and also faster. Through the use of OpenCV, the

script extracts images in a matter of seconds instead of approximately 20 minutes. More information can be found in Appendix III.

Table 10. Additional information regarding the sixth test

Process	Software	Remarks	Time Taken	Total time
Image extraction from a video	Command Prompt	Depending on the length of the video, the value of frame extraction should be taken into account in order to save time and extract the amount of images needed, which is 50.	18 minutes	1 hour 30 minutes
3D scan Generation	3DF Zephyr	All the settings were set to highest, which usually takes more time.	8 minutes	
Wrapping the 3D scan	R3DS Wrap3	A big amount of target points were placed in order to achieve an accurate result.	25-30 minutes.	
Editing Morph target and adding characteristics in ZBrush	ZBrush	Morph target was added and restored in order to restore some shapes like neck, head, and ears. Later some of the brushes were used in order to add some of the wrinkles back.	30 minutes	

5.8 Workflow tested by an artist from the company

In order to test and validate the main research question, a draft workflow document guide was created to demonstrate the process and summarize all the gained knowledge from the sub-questions. The feedback was essential in order to validate if the workflow is in a good direction and the guide is clear enough.

5.8.1 Tester

As the company is in a tough spot and requires most members working on separate projects, only one tester could be organized. The draft guide was given to that individual who has a lot of knowledge in creative programs.

Nathan Ecury: Nathan is a Saxion graduate with a CMGT bachelor degree. He is really experienced in 3D modeling and using Maya in particular.

5.8.2 Test results

The result of the test were successful. The tester managed to reconstruct an object in 3DF Zephyr. The whole process took the user approximately 2-3 hours.

The tester shared that having all that images as a guide is really helpful. They also shared that the result of the scan are much better than those in Polycam, also the whole process is easier and less technical.

They stated that using a video is a cleaner method than having to orbit around and taking pictures, as doing both actions led to ruined shots and thus incorrect reconstructions. In addition, the tester stated that this would really make the life of the client easier. Ultimately, it is, quote “a huge win”, for the company.

5.8.3 Conclusion

Additional feedback stated that having a video would be also really useful, yet the document is clear enough as well. Another remark was to better explain tools, actions and settings that are most used. The feedback was taken into account and certain steps were taken in order to improve on the current products:

- New, cleaner layout was done in order to better represent and explain the steps.
- A video was made with an explanation for each step.

Note: as most artists are familiar with R3DS Wrap3, the guide is brief and does not go too much into detail.

6. Conclusion and discussion

A big variety of scanning tools and software were tested, in order to see which method is best applicable to answer the main research questions and become a solution to the issues at hand. As discovered, the best photogrammetry and overall scan-creation tool is 3DF Zephyr. Comparing it to other photogrammetry software, 3DF Zephyr is free, and it reconstructs better results in all tests on average. Other photogrammetry programs that can generate decent results, but they are extremely costly.

On the other hand the NeRF technology is promising and is at some point expected to surpass photogrammetry. However, although NeRFs being free to use, they have high requirements for both computer setup and time. Currently, although having this technology free, it takes way too long to create an outcome, which in the end is not ideal to work with. If using Instant NGP and have a machine with greater specifications might be able to generate a clean NeRF but it is a speculation, as it cannot be tested further.

It is equally important how a scan is generated and created. When it comes to image quantity and a way to capture images for a 3D scan, a video is the cleanest method. Consistent pictures and no missing angles guarantee maintained details throughout reconstruction. It also makes it possible to zoom in or maintain a constant distance between the camera and the model without worrying that it won't match earlier pictures.

Creating a custom code also boosted the results and overall showed less time needed for extraction compared to the previous method, which was to use the script within Instant NGP.

Several choices for wrapping software were tested, some of which are industry standards and others which are not as well known in this field. R3DS Wrap3 is the most effective wrapping program overall. The most crucial feature that makes this software the best is that its node functionalities are straightforward to grasp. In contrast to Houdini's UI, which feels much more densely packed, in R3DS Wrap3 is neat and orderly.

Another reason that makes R3DS Wrap3 better is that there is no need for manual alignment of the scan and the model, which is a process that has to be done manually in any other software.

The overall wrapping process is better and the result much cleaner and accurate because of the better dot-placing. That is why R3DS Wrap3 has proven to be most reliable when it comes to wrapping. There is also the option to be used in ZBrush, however some features are then unavailable.

Overall, the process cannot be fully automated, as the results will not be accurate and will undoubtedly lack certain characteristics, which could be crucial for accurate representation of the model and thus realism. As proven, the workflow can be faster and better in terms of technical requirements for the clients and pipeline for the company. Nonetheless, it still requires a human interference in order to adjust or add characteristics to the model.

7. Recommendation

A certain recommendations were given to the company based on the findings of the research.

When it comes to tools that make a good 3D scan, a safe and efficient option for the company would be to consider using 3DF Zephyr instead of Polycam. It is free, unlike Polycam, and it is really easy to use.

The results are of great quality and ideal for wrapping.

The maximal amount of images needed for the software are 50, and it has shown that having 50 images to use will definitely give results of great quality. If combined with the image extraction from a video workflow, this might really allow the company reach new markets, as the expectations for the clients are low and are not demanding. It is easy to explain to people that lack technical knowledge and overall allows to capture a lot of frames and also close-up detail, which makes for a better reconstruction.

The cleanest workflow to treat 3D scans is by wrapping them in R3DS Wrap3. The software allows most control over technical parameters and overall gives best results.

To validate Instant NGP can reconstruct useful scans, it should be tested on a powerful PC. If applicable, this can be a pretty good technique to quickly generate scans. Not to mention that it does not require any subscription.

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Appendix I

Additional theory and knowledge

1. Creation of neural fields

The output is a volume whose color and density are dependent on the direction of view and emitted light radiance at that point. For each ray, there is an output volume and all volumes make up a complex scene. (Karagiannakos, 2022) The actual operation uses the 3D physical location and the 2D direction, the simulated camera is pointing at, for the input and then generates a response as a color and density for each pixel image, as seen in Figure 39. (Lawton, 2023) A static scene is represented as a continuous function.

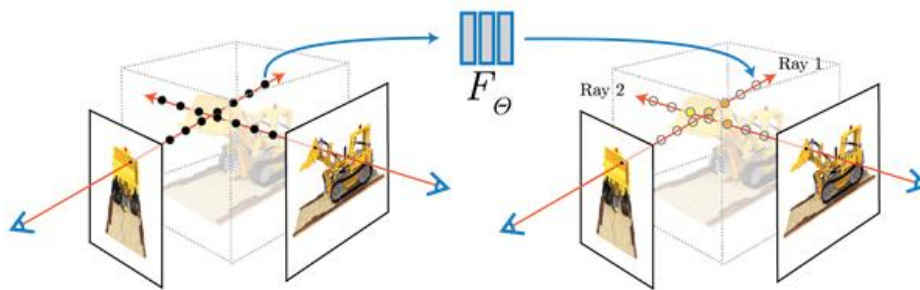


Fig. 39 - Neural Radiance Rays forming a volume point

In order to create a NeRF it must be trained. The training algorithm needs images or scene captured in different points of view. It then calculates the relative position each image was taken from and then uses this data to adjust the weights on the neural network nodes until their output matches these images. This process creates a point cloud, which is a visual representation of the vertexes that would later form the mesh. (Niyemer, 2021)

2. Laser Scanning

3D laser scanning is a technology that uses lasers to measure an object's geometry to create a digital 3D model. This technology is used throughout a number of industries, as 3D laser scanning can capture three-dimensional data of objects, regardless of their size and surface. (Duncan-Parnell, 2018) One of the advantages is the quality control. When it comes to ensuring that products are being properly produced, 3D laser scanning is quickly becoming a must. It has proven its value by being able to provide users with a quick update on a product's construction. For example, a company can take the data gained from a scan to catch any errors that have been made and correct them before a product is unveiled to the public.

3. Difference between Nerfstudio and Luma AI

Similarly to Luma AI, Nerfstudio also generates NeRFs. However there are a few differences that really distinguish the one method from the other. While Luma AI need a bigger batch of images in order to produce an output, Nerfstudio can manage to generate the scene from a very small number of images, depending on the complexity of the object. The reason is because of the interpolation. Through the use

of machine learning, NeRF assumes consistency, both spatial and temporal, in its input views. As long as the object is static, through images taken from dramatically different viewpoints, in different time of the day or a season, NeRF will be able to interpolate and create a believable result. The machine learning algorithms can go a lot further and the results can be fascinating once writing the most appropriate script for targeted object.

Another difference that is favoring Luma AI is that there is no need to understand Colmap, which is a general-purpose structure-from-motion and multi-view stereo pipeline with a graphical and command interface. Colmap is used in order to generate a transform JSON file which contains the scripted information regarding the camera positions. Colmap is one of the struggles when dealing with reconstructing on a computer. Luma AI has their own camera pose estimation pipeline. However, they share a few similarities as well. Both Luma AI and Nerfstudio take a lot of time generating output. Needless to say, that depends primarily on the parameters of the device, and the algorithms used.

4. Lightroom- software for photo improvements

Lightroom is a non-destructive photo editing software that keeps original image separate from any in-program edits. Compared to Photoshop, Lightroom is a library and development software. It does not allow editing of non-photographic images, such as drawings, symbols, line art, etc. (Wikipedia contributors, 2023)

The advantage when using the software is that it allows non-destructive editing of a batch of images. It can store a huge dataset and allow manipulations be applied from 1 image to all the rest of the batch. This process is called synchronized edit and it is really powerful, as the user does not need to edit image per image, and later can export the whole batch at once.

5. PIFuHD- Multi-Level Pixel-Aligned Implicit Function for High-Resolution 3D Human Digitalization

This algorithm is a product of recent advances in image-based 3D human shapes. Estimations have been driven by the significant improvement in representation power afforded by deep neural networks. As the current approaches have demonstrated the potential in real world settings, they still fail to produce a reconstruction with a level of detail often present in the input image. This is due to two conflicting requirements: accurate predictions require large context, but precise predictions require high resolution. This limitation is addressed by formulating a multi-level architecture that is end-to-end trainable. That enables context to a fine level which estimates highly detailed geometry by observing higher-resolution images. Meaning, the higher the resolution, the better the result. (PIFuHD, n.d.)

6. Autodesk Maya

Maya is a 3D software that is used to model 3D assets for film, games, television, commercials, and many more. The software is widely used in the industry and it is one of the standard ones. It has a ton of functionality from modeling to animating, creating groomers, retopology, creating UV maps, rendering, and also supports custom controllers and plug-ins.

Maya is also very good for editing and polishing scans as it has the sculpting tools that are necessary and also can great blendshapes, which is very useful when it comes to testing 3D scans. It is most commonly used to clean-up the shape of the new topology and optimize if needed.

7. Types of Photogrammetry

As observed by TOPS (n.d.) photogrammetry is widely used in many different industries, such as medicine, construction, nature preservation, historic monuments and artefacts preservation, gaming and many more. As stated in the research from TOPS (n.d.) these industries primarily use either aerial or close-range photogrammetry, which depends on the user's objectives.

Aerial photogrammetry is used for large-scale objects like entire cities, mountains, or buildings. It is also used for educational purposes, obtaining precise mathematical measurements, and preservation purposes. (All The Science, 2023) One of its best uses it to measure large terrains in order to provide information and make planning easier.

Close-range photogrammetry is used primarily for small to medium-scale objects and is more widely used in multiple industries. Close-range photogrammetry is widely used in the fashion and clothing industry for the creation of believable avatars, reconstructing real-life garments into the digital fashion world, and much more.

7. Photogrammetry software used by professionals

- **Reality Capture-** Reality Capture is a photogrammetry software for making 3D models out of photos or laser checks without cases. It is widely used in social legacy, full body filtering, gaming, reviewing, planning, and augmented reality. It allows the creation of ultra-realistic 3D models from a set of images and/or laser scans. Other strong points are automatic image alignment, automatic calibration, calculating a polygon mesh, coloring, texturing, parallel projection, simplification, scaling, filtration, smoothing, measurement, inspection, and multiple export/import formats. A developer kit is also accessible.
- **3DF Zephyr-** 3DF Zephyr is developed by 3DFLOW and was originally released as 3DF Zephyr Pro, which was a consumer-centered version. Soon the 3DF Zephyr Lite version was released and afterwards GIS and map-centric version called 3DF Zephyr Aerial. Currently, the previous versions were discontinued and a new, merged version was released (Zephyr 3DF). (Wikipedia contributors, 2022)
- **Polycam-** Polycam is the leading 3D capture application for iPhone and iPad. It creates high-quality 3D models from photos with any iPhone and rapidly generates scans of spaces with the LiDAR sensor. It allows editing captures directly from the device, and export in multiple formats. Other highlights are the ability to take unlimited measurements with inch-level accuracy, and creating accurate floor plans with the LiDAR sensor. (App store, 2020)
- **Luma AI-** Luma is a new way to create incredible lifelike 3D with AI using your iPhone. (App store, 2022) It captures three-dimensional images using a technology known as Neural Radiance Fields (NeRF). It's similar to the ray-tracing technique that makes the graphics in high-end gaming look so realistic. The NeRFs have been around for a few years now but with the introduction to AI image generation, NeRFs are just beginning to be explored. (Truly, 2022) The machine learning behind the Radiance Fields allows one to render completely new angles of the given object, making it ideal for 3D video making and even creating 3D objects.

- **Nerfstudio**- Nerfstudio provides a simple API that allows for a simplified end-to-end process of creating, training, and visualizing NeRFs. The library supports an interpretable implementation of NeRFs by modularizing each component. (Contents, n.d.) The developers provide a big quantity of resources in order to understand the basics and also keep it up-to-date so that everyone can get onboarded with this next-gen technology. As this technology is still evolving, it is mostly intended for hard-surface objects, which have a clearly defined shapes.

Appendix II

Additional methods

1. Additional method to speed up the process

When using the real textures from the scans, it can really overwhelm the process of integrating them in a software or a platform. They take up more space and overall are more work for the developer to match them with a certain face. As Reblika's goal is to implement all the scanned faces in a software, developed by them, they suggested that creating template textures will indefinitely reduce the production time, as cleaning up textures can be demanding.

This method is really efficient and if there are specific features such as scars, or models, they can be added as a texture separately.

Appendix III

Additional tests

1. Additional test using Machine Learning

An interesting opportunity was discovered during desk research. It is a Python algorithm that uses machine learning to generate full-body 3D models out of only 1 image. It is a really advanced and innovative method of quickly creating human bodies. The method is called PIFuHD, which stands for Multi-Level Pixel-Aligned Implicit Function for High-Resolution 3D Human Digitalization. Even Facebook / Meta AI are developing a similar tool. It is based on neural networks, similar to NeRFs.

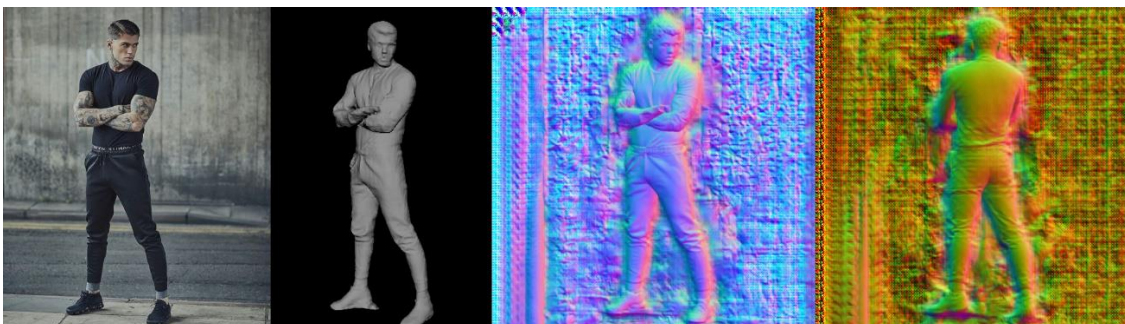


Fig. 40- 3D model generated out of an image from the researcher

Two tests were conducted with images from previous sessions, in order to see if it can successfully generate a model of a face from a single image.

Generation 1

The generation input is as mentioned only one image. The image used is from the dataset used in test 3. The generation starts once there is an image input and finishes by allowing the user to download an .obj and a .png file containing the textures. Result can be seen below in Figure 41.

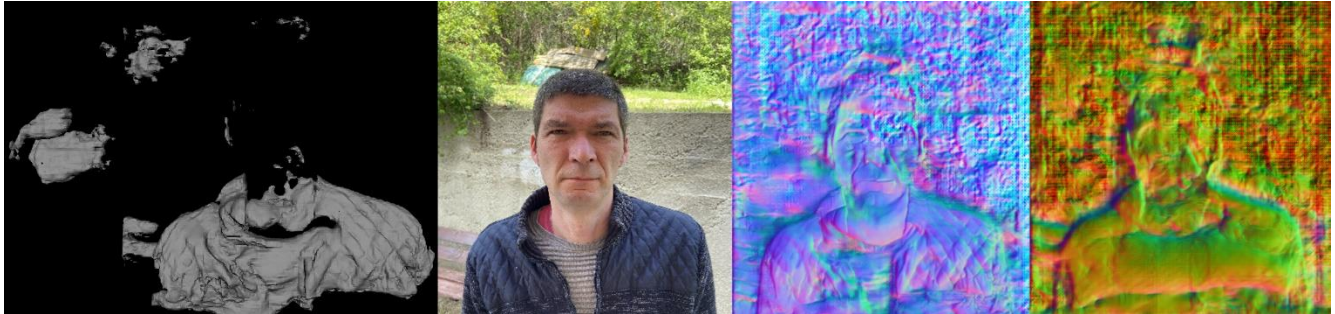


Fig. 41- 3D model from generation 1

As it can be seen, the result is of no use and the algorithm does not work properly for people. It generates some parts of the clothing, which can lead to the conclusion that it is created for primarily clothing generation, using machine learning to interpolate the back side of the model and also predict folds. That is why in Figure 40 it can be seen how detailed the clothing is and the face is not detailed at all.

Generation 2

In order to test the hypothesis and make sure that this method is unapplicable, the dataset from test 4 was used, as it has almost no clothing. Results of the test can be seen below in Figure 42.

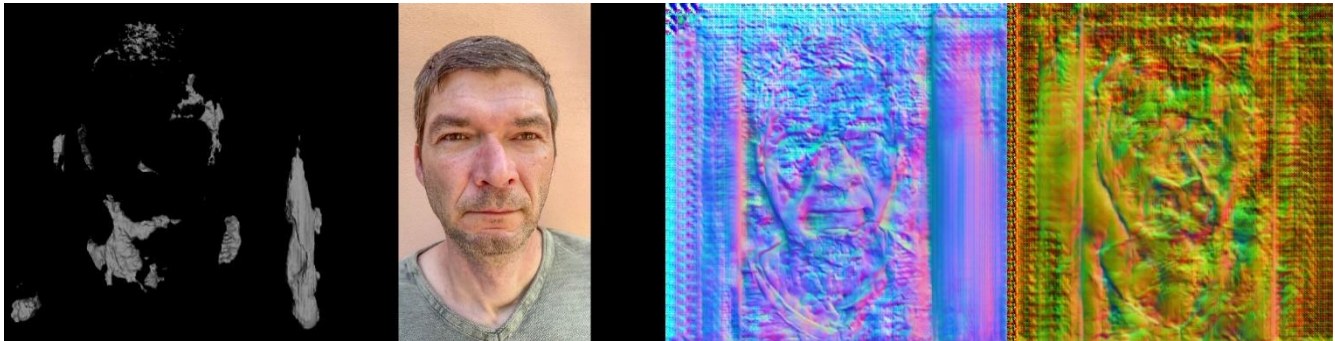


Fig. 42- 3D model from generation 2

The mesh is barely generated. As speculated, the algorithm cannot be used as a solution as it cannot handle human faces at all.

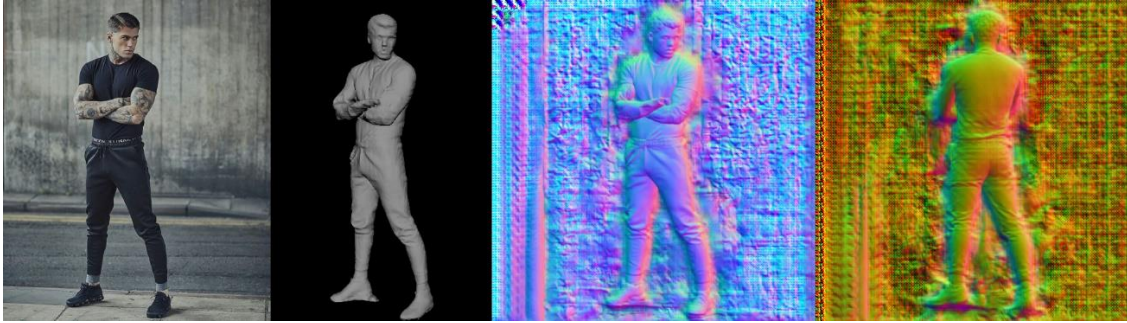


Fig. 43- 3D model generated out of an image from the researcher

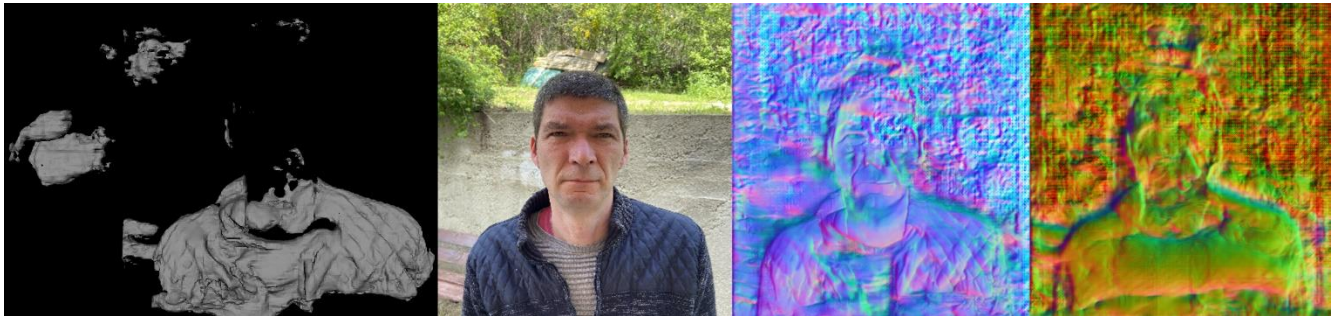


Fig. 44- 3D model from generation 1

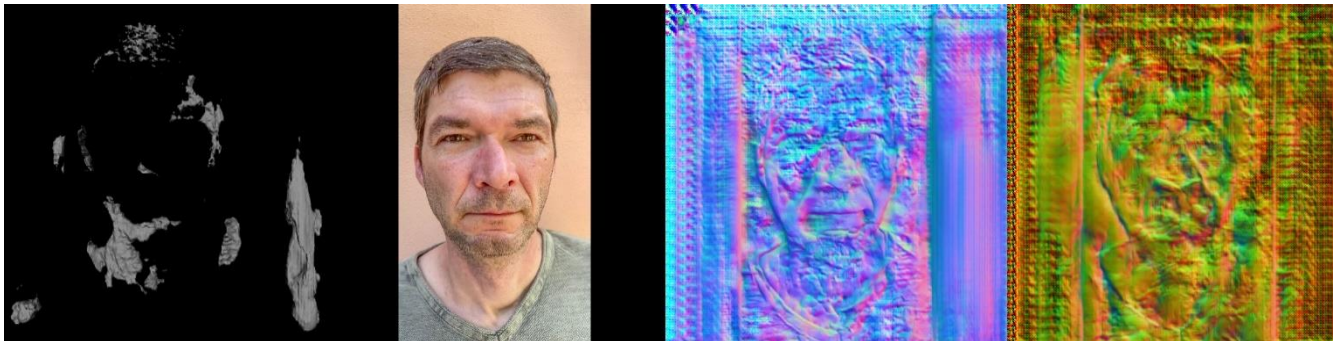


Fig. 45- 3D model from generation 2

Conclusion

To conclude, this method was required to be tested by the company as a possible method that can generate 3D models of faces. Unfortunately, it does not work of faces at all.

2. Additional test using Blender Addon- FaceBuilder

For this test, Blender was used. This software is similar to Maya, but the difference is that it is free and it is also widely used in the industry.

After doing desk research, it was discovered that the software is capable of a similar function to wrapping, yet not the same. The addon used is called FaceBuilder and it is also free.

After installing the addon, the user can insert a default head and the desired images and start with the process.

Overall, similarly to R3DS Wrap3, this addon also uses dot-placing to capture the shapes, only it happens in real-time. The mesh is deformed instantly while dragging each dot to the shape in the

image. One disadvantage is that the mesh is in wireframe mode so it is really burdensome to see where to place the dot correctly.

The result can be seen below in Figure 46.

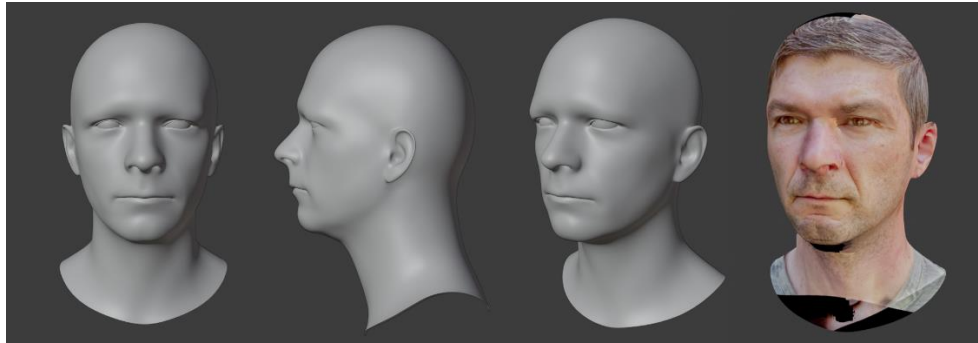


Figure 46. FaceBuilder model

Conclusion

Overall, the final result was not perfect or completely accurate and would still require a lot more sculpting to fix. Not to mention that the mesh is not the custom one that the company uses so this means that the topology is different and thus it is unusable.

3. Fifth test: Intermediary tests full information

3.1 Houdini wrapping output- less points

Wrapping

As seen below, the first mesh contains the target topology and the second (yellow) mesh contains the target shape. When wrapping, the final result has the target topology and the target shape, as it can be seen.

When it comes to wrapping, Houdini has a very simple workflow. It is based on 3-4 nodes. However, as the software removes all textures while placing points, this made the process tougher and the results distorted. The first mesh was created with a smaller amount of points in order to compare later if more points bring a better result and if small amount is still enough. See Figure 47 below.

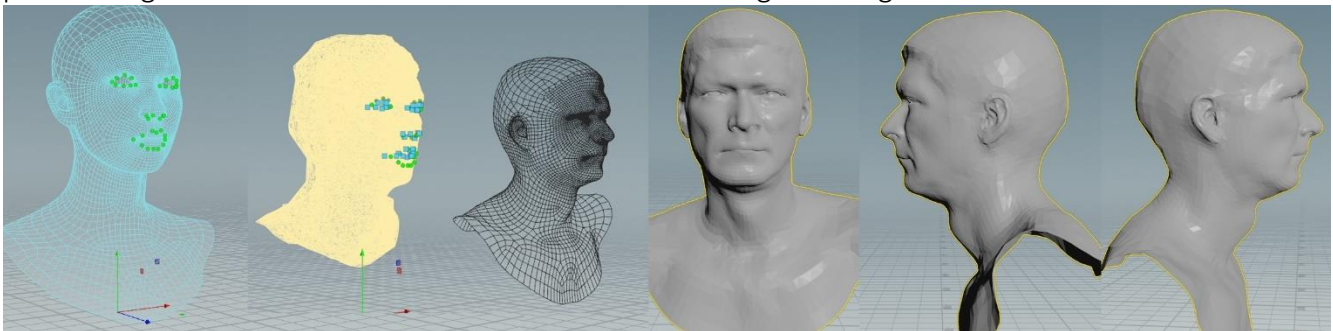


Figure 47. Wrapped model with less points- Houdini

When dealing with scans there is one really important aspect, that is the clavicle area, or the area below the neck, must remain the same. For that, a morph target is most commonly used that can preserve or copy MT from one model to another. It is most easily used in ZBrush or Maya.

As seen in Figure 37, this area is not preserved well which means that it would have to be exported from Houdini and fixed in one of the above mentioned software. Also, the wrapping process lost a lot of the definitive shape of the lips, eyes, and nose. This would mean that the point cloud is not enough and the model would need a lot of clean-up in a sculpting software, for instance.

3.2 Houdini wrapping output- more points

Wrapping

As mentioned above, getting as much of the features and characteristics as possible from the wrapping process is a requirement. That is why a second try was initiated, where more points were added in order to see if this will improve the result. See Figure 48 below.

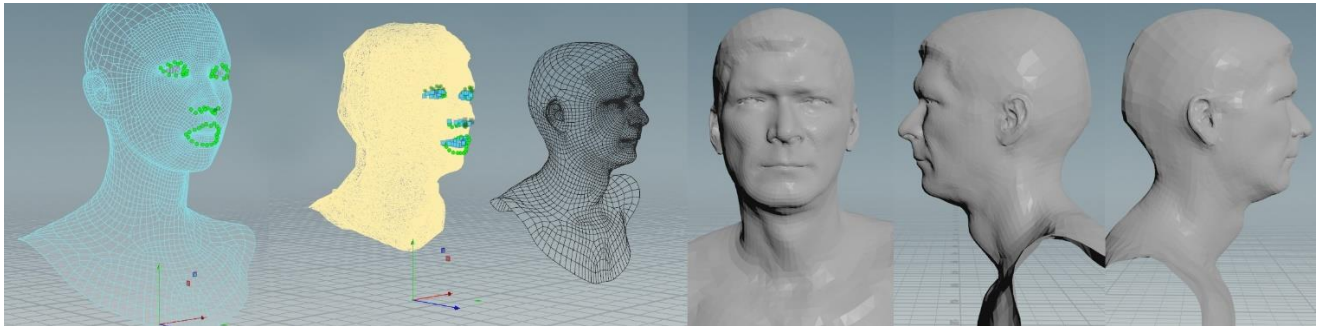


Figure 48. Wrapped model with more points- Houdini

The result had an obvious improvement on the mouth and nose area, however, the eye area was still not up to standard. As the textures are not visible, it is really hard to decide where each point should be, which makes this process unrecommendable and not user-friendly at all.

3.3 ZBrush wrapping output- less points

Wrapping

Same as in Houdini, two wraps were created, one with more and one with less points.

As mentioned, the process in ZBrush is similar to the R3DS Wrap3 one. All textures are visible and the texture created as a guide can be applied. This makes the whole process easier. See figure 49 below.

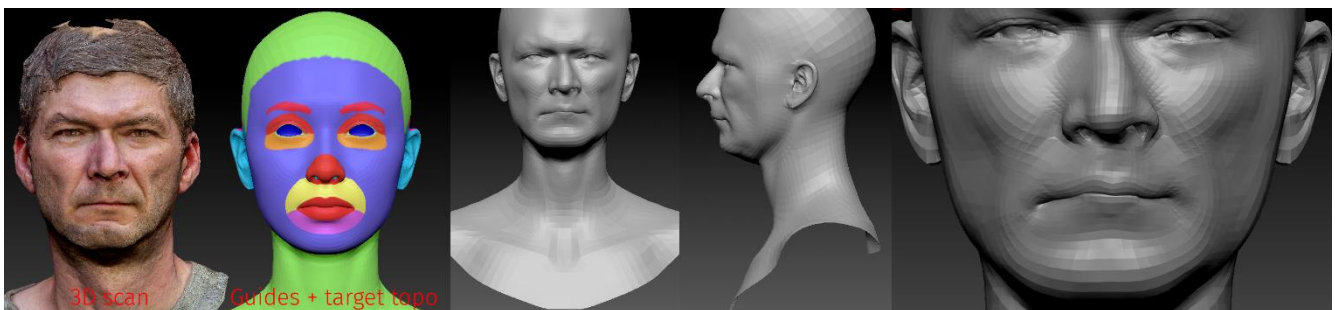


Figure 49. Wrapped model with less points- ZBrush

As it can be seen, the result is not perfect and there is some features missing in the mouth and eye area mostly. The result has a lot to fix if left like this. This means that this method is not ideal and adding more points is necessary.

3.4 ZBrush wrapping output- more points

Wrapping

By adding more target points, the wrap will inevitably become better. It takes a bit more time, although sculpting it to bring back the detail will most likely take more time.

In this case is better to focus on placing useful target points. The result of the second ZBrush wrap with more points can be seen in Figure 50 below.



Figure 50. Wrapped model with more points- ZBrush

Although not perfect, the result is a lot more accurate to the scan than the previous result, having less points. The nose area can be improved but overall this time the software did a really good job of capturing essential characteristics. See below after adding Morph target in Figure 51.

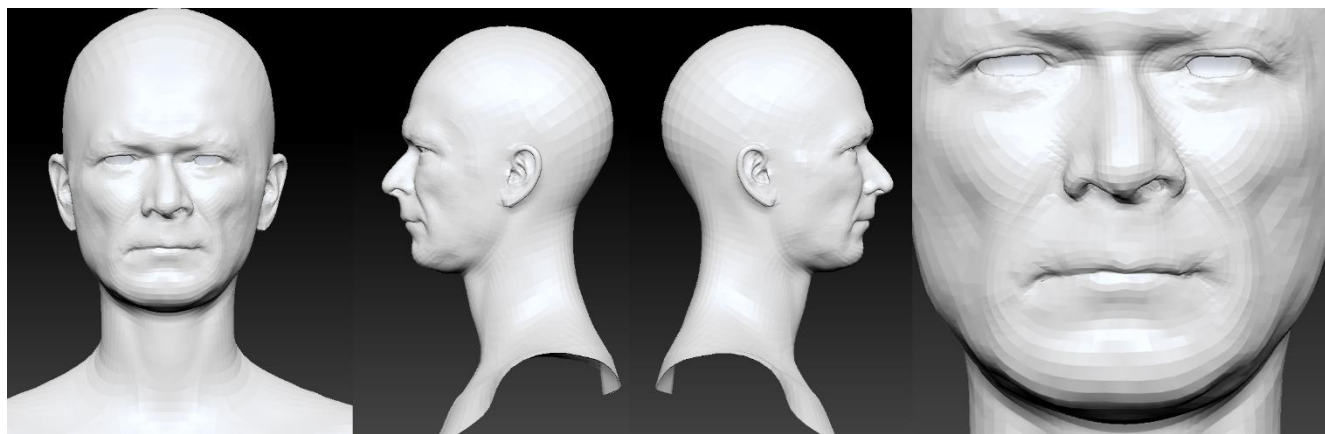


Figure 51. Wrapped model after Morph target- ZBrush

The Morph target sometimes tends to remove or smooth-out some of the detail. That is why sometimes it is essential to sculpt back some of the features, such as neck, chin, cheekbones, etc. Nonetheless, adding Morph target is essential to the workflow, otherwise the avatars would look uneven and crooked overall. The animations will have holes and it will be very unclear. Overall, ZBrush did a really good job when wrapping the scan and it can be sculpted on after which makes it really easy.

3.5 Mudbox output

Extraction

When it comes to topology transfer, Mudbox's way is to extract a displacement map.

To extract the map, first the target topology must be well aligned with the 3D scan. Afterwards, it is a good idea to use sculpting tools and cover the scan with the base mesh. This process ensures that details will be lost. Then an extraction is done and a displacement map is created.

Next step is to subdivide the model which will ensure that it will be able to capture detail. Afterwards, a projection is done on the previous topology and usually the result is available. See Figure 52 below.



Figure 52. Projected detail- Mudbox

As it can be seen, this method is not suitable at all. There are a couple of reasons which came to be after testing.

Firstly, the topology around the eyes and the mouth area is terrible. That is because of the eye sockets and the mouth hole. This kind of projection likes flat topology, one without holes for eyes or mouth, or nose holes, but rather flat. As it turned out, having this "hidden topology" is causing issues and the projection can never be clean.

Another issue is that subdividing the base mesh changes the topology. If reducing it, it would be hard to get to the exact number and it will destroy the overall look of the 3D scan. If remeshing it, it will make a new topology, new edge flow, and it will not match the one of the body, which can lead to broken UV maps and other issues.

All in all, this method is not ideal for the current situation, because it causes too many issues that are hard to fix.

3.6 R3DS Wrap3 wrapping output- less points

Wrapping

Two wraps were created in order to estimate the proper number of points needed. First one is the one created with less points. In contrast with other software, R3DS Wrap3 really allows one to be precise and it is really easy to work when you set it up.

In Figure 52 is the result of the first wrap with less points.

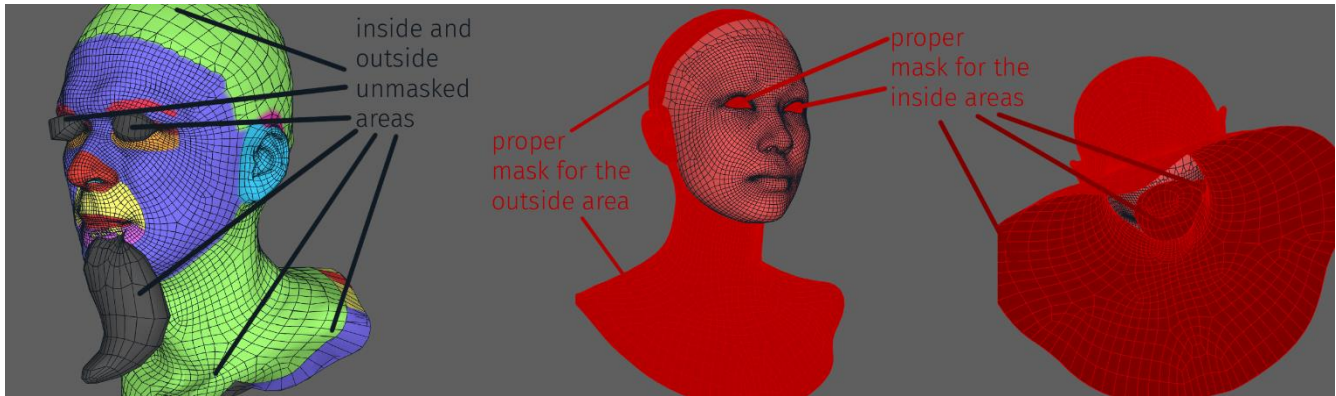


Figure 53. Result of wrapping without a mask and proper mask displayed

As it can be seen, the result is not ideal and that is because a mask hasn't been set up, and R3DS Wrap3 is really demanding when it comes to masking. The unwanted pieces are the ones in dark gray and they are the topology that is inside the base mesh, mouth hole and eye sockets. Another issue if not masking also the outside is that there will have to be more cleaning afterwards when doing the Morph target, which can take away some detail. It is easy to avoid losing topology later by setting a proper mask in the beginning. Not to mention, that the mask can be exported and re-used for the specific topology, which is really handy. See results after masking in Figure 53 below.

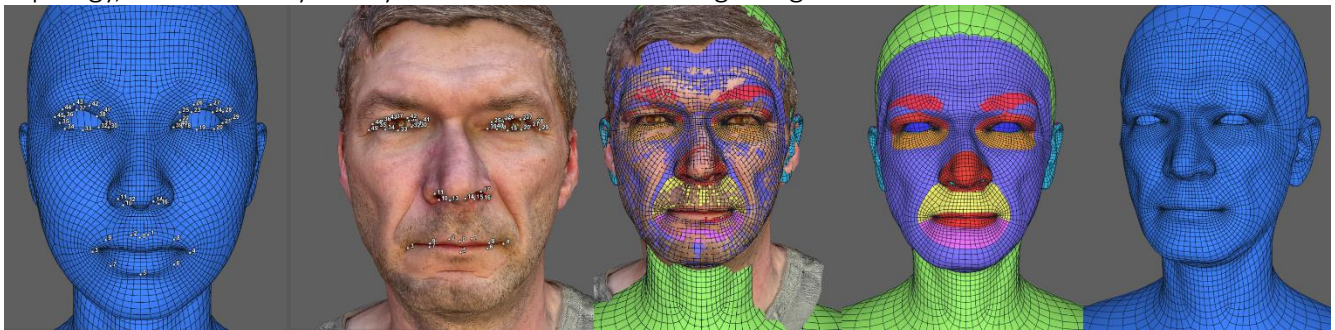


Figure 54. Wrapped model with less points-R3DS Wrap3

In general, the more overlap there is between the scan and the new topology after the wrapping the better the wrap is. As it can be seen in the middle of the image, there is a good amount of overlap, and most of the features are correct. However some of the guidelines are not following the shape flow properly, so that is why there is another wrap with more points, and more accurate ones.

3.7 R3DS Wrap3 wrapping output- more points

Wrapping

Same procedure was applied, same masking and aligning method, but this time more target points were added, which took a little more time, but they really defined important features. See results in Figure 54.

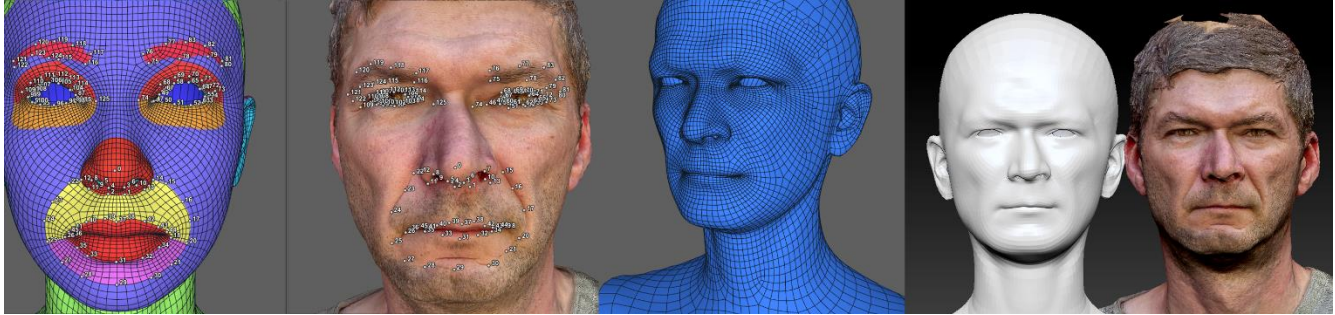


Figure 55. Wrapped model with more points-R3DS Wrap3

Overall, this worked better than other software because the advantages and tools of R3DS Wrap3 are more and make the workflow easier and faster. In general, Adding more points really helped define the important guidelines, but less points also could capture the features and the model is looking a lot more accurate to the scan than in other software.

4. Image extraction improvement through custom script information

Installing and dealing with Instant NGP so that one can use the image extraction function seemed too unnecessary and somewhat time-consuming. In order to remove the need for it a custom script was created which made the whole workflow a lot easier and also faster.

Through the use of OpenCV, the script extracts images in a matter of seconds instead of approximately 20 minutes. It is based on a variant which extracts images based on frames per second. If a video would be 25 seconds and is 60 frames per seconds, the image quantity extracted will be approximately 1500 images. This amount is extreme, which made the variant of the script unusable. After some desk research, it was discovered a way that would extract frames after a couple frames. This count is a variable that is changeable. Also, for the sake of convenience, the script automatically creates a folder for the images within the main folder. The whole process is really easy and most importantly- fast. To examine the code snipped, see Figure 56 below.

```

1 import cv2
2 import os
3
4 cap = cv2.VideoCapture('video.MOV') #change the name of the video and the extensions
5
6
7 count = 0
8
9 cam = cv2.VideoCapture("video.MOV") #change the name of the video and the extension
10
11 #-----
12 try:
13     if not os.path.exists('data'):
14         os.makedirs('data')
15 except OSError:
16     print("Error: Creating Directory of Data")
17
18 #-----
19 if input("Process is starting, have you saved and double-checked? (y/n)") != "y":
20     exit()
21
22 #-----
23 while cap.isOpened():
24
25     ret, frame = cap.read()
26
27     if ret:
28
29         cv2.imwrite('data/frame{:d}.jpg'.format(count), frame)
30
31         #-----
32         count += 15 # i.e. at 30 fps, this advances one second, meaning a 24 second video is going to extract around 25 frames *CHANGE THIS DEPENDING IN THE VIDEO LENGTH*
33         #-----
34         cap.set(cv2.CAP_PROP_POS_FRAMES, count)
35
36     else:
37         cap.release()
38
39         print("Image Extraction Complete!")
40
41         break
42

```

Figure 56. Image extraction code snipped

Appendix IV

Software User Journeys

3DF Zephyr User journey

3DF Zephyr is a straight-forward and easy to navigate through software. The menus and icons are clear and self-explanatory. The 3D orientation is similar to Maya's and it easy to get used to. When it comes to reconstructing, the software has a step-by-step method of generating an output. First step is to import datasets for reconstruction. Sometimes there are issues that do not recognize some of the images if the calibration is incorrect or unrecognized. In these certain cases it is a good practice to import the dataset into two different pieces. The following step of the process is generating a sparse cloud, or point cloud, based on the images and then generate a mesh, and lastly extract a textured mesh. There are two way of approaching this process:

1. First step is to generate a sparse cloud and generate a 3D textured model directly from it, which might sometimes result in a less detailed texture and mesh normal, and usually the vertex carries the texture and not the model.
2. Generate a dense sparse cloud, then extract a mesh and later generate a textured mesh, which then is an actual texture and not a textured vertex.

Reality Capture User journey

Reality Capture's interface was overwhelming and somewhat challenging. It is not very user-friendly when it comes to clarity of the workflow. Not to mention that most of the online tutorials contain a

different-looking UI and some options were not the same or even existed anymore. Still, there is a dedicated page that contains explanations and tutorials that can help guide the user. The navigation within the 3D space can be confusing. A major inconvenience is that in order to export a mesh, the user must pay credits, called PPI (Pay-Per-Input). The price per export is approximately 0.34 cents per export.

Polycam User journey

Polycam's web version was unable to reconstruct the object as importing images is not available. Instead, the tester had to use the mobile application. The interface is pretty understandable as the only thing the user must do is capture images same as a camera. Afterwards, the application processed and reconstructed the object.

Luma AI User journey

Luma AI's interface is extremely user-friendly. There are no additional steps that one must take in order to proceed with scanning. Luma AI presents three options when it comes to scanning:

1. The "Upload" option allows one to upload a pre-taken dataset of images.
2. The second option, and the most user-friendly one is the "Guided" option which contains explanations before scanning, which gives the user a clear idea of what is expected of them.
3. The "Freeform" option is most likely meant for more experienced users. It allows them to make a scanning session without guidance.

The researcher used the "Guidance" option, which needs at least a 180 degrees rotation around the object so it can define it and create the bounding box, which can later be adjusted manually.

Afterwards, the process is essentially following the lines around the bounding box and the application makes the shots automatically.

Nerfstudio User journey

The online installation guide (Installation, n.d.) and a video tutorial (EveryPoint, 2022) were used to get Nerfstudio working. The process can be extremely overwhelming for someone that does not do scripting every so often. In order to start the process a certain few things must be done. One of the things is to download a proper prompt that support this process then install Python 3.8 through the prompt. Later a few commands must be added, such as creating the environment for the codes, installing Pytorch and depending on the machine a CUDA must be installed. There are a few other commands that must be executed, but Nerfstudio has an extensive guide online, which provides the users with the necessary information. There is also a really helpful Discord server.

Instant NGP User journey

The installation followed the guides from Github (NVLabs, n.d.) and a video tutorial (bycloudump, 2022). The installation of the API is one of the hardest steps the user must take to use this algorithm. It also Python-based such as Nerfstudio. The UI/UX is somewhat clear but it contains the most important settings while training, rendering, and exporting the model. As mentioned earlier, the result is entirely dependent on the capability of the computer, but also the resolution and clarity of the images. The bigger and less blurry or noisy the image is, the better the result. These conditions cannot be fully met for this research as the researcher does not possess the setup to meet the needs for a high-quality product. Nevertheless, this method is capable of producing really clean and highly-detailed results, as

seen after some research. The result of this test is better than the one in Nerfstudio and was constructed in significantly less time.

Houdini Wrapping User journey

Houdini is a complex software, as it is not only 3D but also node-based. In general, whatever action is intended a corresponding node has to be created. The UI also feels a bit cluttered. Navigation within the software is good, although sometimes, for instance while in a certain node, one can only move or pan while holding ALT key, which can be frustrating.

ZBrush Wrapping User journey

It is really handy to wrap within ZBrush as it allows you to further sculpt and add details after the wrapping without switching software. Another handy thing is that the user can use masking of ZBrush, which is really powerful when combined with polygroups. Almost every wrapping process requires a mask for those areas, as there is topology for the eye sockets and mouth area, which should remain unchanged.

It should be noted that the plug-in for wrapping, or Zwrap, is not available by default in the software. It needs to be downloaded and installed to the current ZBrush version used, otherwise it won't work.

The processes are straight-forward, and as the plug-in is based on R3DS Wrap3 it makes it very easy to get, especially if one is familiar with R3DS Wrap3.

Placement of 3D objects in the Subtool hierarchy is really important, as it might not give the desired results if not placed properly. The mesh on the very top should be the target topology, or the clean mesh. Then the unclean 3D scan should be placed below the target topology.

Mudbox User journey

As mentioned, Mudbox is a software which is not doing wrapping. Instead, the process here is a lot different.

To begin with, this is a software for sculpting and painting, and mostly for creating custom topology. The software is not as complex as Houdini for example, and if one is familiar with Maya orienting withing it will be easy, as they use the same controls. The main menus for sculpting, painting, or transforming the object are down below and are self-explanatory. All the necessary tools are within these menus.

R3DS Wrap3 Wrapping User journey

R3DS Wrap3 is a node-based software as mentioned earlier. The wrapping process takes a couple of nodes, but the more advanced nodes added, the better the scan. It has an advantage over the plug-in for ZBrush, because here there are advanced nodes for masking, aligning, cleaning up and smoothing.

More information regarding test four

The subject of the test was the same male model used in the previous takes, only this time a video was taken, instead of images. By doing so, it was ensured that there will be consistency with the shots and a good amount of overlapping images will be available for 3DF Zephyr. Another advantage of taking a video is that one can get closer to the model with the camera and capture detail without worrying of missing out frames, which could be crucial for a proper reconstruction. In addition, the light was neutral which really helps the shots come out more even and not have strong highlights or shadows.

The video was later ran through a code which extracts a certain amount of frames per second, which depends on the input of the user. In this case 55 frames, or images, were extracted from a 24-second video. Later 5 frames were removed in order to stay within the limit of 3DF Zephyr.

An additional adjustment had to be done in order to improve the scan. The 50 images were placed in Lightroom, in order to adjust the contrast, exposure, highlights, and shadows. Refer to Appendix I to see additional information regarding Lightroom.

Overall, a little exposure was added, a little decrease of the contrast, shadows were increased, and highlights decreased. This step is optional but it really helps with reconstructing as it makes the images flatter, which helps 3DF Zephyr capture more of the detail, and thus not create dented surfaces.

The whole extraction of frames and editing tool about 15 to 20 minutes, which is acceptable.

Appendix V

Links to final products

1. Link to Final Document Guide

<https://drive.google.com/drive/u/2/folders/1kQvfAKE9YXJOHYOsfPYMCv0SS2oUOM-j>

2. Link to Final Video Guide

https://drive.google.com/drive/u/2/folders/1PqLO_Zb_THNA2DE1uqGu0FYpf_1pCc1w