Bachelor’s thesis

Information and Communications Technology

2023

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The use of smartphones in the content production of applied games

TURKU AMK
TURKU UNIVERSITY OF APPLIED SCIENCES

Bachelor’s Thesis | Abstract

Turku University of Applied Sciences

Information and Communications Technology

2023 | 50 pages

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The use of smartphones in the content production of applied games

There exist multiple techniques for simplifying a 3D modelling workflow, particularly for intricate models. Contemporary practices in game development include constructing models utilising photogrammetry and Neural Radience Field (NeRF) techniques and Light Detection and Ranging (LiDAR) to laser scan objects. However, industry-standard setups for these approaches may entail a significant expense, occasionally amounting up to 50,000 euros.

The primary objective of this thesis was to explore the feasibility of using smartphones as a substitute tool for creating content in an applied game. To compare the effectiveness of this approach, three applications were selected to represent the smartphone capabilities (photogrammetry, NeRF, LiDAR) and were evaluated against an industry-standard DSLR camera photogrammetry. Two separate real-life objects were chosen for the purpose of converting them into three-dimensional models. This was accomplished by first deploying a suitable LED lighting arrangement and then conventional indoor lighting within a specifically designed area for object capturing. The outcome of these tests was 16 results from the first set of tests and 4 from the second set.

Based on the findings, smartphone NeRF and photogrammetry outperformed digital camera photogrammetry in terms of creating comprehensive and detailed models. However, the texturing accuracy of smartphone-generated models was slightly lower than that of the digital camera. The LiDAR scans were of unsatisfactory quality although this outcome was somewhat expected.

In conclusion, smartphones are indeed a viable technique for 3D modelling and often a better alternative to the costly and more time-consuming digital camera photogrammetry. In particular, NeRF technology may surpass all other tested methods in the future.

Keywords:

Photogrammetry, LiDAR, NeRF, DSLR, Applied games

Opinnäytetyö (AMK) | Tiivistelmä

Turun ammattikorkeakoulu

Tieto- ja viestintätekniikka

2023 | 50 sivua

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Älypuhelimien käyttö hyötypelien sisällöntuotannossa

On olemassa useita tekniikoita 3D-mallinnuksen työnkulun yksinkertaistamiseksi erityisesti monimutkaisille malleille. Pelikehityksen nykykäytäntöihin voi kuulua mallien rakentaminen fotogrammetrian ja Neural Radience Fieldin (NeRF) tekniikoita käyttäen tai valontunnistuksen ja etäisyyden (LiDAR) avulla objektien laserskannaus. Näiden lähestymistapojen standardikokoonpanot voivat kuitenkin aiheuttaa merkittäviä kustannuksia.

Tämän opinnäytetyön ensisijaisena tavoitteena oli selvittää älypuhelimien käyttökelpoisuutta korvaavana työkaluna sisällön luomiseen hyötypelissä. Käyttökelpoisuuden vertaamiseksi valittiin kolme älypuhelimen sovellusta (fotogrammetria, NeRF, LiDAR), ja niitä arvioitiin alan standardinmukaista DSLR-kameran fotogrammetriaa vastaan. Tutkimukseen valittiin kaksi erillistä objektia ja tarkoituksena oli muuntaa ne kolmiulotteisiksi malleiksi. Tämä saavutettiin ottamalla käyttöön ensin sopiva LED-valaistus ja sitten perinteinen sisävalaistus kohdekuvausta varten suunnitellulla alueella.

Tulosten perusteella voidaan päätellä, että älypuhelinten NeRF ja fotogrammetria ylittivät digitaalikameroiden fotogrammetrian kattavien ja yksityiskohtaisten mallien luomisessa. Älypuhelimilla luotujen mallien teksturointitarkkuus oli kuitenkin hieman pienempi kuin digitaalikameran. LiDAR-skannaukset olivat laadultaan heikkoja, ja tämä lopputulos olikin odotettu.

Voidaan päätellä, että älypuhelimen tekniikka on todellakin käyttökelpoinen 3D-mallinnukseen ja usein parempi vaihtoehto kalliille ja aikaa vievälle digitaalikameroiden avulla tehtävälle fotogrammetrialle. Erityisesti NeRF-teknologia voi tulevaisuudessa ylittää kaikki muut testatut menetelmät.

Asiasanat:

Fotogrammetria, LiDAR, NeRF, DSLR, Hyötypeli

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List of abbreviations

Blender	A free, open-source 3D modelling software
DSLR	A digital single-lens reflex camera
LiDAR	Light Detection and Ranging (NOAA, 2023)
NeRF	Neural Radiance Field
Vertex	A corner of a 3D shape
Face	Flat surface of a 3D shape
Edge	A straight line between faces of a 3D shape

1 Introduction

Smartphones are ubiquitous, with nearly everyone owning one. Many essential aspects of our lives are stored on them, and the number of smartphone users is expected to reach around seven billion by 2027 (Petroc, T. 2023).

Most of us associate phones as a tool for small everyday tasks or a gateway to a promised land of mobile gaming, which incidentally dominates the gaming industry market with a revenue share of over 40% (Grandview Research, 2022). However, not only are phones a device to play games with, but also a tool to be used in the development phase of games. In this case, they can be used to bring objects from real life to the development environment of an applied game by creating a 3D model using various smartphone applications.

These are methods in which a real-world object is analysed to collect data on its shape and appearance, which can be used to build 3D models. This process has multiple different tools available, from gathering data with numerous images using Photogrammetry and NeRF (Neural Radience Field) to laser scanning an environment or an object with LiDAR (Light Detection and Ranging). While these tools significantly improve and hasten the workflow for incredibly complex models, a proper LiDAR setup can cost well over 50 000 euros (Hetherington, E 2021). Hence, the improvements in smartphone capabilities are a blessing for an indie to AAA developers alike since one may easily carry a smartphone with a fraction of the cost of a DSLR (Digital Single-Lens Reflex) camera and proper lighting or a 3D scanner mounted on an aircraft or a drone.

This thesis is completed in collaboration with Turku Game Lab, a joint working environment of the Turku University of Applied Sciences for students of technical and artistic backgrounds. The objective is to demonstrate the capabilities of using different modelling technologies on a smartphone (Photogrammetry, LiDAR, NeRF) to produce an applied game’s content. Two models created with these three technologies will then be compared to photogrammetry models of a digital camera to determine the usefulness of smartphones in a developmentary environment. The prime objective is not to simply narrow down the difference in modelling workflow between smartphone and industry-standard digital camera setups but also to demonstrate the versatile utility and user-friendliness of a standard smartphone for the future of game development.

Chapter 2 of this thesis narrates existing research on smartphone and digital camera rivalry in 3D scanning and photogrammetry and compares these methods to more traditional ones. Chapter 3 thoroughly analyses the theoretical aspects by elaborating on Applied games, Photogrammetry, NeRF, LiDAR and the entire workflow behind them. Chapter 4 of this thesis further elaborates on the aims and objectives of this research, followed by methodology in Chapter 5. Chapter 6 showcases the results of this study, followed by the discussion section of these results in Chapter 7 and lastly, the conclusion and recommendation in Chapter 8.

2 Theoretical background

2.1 Smartphone versus a digital camera

Despite the growing popularity of smartphone-based 3D modelling workflows, research into their potential as an alternative to more traditional digital camera Photogrammetry is still in its early stages. Samosir and Riyadi (2020) experimented to better understand the differences in quality between 3D objects captured using a smartphone and a DSLR camera. The study's conclusion found that the quality of geometric and texture data produced by smartphone-based photogrammetry is comparable to or exceeds that obtained from DSLR-based photogrammetry. Smartphones were also found to be advantageous due to their size, weight, and portability.

On the contrary, Saif and Alshibani (2022) found that a Digital Camera's geometrical detail representation, mesh quality and final textures were of higher quality than smartphones, yielding a more photorealistic result. Although the smartphones' geometric detail and textured models were of lesser quality, processing time was significantly reduced. It is worth noting that while results will differ based on the model of both devices, smartphone scans were never seen as sub-par quality.

2.2 Photogrammetry, scanning and traditional methods

Bures and Polcar (2016) conducted a study comparing the time and accuracy of traditional modelling techniques with those of an industrial scanner when creating a 3D model of a workplace. On average, the 3D scanning method was four times faster than the classical 3D modelling and more precise by 3 cm to 5 cm. Albeit faster than the traditional method, the scanned model contained some completely missing parts and was inferior to the traditional one. This indicates that scanning is an excellent method for speeding up a modelling workflow but cannot be used as a ready model.

Another study by Cardaci and Versaci (2013) set out to analyse medieval outdoor architecture by creating a 3D model with Photogrammetry and laser scanning and comparing these methods. They found that while requiring a high-end computer to process the final scan, the laser scanner is more suitable for quickly acquiring geometric data. In this case, Photogrammetry with a digital camera was found to be lacking, as the “ideal condition for the photographs taking does not necessarily coincide with that of the laser”. While not as accurate as laser scanning, Photogrammetry had its strengths in texture qualities. We can conclude that both methods will perform differently in certain conditions, such as lighting. In this thesis, this subject area will be expanded further by taking lighting and other variables into consideration.

3 Theory and workflow

3.1 What is an applied game?

Applied games are a video game genre that primarily aims to train or educate the player about a specific topic and capture their attention for purposes beyond pure entertainment value. They have been developed in several areas, including defense, education, scientific exploration, health care, emergency management, city planning, engineering, politics, and religion. (cs.gmu.edu 2023). It is based on connecting a serious purpose to knowledge and technologies from the video game industry. (Sawyer, B. 2002). For example, a game where the player drives a forklift in Virtual Reality to learn its controls and usability in a construction environment. (Figure 1). The game in question was developed by me and various other students during an applied games course.

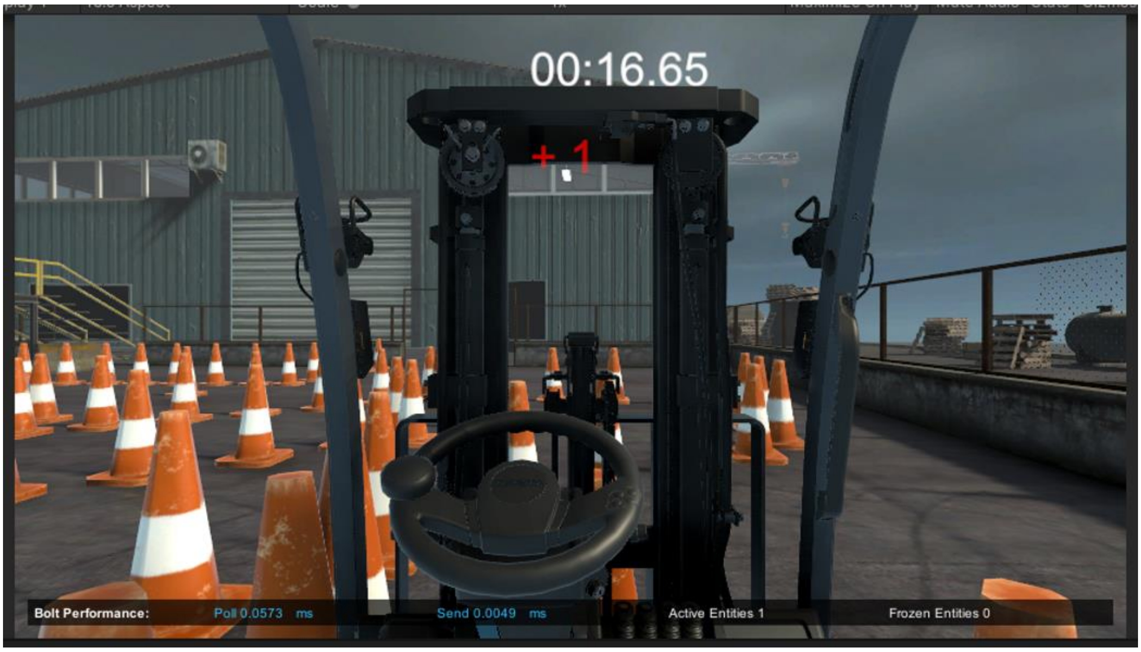

Figure 1. An example of an applied game aimed to teach forklift controls.

3.2 Scanning applications

3.2.1 Photogrammetry

Photogrammetry is a method used for obtaining information about a physical object or area by capturing images from various angles and locations, which are then used to generate 3D models and environments. (TOPS Marketing, 2023). The technique involves taking a series of photos of an object from around its circumference, each time alternating the x, y and z coordinates. (Ruta, K. 2018). These photos are then processed through a photogrammetry software such as Meshroom or Substance Sampler, which aligns the images and creates a 3D mesh using point cloud data. (Figure 2). Photogrammetry is not solely used in 3D modelling, as the technology is used for infrastructure planning, design and topographic mapping. (Brusco, J. 2022).

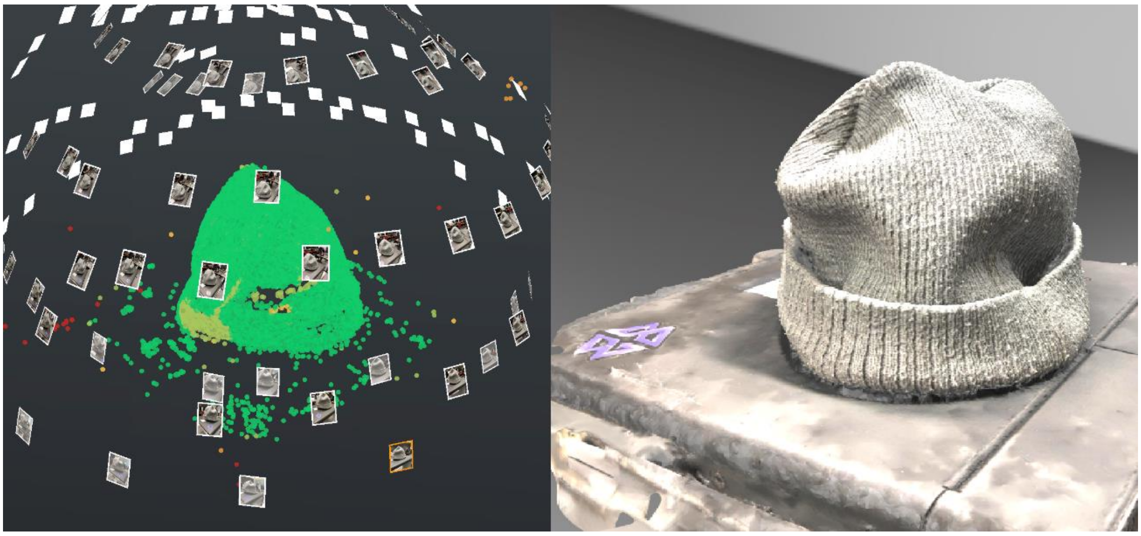

Figure 2. Image data set with point cloud in the green and raw 3D mesh.

3.2.2 LiDAR

Light Detection and Ranging, or LiDAR, is a remote sensing method that “uses light in the form of a pulsed laser to measure ranges to the earth” (NOAA, 2023). This technology relies on laser pulses that bounce off surrounding objects and then return to the sensor, allowing for accurate distance, height, and shape calculations. The resulting point cloud from said calculations, much like photogrammetry, contains XYZ coordinates that indicate locations where the sensor detects something solid. (Wiens, D. 2022), (Figure 3). LiDAR is used in various industries, including self-driving cars, building construction, and agriculture, to name a few.

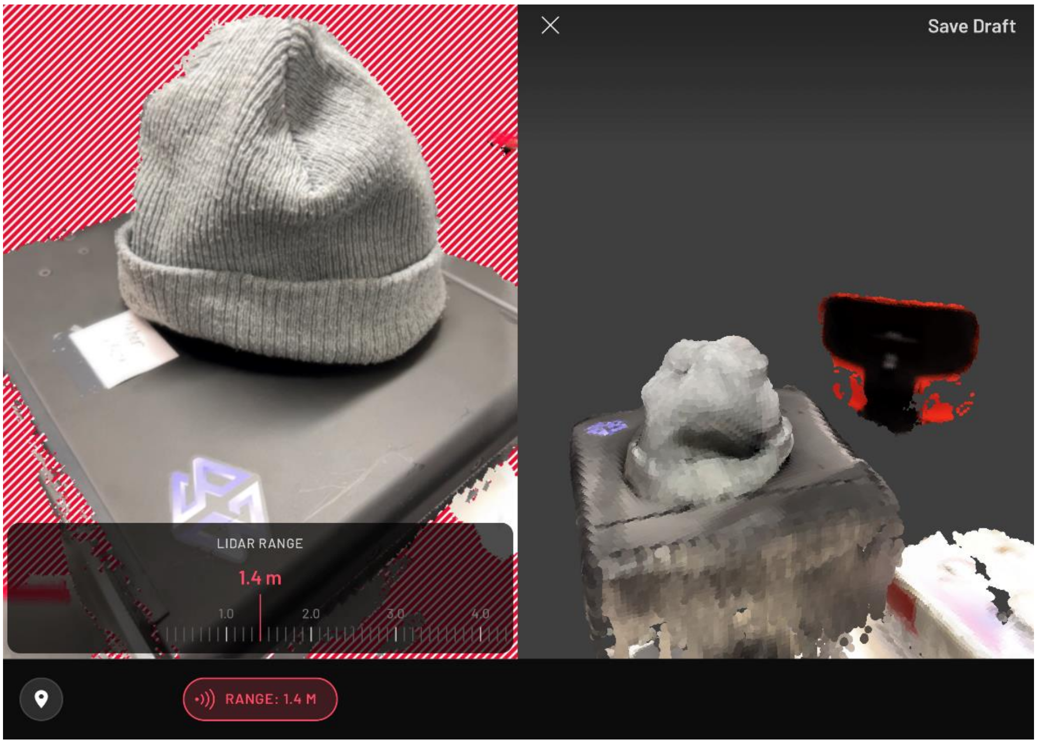

Figure 3. Scanning process and raw 3D mesh.

3.2.3 NeRF

Neural Radiance Field, also known as NeRF, is a recently developed scanning technology that operates similarly to photogrammetry. It requires a set of 2D images captured from various angles to render 3D objects precisely. (As showcased in Figure 4). These images are then fed into neural networks of NeRF to reconstruct the object by estimating the directions of light radiations. (Salian, I. 2022). With the added advantage of volumetric capturing capabilities, it can capture transparent or metallic objects with reflections, giving it an edge over photogrammetry. (Blanco, J. 2022).

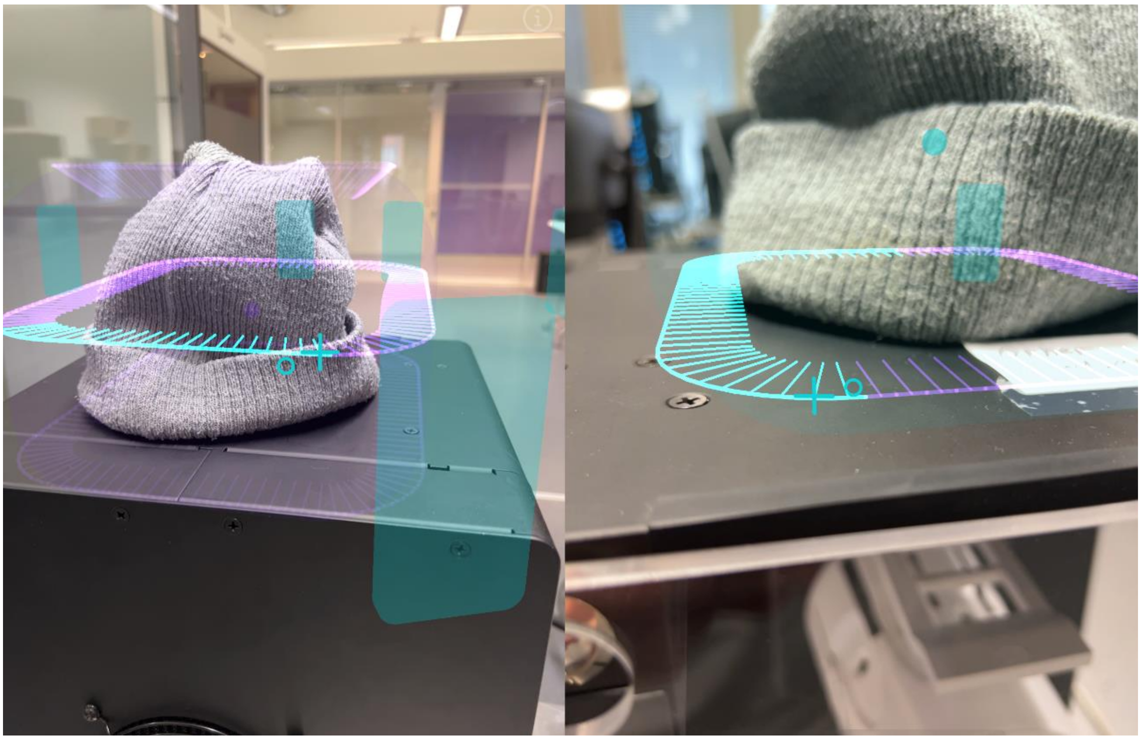

Figure 4. The cyan colour indicates that photos were taken, and the purple images are the ones that need to be taken.

3.3 Workflow from a scanned object to a game-ready 3D model

3.3.1 Images and point clouds to a raw mesh

To create 3D models from data sets such as NeRFS's and Photogrammetry's collection of images or LiDAR's point clouds, the data must be transformed into raw 3D meshes. By default, the smartphone has an advantage in this phase, as its applications have their own tools for processing the mesh automatically after submitting the images or scans. However, digital camera images must be uploaded to a 3rd-party site to turn them into a raw 3D model. For this, we will use Adobe’s Substance Sampler, as it has a tool designed for photogrammetry mesh creation. This process is not much more complicated or time-consuming than a smartphone’s automatic one. All that needs to be done is to upload the image data set to Substance Sampler, which will then create a raw 3D mesh. (Figure 5).

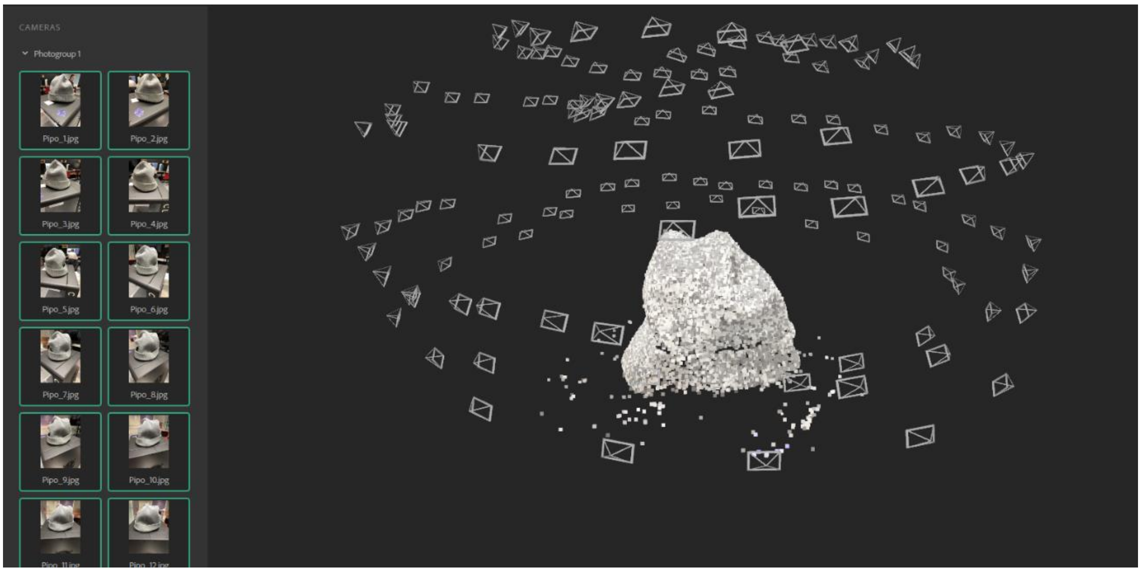

Figure 5. Imported data set in Substance Sampler.

3.3.2 Blender

After creating the raw mesh for the 3D model, we will import it to blender, a free, open-source 3D modelling software. A basic 3D mesh consists of vast amounts of polygons, which are geometric shapes that make up a 3D model. (Figure 6). The topology of a model consists of straight edges and vertices, and these together form faces, which are universally known as polygons. (Figure 7). Polygons can be triangular (three-sided), quads (four-sided) or n-gones (multiple-sided). (Lewis, I. 2023).

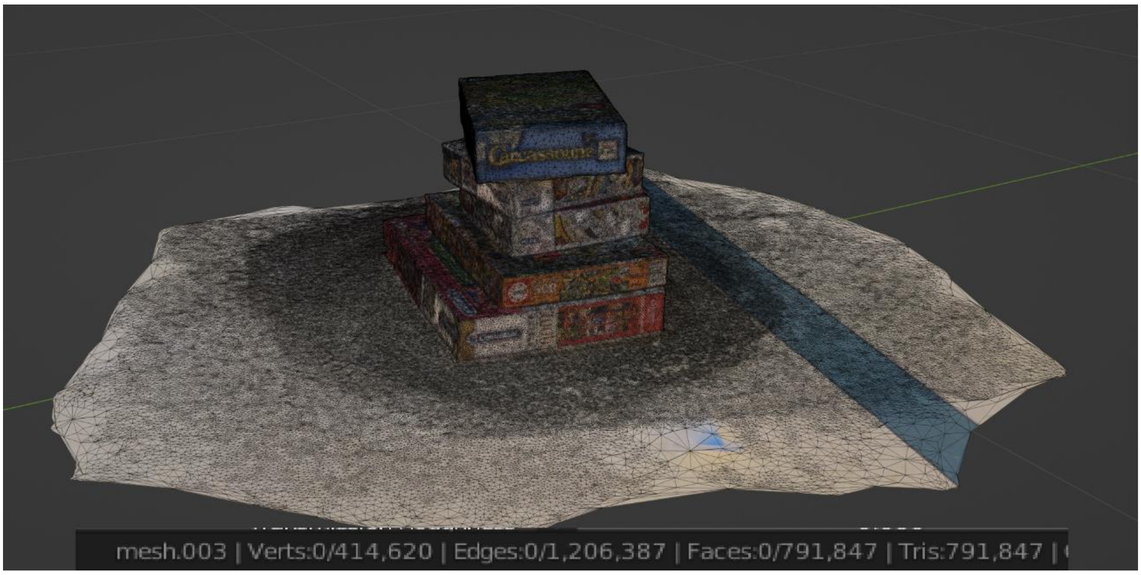

Figure 6. Raw 3D mesh imported to blender.

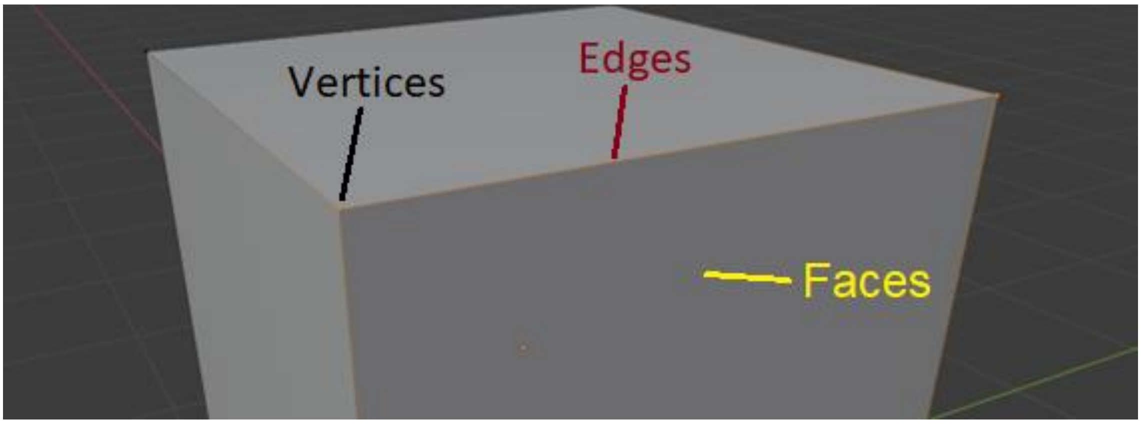

Figure 7. Vertices, edges and faces of a 3D model.

To restate, a raw 3D mesh generally contains an excessive amount of polygons which leads to bad geometry, making it unsuitable for use in a game environment. To overcome this issue, a viable solution is to retopologize the mesh, simplifying its topology by reducing the number of polygons and making it more uniform. (Blender, 2023). Various methods are available to facilitate the topology of a 3D mesh, ranging from manual to automatic techniques. However, for this specific board game pile we used primitive cubes to generate a low-poly version of the model as a starting point for my modelling process. (Refer to Figure 8 for visual representation).

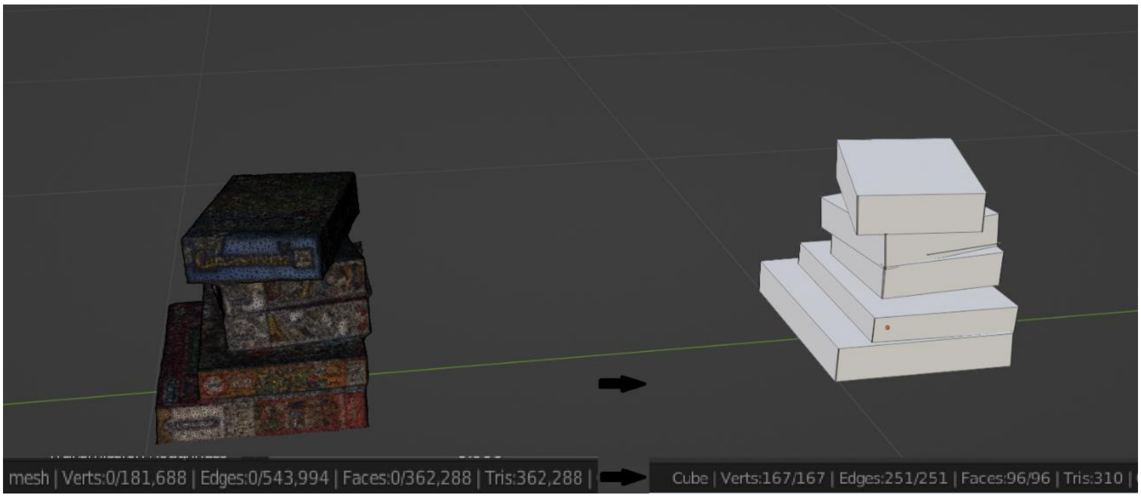

Figure 8. Cleaned high-poly mesh and low-poly mesh.

The raw 3D mesh is often more complex than necessary, requiring additional tools to create a simplified version. A practical solution for this is to use the Bsurfaces addon, which allows for the creation of a mesh through annotation strokes. (Blender, 2019). These strokes project onto a surface, specifically the high-poly model's surface in this context, creating a new mesh on top of it. This technique is demonstrated in Figure 9.

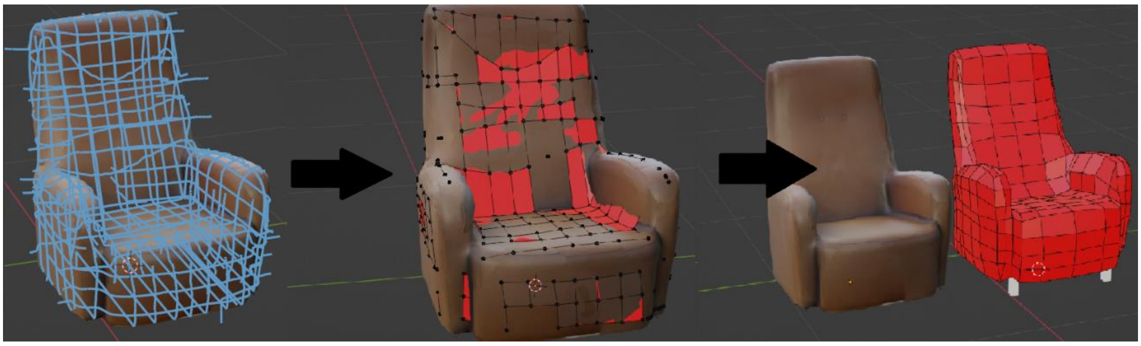

Figure 9. Workflow with the Bsurfaces addon, from start to finish.

Before our work in Blender can be concluded, the low-poly version of the mesh needs to be unwrapped and then laid on top of the high-poly model. Unwrapping means unfolding a 3D model at its seams and laying it flat on a 2D space for a texture to wrap correctly around a 3D model. (Calvello, M. 2021). This step is crucial to ensure that the texture of the high-poly model wraps around the mesh correctly. A good rule of thumb in unwrapping is to think where the natural seams of an object would go. (Figure 10). Finally, the low-poly and high-poly models must be positioned on top of each other to allow the next step in Substance Designer to proceed accurately.

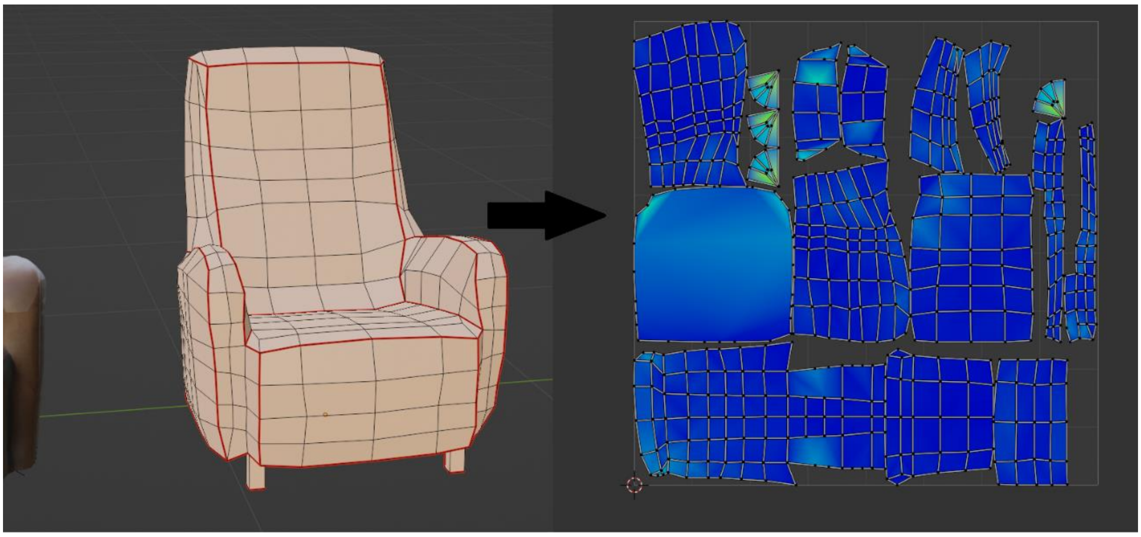

Figure 10. Marked seams in red colour and the unwrapped mesh in 2D space.

3.3.3 Substance Designer & Sampler

Substance Designer uses a method to transfer high poly mesh models onto individual textures. This approach helps keep all the intricate details of the high-poly model, such as its normal data, base colour, and height, onto a low-poly model. The result is a final model that resembles the high-poly version without excessive polygon count. This process is illustrated in Figure 11.

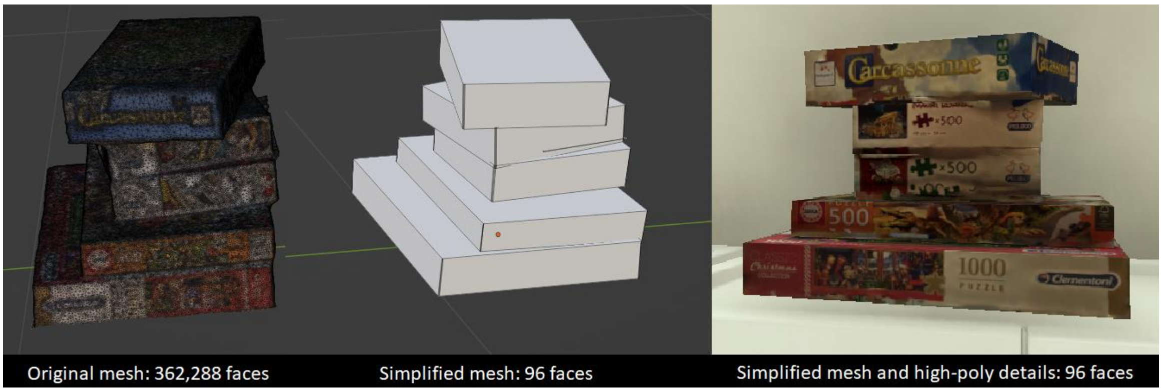

Figure 11. Original, simplified and original mesh with high-poly details.

Finishing touches to the textures can be performed in Substance Sampler & Painter, such as fixing any noticeable seams, rough edges or other texture bugs such as holes (Figure 12). Clone stamp helps one duplicate or patch parts of the texture, and content-aware fill is used to seamlessly fill portions of a surface by sampling it from other regions. (Adobe 2023a).

Figure 12. Texture seam fixes.

After the texture fixes have been concluded, the model and its textures are ready to be imported into an applied game environment. The end result in Unity Game Engine can be seen in Figure 13, inside an applied game scene. The scene in question is of an applied game developed to teach behavior management of aggressive children.

Figure 13. Final model inside an applied game scene.

4 Aims & objectives

This thesis aimed to study the potential of three smartphone applications for 3D modelling, as there is limited research on this topic. Additionally, performance of the smartphone applications was compared against digital camera photogrammetry, which is considered the industry standard. Two real-life objects were scanned using these methods under LED studio lighting and standard indoor lighting, resulting in 20 distinct outcomes. These results were then analysed using picture comparisons and quantitative data in tables.

The primary aim of this study was to investigate whether a smartphone is a viable alternative to creating content for an applied game. To achieve this goal, various data-gathering methods were employed, and the findings were used to answer a plethora of hypotheses:

A smartphone is faster overall and provides better results than digital camera photogrammetry.

The smartphone’s NeRF application yields better results than all the other methods, especially in poor lighting conditions and reflections.

Digital camera photogrammetry provides better results compared to smartphone photogrammetry.

5 Methodology

5.1 Prototype

In order to conduct the initial tests, a specific area was established for the purpose of photogrammetry and scanning. This designated area consisted of a stationary table, which was appropriately illuminated by multiple light sources. A comprehensive setup of this area can be seen in Figure 14. To prevent any undesired reflections, the table was covered with a white fabric. The process of capturing images and scans involved rotating around the table using both a smartphone and a digital camera. The first half of the captures were taken using LED lighting to illuminate the objects, while the latter half employed standard indoor lighting.

Figure 14. Prototype setup for the first set of tests.

In the second round of experiments, the stationary table was replaced with a rotating turntable. The table was controlled remotely using the Bluetooth connection of another smartphone and manually set to rotate 15 degrees by pressing a button on the application. As the table rotated, photographs and scans were captured using both the smartphone and a digital camera with the objective of capturing the x, y, and z positions of the objects. As mentioned earlier, half of the captures were taken under LED lighting to illuminate the objects, while the remainder were done under standard indoor lighting conditions.

5.2 Experiment design

Comparative research was carried out to evaluate the differences in the methods used in the experiment. For this, two distinct objects were utilized, each possessing unique features like a reflective surface, a wide range of colours or a non-reflective surface with muted colours (as shown in Figure 15). All four methods, i.e. Smartphone Photogrammetry, LiDAR, NeRF, and Digital-camera Photogrammetry, were employed to film these two objects under both LED panel lighting and standard indoor lighting, in a two sets of tests, yielding a grand total of 20 unique results.

The techniques used in the scanning process differ depending on whether LiDAR, Photogrammetry or NeRF was used. LiDAR utilises laser pulses to calculate objects, whereas Photogrammetry and NeRF rely on images. In the case of LiDAR, the scanning continued until there were no missing spots around the object, which were highlighted in red. On the other hand, Photogrammetry and NeRF models were captured using approximately the same number of images, ranging from 100-125 images per model.

Figure 15. Objects used in the experiment.

Each result was subsequently transformed into a raw mesh and then imported to Blender. Variables such as how well the different methods handle reflective surfaces, colours, and artificial & default lighting conditions were taken into account by direct picture comparison to the original pictures of the two objects. Various data were gathered, such as the models’ vertex, edge and face count.

5.3 Technical details

5.3.1 Smartphone

For this research, the iPhone 14 Pro Max was used as the smartphone of choice. It was the newest product of Apple’s iPhone series during the making of this thesis, with a front camera of 48 megapixels. This means that one image taken with this phone will contain 48 million pixels.

RealityScan, Scaniverse, and Luma AI were the applications used for photogrammetry, LiDAR scans, and NeRF image reconstruction respectively, all of which can be downloaded for free on any Apple device. The images and scans were processed using their respective applications, without any additional add-ons present in the iPhone such as lenses, to preserve its original capabilities.

5.3.2 Digital camera

The Nikon D5 was utilised as the digital camera option. It is a DSLR (digital single-lens reflex) camera, meaning that it captures images digitally on an image sensor rather than on photographic light-sensitive film. (Hein, J. 2022). Furthermore, this camera uses only one lens, which enables the photographer to see precisely what scene will be captured. For photogrammetry, a DSLR camera is the most suitable digital camera option as it has a manual mode, which enables the user to adjust its aperture, focus, white balance, and ISO to fit a lighting environment, producing the most detailed photos possible. (Haines, J. 2019).

While the Nikon D5's camera has less than half of the iPhone's total megapixel count (20.8), it does not mean that the images taken with the digital camera are of lesser quality. Only noticeable difference between 20.8 and 48 megapixels can be noted when cropping a picture or zooming very close onto the picture itself. Full pictures will be used in this experiment without any editing done to them, hence the megapixel difference will not affect the end result in any shape or form.

To ensure consistent results when taking photographs for photogrammetry, it is essential to choose the appropriate camera settings. Using manual mode enables greater control over settings such as ISO, aperture, focusing, and white balance, whereas automatic mode adjusts these settings based on the camera's algorithms. While auto-mode may seem quicker and easier, it is not suitable for photogrammetry image capturing. Furthermore, a tripod was utilized to mitigate a possibility of blurry images. For digital cameras, here is a list of the settings used to capture high-quality photos in manual mode:

In order to produce the cleanest images, it is recommended to keep the ISO value as low as possible, and for this experiment, it was set at 100. The ISO setting determines the camera's sensitivity to lighting. Lower ISO values result in higher quality images and are beneficial when shooting in bright conditions. (Figure 16). To decrease the graininess and noise in images, it is advisable to decrease the ISO value. (Adobe 2023b). However, when shooting under lower lighting conditions, it is recommended to increase the ISO value to achieve desired results. For the indoor lighting captures the value was increased to 400.

Figure 16. How different ISO values affect the end result. (Corradino 2016).

Aperture is an adjustable setting in a camera's lens which allows the control of light entering the camera. A small aperture corresponds to a high f-stop number, whereas a large aperture corresponds to a small f-stop number. (Adobe 2023c), (Figure 17). The aperture setting also affects the depth of field of an image. A smaller aperture opening results in a greater depth of field, which means that the image appears blurrier. (Nikon, 2023). A large depth of field and a small aperture are most preferred for photogrammetry and as such, this experiment used f/16 as the aperture setting.

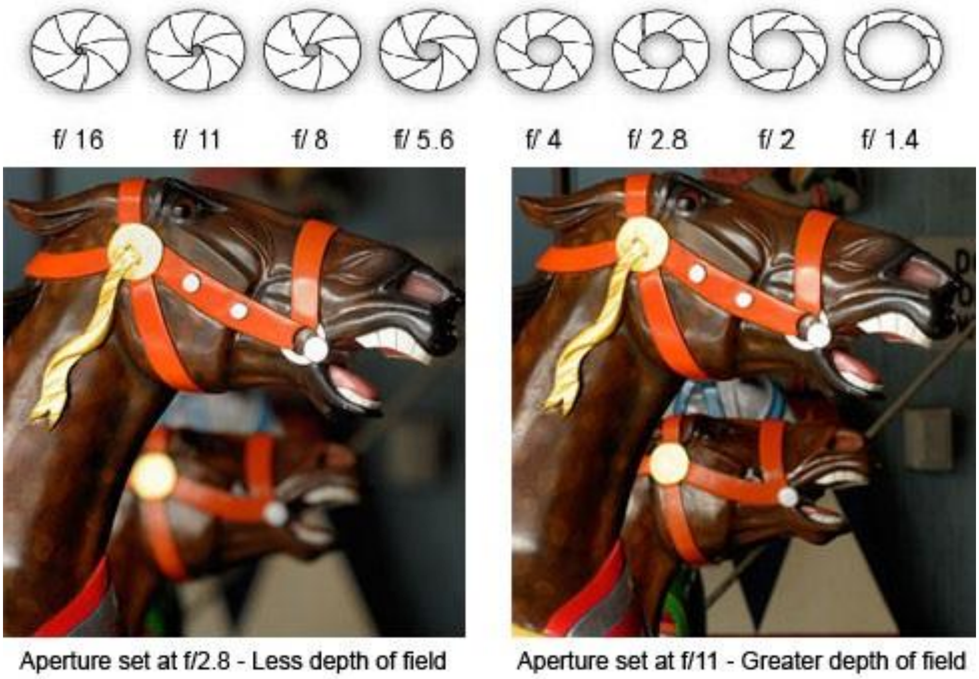

Figure 17. Aperture settings and how they affect the depth of field. (Nikon 2023).

Lastly, to ensure image clarity, the use of an appropriate shutter speed in conjunction with a small aperture is crucial. For photogrammetry purposes, a shutter speed of 1/250 or higher is recommended, as this results in an image being captured within 1/250th of a second. (Figure 18). A faster shutter speed is advantageous as it prevents blurring and captures the exact moment, resulting in a clear and sharp final image output. (Adobe 2023d). In accordance with this study, the camera's shutter speed was set to 1/500th of a second.

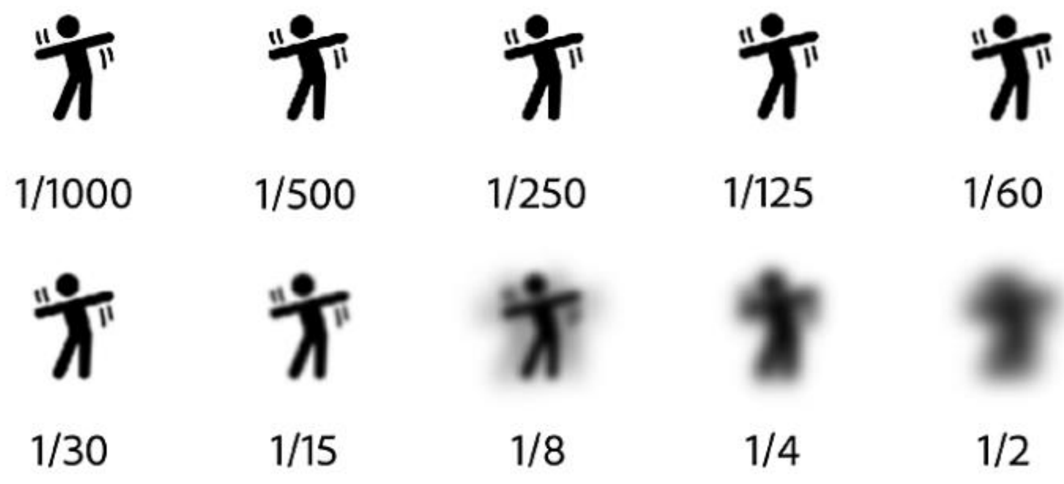

Figure 18. How shutter speed affects the sharpness of an image. (Adobe 2023d).

5.3.3 Lighting

Two pieces of Godox LEDP260C-led panels were used as the Lighting choice for the first halves of the experiment. Colour temperature with this light ranges from 3300k to 5600k, and their intensity can be controlled with a remote control, and for this experiment, 5600k was chosen as the intensity. Both lights were installed on opposite sides, pointing at the table to mitigate any shadows emerging from the test objects.

For the second half of the experiment, default indoor lighting was used. For this, the led panels were removed and both the smartphone and digital camera captured objects with basic indoor lighting. The goal of this addition to the study was to determine the extent to which proper lighting arrangements influence the final results of image/scanning methods.

5.3.4 Table

The Foldio360 table was used in the second set of tests, which was produced and manufactured by orangemonkie. This table is designed for capturing 360 images using a smartphone or DSLR camera. In this study, objects were positioned on top of the circular turntable and can be continuously rotated in either clockwise or counter-clockwise directions through its designated application, which was managed by another smartphone. (Figure 19). The primary benefit of using this table for photogrammetry is its rotation feature, which enables the user to produce matching images and scans while remaining stationary.

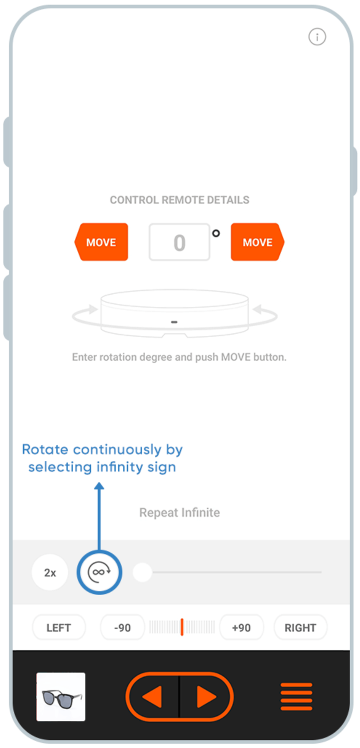

Figure 19. Foldio 360's app that was used to rotate the table manually. (orangemonkie 2023).

5.3.5 Mesh creation

Meshroom was employed to process the Photogrammetry models of Nikon D5, a third-party program that can be downloaded for free and used for 3D reconstruction. Substance Sampler’s image data set tool was tested first but Meshroom was found to be a better option for this study, as Sampler’s tool is still in its early stages and provides an end product of lesser quality.

External application for the mesh processing was chosen as Nikon D5's Digital Camera does not have any in-built tools for Photogrammetry. Regarding the processing of iPhone models, they were only processed using their respective native applications. Initially, the idea of using a third-party tool for processing crossed my mind, but it proved to be obsolete for the smartphone models. This is because not only do all applications have built-in processing tools that need to be considered and utilised, but some of them cannot be conveniently brought into a third-party tool. For example, NeRF requires its own application for neural network processing. Since it is a relatively new addition in the area of image reconstruction, there are not many tools available to support it. Moreover, if the NeRF’s images were uploaded to Meshroom, they would have only resulted in Photogrammetry.

5.3.6 Post-processing

Blender was used for the model comparison process. As it is a software widely recognized for 3D modeling, it precisely assesses the number of vertices, edges, and faces and can also help in portraying several models. To compare all models in a single Blender scene, they were kept in their respective collections and rendered with identical settings.

6 Results

6.1 First set of tests without rotating turntable

6.1.1 Object 1 – Black shoe (LED lighting)

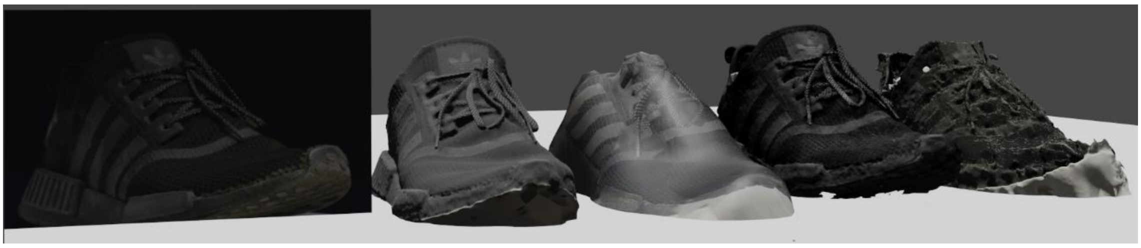

Figure 20. From left to right: original object, smartphone photogrammetry, LiDAR, NeRF and digital camera photogrammetry.

Figure 21. From left to right: original object, digital camera photogrammetry, NeRF, LiDAR and smartphone photogrammetry.

Table 1. Object 1 vertex, edge, and face count (LED lighting).

	Smartphone Photogrammetry	LiDAR	NeRF	Digital Camera Photogrammetry
Vertex count	140,010	3,573	440,546	309,207
Edge count	420,108	8,507	1,316,572	925,822
Face count	280,072	5,057	875,949	616,587

6.1.2 Object 2 – Kid's toy (LED lighting)

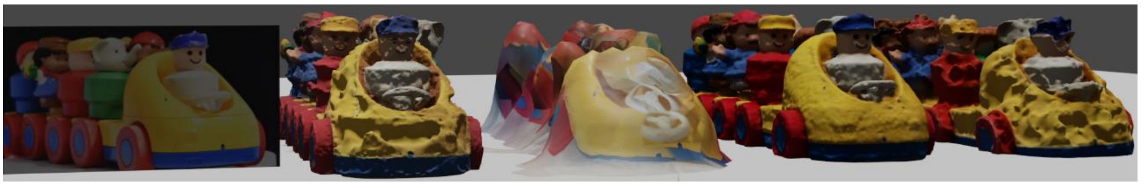

Table 2. Object 2 vertex, edge, and face count (LED lighting).

	Smartphone Photogrammetry	LiDAR	NeRF	Digital Camera Photogrammetry
Vertex count	143,984	3,479	504,414	283,804
Edge count	431,970	8,329	1,504,589	849,604
Face count	287,980	4,957	999,963	565,813

6.1.3 – Black shoe (no lighting)

Table 3. Object 1 vertex, edge, and face count (no lighting).

	Smartphone Photogrammetry	LiDAR	NeRF	Digital Camera Photogrammetry
Vertex count	123,091	3,292	411,280	451,594
Edge count	369,351	8,014	1,225,301	1,353,104
Face count	246,234	4,814	814,001	901,299

6.1.4 – Kid's toy (no lighting)

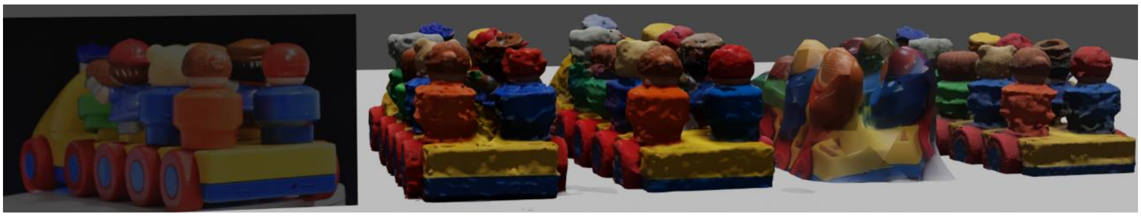

Table 4. Object 2 vertex, edge, and face count (LED lighting).

	Smartphone Photogrammetry	LiDAR	NeRF	Digital Camera Photogrammetry
Vertex count	126,435	3,740	504,997	333,067
Edge count	379,317	8,506	1,504,926	997,842
Face count	252,878	4,925	999,871	664,716

6.2 Second set of tests with rotating turntable

6.2.1 Black shoe (LED lighting)

Figure 22. From left to right: original object, smartphone photogrammetry and digital camera photogrammetry.

Figure 23. From left to right: original object, digital camera photogrammetry and smartphone photogrammetry.

Figure 24. Closeup image of the models.

Table 5. Black shoe vertex, edge, and face count (LED lighting).

	Smartphone Photogrammetry	Digital Camera Photogrammetry
Vertex count	148,065	68,244
Edge count	442,410	203,083
Face count	294,243	134,798

6.2.2 Black shoe (no lighting)

Table 6. Black shoe vertex, edge, and face count (no lighting).

	Smartphone Photogrammetry	Digital Camera Photogrammetry
Vertex count	131,438	61,191
Edge count	393,684	182,274
Face count	262,157	121,042

7 Discussion

7.1 Test results

7.1.1 Smartphone photogrammetry

Smartphone photogrammetry consistently produced good results in all the tests conducted. However, it faced some challenges when it came to accurately texturing the black shoe object, causing it to fall behind NeRF's models. On the other hand, smartphone photogrammetry yielded the best results for the kid's toy object when it came to the models tested with no lighting. Despite the presence of some missing mesh due to the object's reflective surface, it still provided the most reliable outcomes and had relatively the second lowest vertex, edge, and face counts compared to other methods, despite similar picture quantities used in all the tests.

The findings of the second round of tests yielded comparable results to those of the first set. When comparing smartphone photogrammetry to digital camera photogrammetry, the former produced precise and more detailed models. However, the texture accuracy remained slightly lower than the original colors of the object. Additionally, the model created through smartphone photogrammetry exhibited higher vertex, edge, and face counts, resulting in a more detailed representation.

Overall, it can be determined that the first hypothesis, stating that a smartphone is generally faster and yields superior outcomes compared to digital camera photogrammetry, can be concluded to be correct for beginner users of the technology.

7.1.2 LiDAR

LiDAR, which performed poorly in all test scenarios, exhibited results that were more or less to be expected. While it is primarily designed for generating comprehensive aerial reconstructions through its scanning technique, it is not well-suited for creating detailed individual models. As a result, the vertex, edge, and face count of LiDAR outputs were significantly lower compared to other methods, leading to an unintelligible and disorderly outcome. While LiDAR managed to capture the approximate size and shape of the objects, this level of detail is insufficient for generating usable models or molds for further modeling purposes.

7.1.3 NeRF

NeRF performed exceptionally well on the initial set of tests for scanning the black shoe object, producing models with minimal or no missing mesh and accurate texturing. Additionally, it boasted the highest number of vertices, edges, and faces, indicating a higher level of precision in the models. However, NeRF's performance on scanning the kid’s toy object was less impressive, particularly when compared to smartphone photogrammetry. In this case, NeRF produced models with a rough surface and a significant amount of missing mesh.

The failure encountered can be attributed to the specific application utilized, rather than the technology itself. In this case, NeRF, being a relatively new technology, was expected to handle reflections. However, the application used was unable to export the raw models with reflections. Despite this limitation, it was capable of capturing and displaying the reflections of objects through an image-based video, as depicted in the figure 24.

Figure 25. Screencapture from the image-based video created with the NeRF application.

With advancements in technology and its corresponding applications, it is reasonable to assert that using a smartphone with NeRF could potentially become the most effective means for generating raw 3D models. Nevertheless, my second hypothesis regarding NeRF's capability to deliver optimal outcomes, particularly when it comes to reflections, was only partially accurate.

7.1.4 Digital camera photogrammetry

The outcomes of photogrammetry using a digital camera were found to be underwhelming, which is surprising considering that digital cameras are generally expected to produce the best results. The initial test results showed numerous gaps in the mesh, but the texturing turned out to be accurate. The likely reason for this disappointing outcome is the failure to consider and adjust the ISO and aperture settings of the camera, which rendered them unsuitable for capturing images for photogrammetry purposes.

The initial test results were not satisfactory, which prompted the conducting of a second round of tests comparing smartphone and digital camera photogrammetry. Interestingly, the second set of tests showed that digital camera photogrammetry outperformed smartphone photogrammetry in terms of highly precise texturing on the original object. However, the digital camera photogrammetry had fewer vertices, edges, and faces compared to smartphone photogrammetry, mainly because some images were not properly aligned during the creation of the 3D model using photogrammetry software, thus creating a less detailed outcome.

Considering the final model outcomes and multiple variables, such as the need to take all camera settings into account, digital camera photogrammetry takes significantly more time than smartphone photogrammetry. Therefore, the third hypothesis "digital camera photogrammetry provides superior results compared to smartphone photogrammetry" is incorrect, specifically when it comes to inexperienced user of said technology. However, it is worth noting that the sample size for determining this hypothesis is small.

8 Conclusion and recommendation

The aim of this thesis was to investigate whether smartphones could serve as a viable alternative for creating 3D models in applied game development, rather than relying on traditional 3D modeling techniques. Additionally, it explored the feasibility of using smartphones as a cost-effective substitute for industrial standard digital camera photogrammetry. To achieve the results of this study, two real-life objects were chosen to be filmed. The objects were recorded using three smartphone applications (photogrammetry, LiDAR, NeRF), as well as digital camera photogrammetry. The experiment comprised of two rounds of testing. In the first round, the objects were placed on a stationary table and captured under LED panel lighting and standard indoor lighting conditions. In the second round, a rotating table was manually rotated using a smartphone application, and one of the objects was filmed under the same lighting conditions as in the first round, with smartphone and digital camera photogrammetry.

The expected result was that digital camera photogrammetry would outperform smartphone photogrammetry, and smartphone NeRF would outperform other alternatives, particularly in the case of the second object that had a reflective surface. The findings suggest that smartphones are not only a practical means for generating content but also a quicker and more effective option for creating 3D models. It can be debated that a digital camera may be superior in creating 3D models that can be used as-is, as long as all the camera settings are considered for photogrammetry purposes. However, if the goal is to retopologize a scanned object, a smartphone currently offers the most efficient approach by having multiple easy-to-access free software. Furthermore, a smartphone is more user-friendly when it comes to beginners. In conclusion, although smartphone photogrammetry currently yields superior outcomes, it is reasonable to anticipate NeRF surpassing it in the future. However, given that the technology is still relatively nascent, additional research is strongly advised to explore its application in the realm of 3D modeling. For instance, this work could be expanded by directly comparing NeRF to all the other methods used in this experiment.

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