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School of Design

*A low cost Reverse Engineering process for generating
Class A Surface models from physical mockups*

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SINTESI

Tipicamente, per decenni l'industria automobilistica ha utilizzato Clay Modeling come uno dei principali strumenti per progettare nuovi modelli delle loro automobili.

Questa tecnica è utilizzata per applicazioni diverse: styling, analisi dimensionale, reverse engineering, ecc. Quando il Clay Model ha raggiunto un certo livello di maturità, viene applicato un processo di scansione 3D per digitalizzare tali superfici e quindi proseguire con il processo di progettazione, generando Superfici Classe A. Durante la scansione di oggetti, la maggior parte del tempo, questa metodologia è legata a attrezzature specializzate e costose, strutture specifiche e controllate (Scan Labs) e, infine, alcuni requisiti di luce naturale e artificiale. Per non parlare delle persone addestrate a tutte queste attività. Tutti questi fattori fanno scansione di una tecnica di acquisizione di informazioni 3D non accessibile. Soprattutto, il costo di eseguire questa tecnica supera il bilancio delle piccolo studio di design oppure dell'officina di Clay Model.

Pertanto, l'obiettivo di questa tesi è quello di dimostrare che la tecnica di fotogrammetria potrebbe essere un'opzione adatta (e meno costosa) per l'acquisizione di informazioni 3D nell'industria automobilistica, quando è necessario digitalizzare un modello di auto argilla o parte di esso, in particolare quando si genera Superfici classe A dell'automobile. Non importa se sono superfici interne o esterne di auto, con meno budget e infrastrutture rispetto ad altre tecniche.

ABSTRACT

Typically, for decades Car industry has used Clay Modeling as one the main tools to design new models of their automobiles.

This technique is used for diverse applications: styling, dimension analysis, reverse engineering, etc. When Clay Model has reached a certain level of maturity, a 3D Scanning process is applied in order to digitalize those surfaces and then continue with the design process by generating Class A Surfaces. When scanning objects, most of the time, this methodology is related to specialized and expensive equipment, specific and controlled facilities (Scan Labs) and finally some natural and artificial light requirements. Not to mention trained people in charge of all these activities. All these factors make scanning a non-appropriate and accessible technique of 3D info acquisition. Above all, the cost of performing this technique surpasses any small design studio or Clay Model independent workshop budgets.

Therefore, the aim of this thesis is to prove that Photogrammetry technique could be a suitable (and cheaper) option for 3D info acquisition in the Car Industry, when it is needed to digitalize a Car Clay Model or some portion of it, specifically when generating Car Class A surfaces. No matter if it is interior or exterior car surfaces, with less budget and infrastructure compared to other techniques.

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1 CAR INDUSTRY INTRODUCTION

Human Society has been in constant change during its entire existence, finding new ways of moving, communicating and living. Moreover, during the last decades the way the human beings move themselves has drastically changed thanks to diverse transportation devices that came out during the last century. Mostly, all these devices are related to the Automobile Development.

Originally, conceived as a utilitarian product, Automobile has suffered different design processes and techniques that have made possible big changes in the perception of the people.

1.1 Car Industry Today

Due to its big impact on the modern society, automobile have turned in to a “liberating technology” (International Organization of Motor Vehicle Manufacturers , 2017), today cars enable people to move, perform economic activities and enjoy in ways that were unreachable at the beginning of 19th century. Therefore, the need of having a car has been increasing during the last decades; in consequence the Car Industry is one of the greatest engines in the World Economy.

During 2015, 91.5 million motor vehicles were produced globally and in 2016 Car Industry has experienced a 3% growth of total Cars sold. This increasing trend has been constant during the last two decades, showing that Car Industry is placed in constant challenge to offer new and innovative products year by year.

“Toyota today (January 30, 2017) announced global sales of 10,175,000 units in 2016, and global production of 10,213,486 units. A few weeks ago, Volkswagen said it delivered 10.3 million vehicles worldwide in 2016” (Schmitt, 2017)

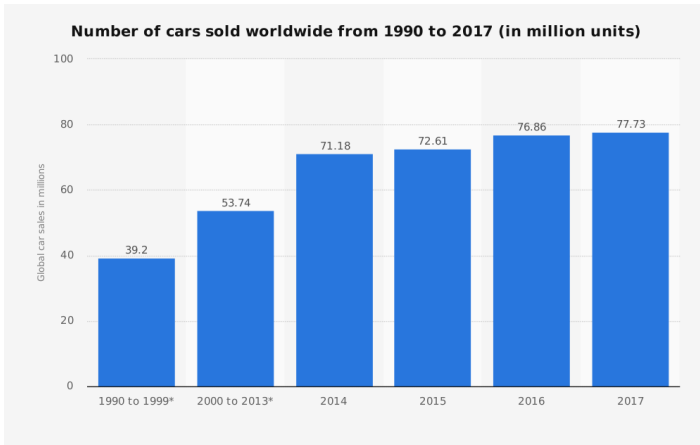


Figure 1.1 Cars sold Worldwide from 1990 to 2017

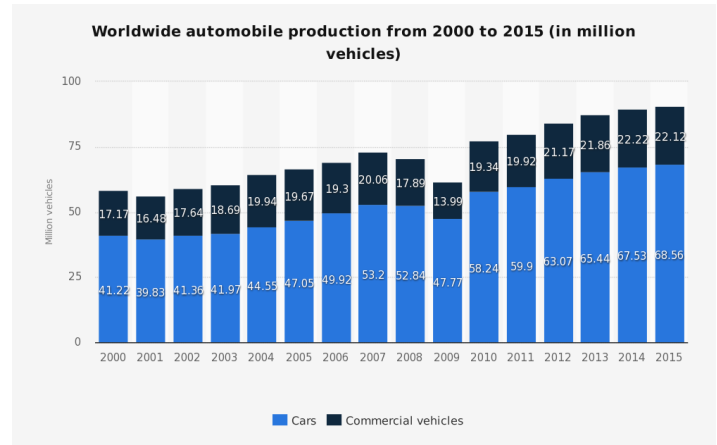


Figure 1.2 Worldwide Automobile Production 2000 - 2015

1.2 Car Design

Nowadays, in this modern and globalized world, every day diverse products are brought to market, each one of them competing in a constant battle. Therefore, all these products must have specific features that make them unique or more desire if compared with others. Design is key for this to happen, a disruptive and well-targeted design can make a product to be a success or a complete failure.

Car Industry is well known for its Design Performance, it is a blend of conceptual and creative skills with a solid understanding of engineering, ergonomics and marketing principles. Typically, with the Aeronautical, Car Industry has been a trailblazer in technology, innovation and design. Inspiring many other economic sectors such as home appliances, tool ware, etc.

This tendency of innovation and constant changing has created a well-defined design cycle, that has been improved during the last decades, using new techniques and technologies to create more appealing and reliable cars, within the less possible time & budget.

1.2.1 Car Design: First Years

Originally conceived as a utilitarian product, Car was not considered to be part in a design process, said by Henry Ford: "you can have it any colour as long as it's black..." Words like styling, appealing or beauty were not considered as key factor for the Product Development. Nevertheless, Ford Model T dominated auto industry form 1907 to the early 1920's, selling more than 15 million in all over the world.

1.2.2 New Era

Just in the mid 1920's, Car manufacturers started to wonder how they could add value to their cars in an already competitive market, but still they had not assigned a big weight to car appearance. It was not until Harley Earl (1893-1969) was contracted by General Motors to lead its Art and Colour Section (after name Styling Section) that the Car Industry started to dive into design approaches such as: Concept Car, Clay Modelling, Styling, etc.

"Harley Earl was the creator of the system of modern automobile design that is still practiced throughout the world" (Gartman, 1994).

During these first years, Car Industry evolved from an entirely Production focused industry to a Styling oriented sector. Standardization started to became an old-fashioned concept; instead words as individuality, customization and variety began to break through the industry.



Figure 1.1
BMW Car Design Evolution

1.2.3 Car Design Methodology

Today, there are more than 50 Car brands all over the world, gigantic or small, big volume or less than 10 cars per year, sedan car or supercar, etc. Therefore, it is possible to assume that, in the market, exist several methodologies and design systems for how to create a car from scratch. Nevertheless, there is a specific flow that many car companies have been followed through years or many Car designers have converged at the same point of how to start with it.

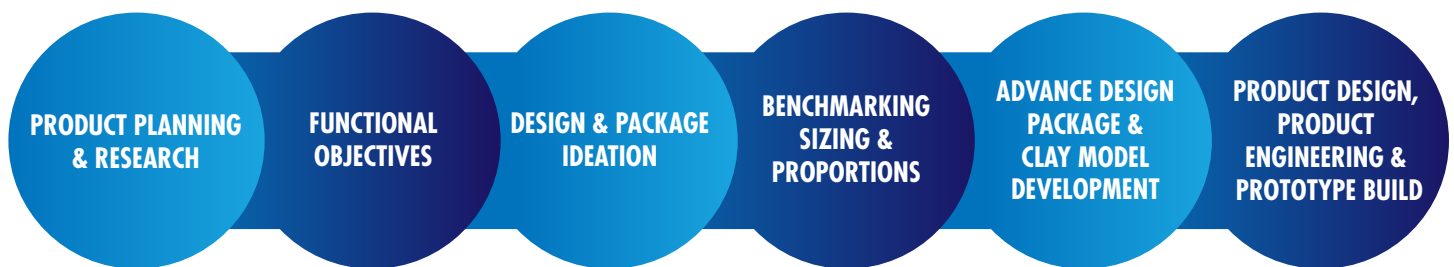


Figure 1.4 The advanced Concept Design Process

“Product Planning and Research: The process starts with researching the intended markets, customers and competition. Emerging technology and manufacturing strategies are also studied.

Functional Objectives: Primary goals for the project are set. These should be considered from both the customer and manufacturer’s perspective.

Design & Package ideation: The basic layout of the major components and any innovative features are sketched loosely in various configurations.

Benchmarking Sizing & Proportions: Existing products with similar attributes are compared to validate the design direction. This process is used to establish the basic proportions.

Advanced Design Package & Clay Model Development: Once the basic dimensions and hard points for the concept are formulated, the scale or full size clay model is build and developed with the package.

Product Design, Product Engineering & Prototype Build, Testing & Launch: The advanced concept is handed to a production /design team. This group will develop the exterior and interior surfaces over a package that 100% feasible for production and meets all of the cost targets”

(Macey, Wardle, Gilles, Freeman, & Murray, 2014)

1.3 Car Clay Model

Back in the 20's, Harvey Earl started to use totally new technique to capture the new concepts and design ideas that were being developed in that time. He started to use full-scale clay models. This pliable material resulted in designs that were less fragmented and mechanical, and more flowing and organic, this new methodology helped to blend the different surfaces into a coherent, integrated form.

Clay models allow designers to blend design sketches and bi-dimensional drawings into a unified, organic whole, whose dimensions could be quickly altered.

In few words, Clay modeling starts with wooden skeleton based the basic dimensions of the design, completed with wheels. This armature is turned over to the design studio team, which applied the clay over it.

The clay is heated up until it is soft and malleable, and then it is applied to the armature using the wooden templates as guides. These actions are applied until the final prototype is finished and ready to apply the last appearance features: “metallic foil to simulate chrome, blacked-out windows, and sheets of colored plastic that looked like lacquer paint when pressed over clay”.



Figure 1.5 Car Clay Model

1.4 Class A Surfacing

When talking about Car design, it is inevitable to mention Class A Surface, which in simple terms, they refer as all surfaces that can be perceived by the customer. On the other hand, Class A Surface is a concept used in most of car design to describe a group of freeform surfaces of high efficiency and geometric quality.

When someone talks about Surface efficiency and quality, this means that the surface geometry has a coherent curvature and tangency alignment. Therefore, these geometric characteristics provide a smooth reflective surface appearance.

These geometrical characteristics can be classified based on the type of Geometric Continuity. Typically, Class A surface is usually closest to Curvature continuity.

1.4.1 Class A Surface Continuity Types

No Continuity (G-) This means that two surfaces are not touching each other and they act as separate elements.

Positional continuity (G0) Exists a touching (coincidence) condition between two surfaces, turning into one geometric element. Normally, this kind of continuity causes a broken highlight on the surface. (Boyd, 2016)

Tangential continuity (G1) It is necessary to have a tangential condition, the two curves not only touch, but also they go the same direction at the point where they touch.

Curvature continuity (G2) Besides the same direction (tangential) it requires to have the same radius at that point, causing the two surfaces to appear as one. This can be visually recognized as “perfectly smooth”. (Autodesk Alias Automotive, 2014)

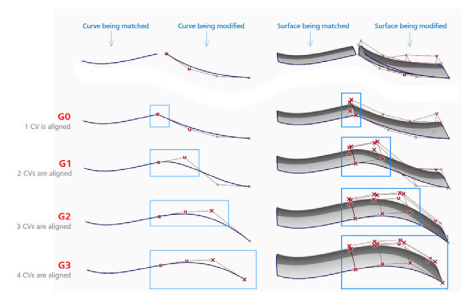


Figure 1.6
Class A Surface Continuity Types
(Munford, 2015)

Acceleration Continuity (G3)

Curves that are G3 continuous touch, go the same direction, have the same radius, and that radius is accelerating at the same rate at a certain point.

Figure 1.7
Class A Surface Continuity Types
(Munford, 2015)

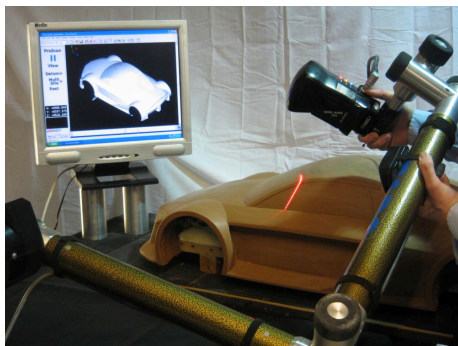
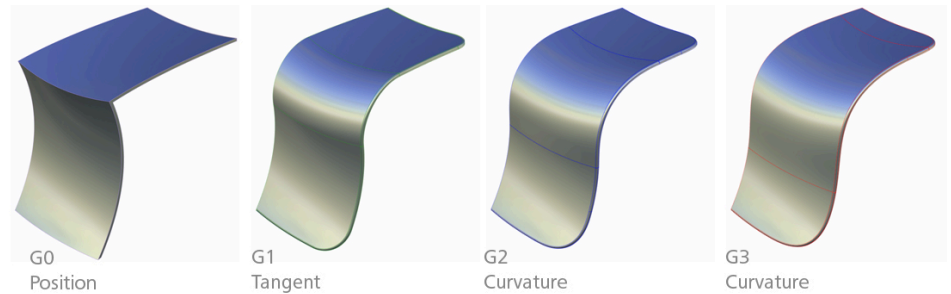


Figure 1.8
Scanning a Car Clay Model

1.5 3D Scanning in Car Industry

Throughout the modeling process, the clay models are regularly scanned and examined as 3D models. Every time the Sculptor wants to 'save' a design they've created before editing it, they'll scan it. That means, if the new design doesn't work as well, they can recreate the exact design they'd previously sculpted.

They're also scanned for the engineers to examine to determine whether the designs are actually feasible. Sometimes the designs don't actually allow enough space for all of the internal components so require tweaking.

Though, nothing is done purely in 3D. None of the designs start life there. Surfaces are always taken from what's been created by hand in clay.

(Macro, 2014)

2 REVERSE ENGINEERING

Reverse Engineering is the process or technique that aims to obtain information from an already existing element; these elements can be from anything man-made (cars, tools, products, etc.) to any natural element (trees, rocks, human faces, etc.). In other words, it enables the reconstruction of an object by capturing the element physical dimension and geometrical features.

“Essentially, it is a converse product design approach where the designer begins with the product and works through the design process in a opposite sequence to arrive at product specifications such as dimensions and form” (Eilam, Eldad). All this can be performed with the most diverse tools and techniques.

“Reverse Engineering is accomplished in three steps: a. Part Digitizing b. Feature Extraction or data segmentation c. CAD or Part Modelling” (Eilam, 2005)

2.1 Why Reverse Engineering?

They are many reasons to use RE for physical objects. For example, the reverse engineering process could be used if the original design is not supported by sufficient information (drawings, product specification or dimensions). Also, if the original CAD model is not enough to support alterations.

More over, in some cases, “the original manufacturer no longer exists, but a customer needs the product. Also, RE could be a very useful tool when *“Inspection and Quality Control—Comparing an already fabricated part to its original CAD description or to a standard item.* “ (Raja & Fernandes, 2008)

On the other hand, RE has been widespread at the art discipline, *“creating 3-D data from an individual model or sculpture to create, scale, or reproduce artwork”*. (Raja & Fernandes, 2008)

Areas of Application:

- Tool making and modifications
- Design and prototyping
- Enhancement and material changes
- Rapid milling and machining
- Research and development
- (Phisycal Digital 3D Measurement, 2017)

“In spite of achieving high measuring accuracy, they are generally limited to conditions such as: sensitivity to vibration, improper scanning due to reflective surfaces and the inability to react to drastic change in surface curvature such as concavities and hidden surfaces.” (Eilam, 2005)

Therefore, in the market, there is a extended list of different techniques of RE, each one of these procedures has their own advantages and disadvantages.

2.2 Measurement 3D: Contact Technique

This 3D acquisition is normally performed by touching the target object in order to get the 3D information. Also called as digitizing, it is when 3D information is gathered and converted to computer language (bits). In the market, there are different types of contact method techniques. Coordinate Measure Machine (CMM) is a device that records the X, Y, and Z coordinates of the target, when the machine touches a specific zone, surface or geometrical feature of the object. *“The use of CMM is recommended when flexibility and accuracy are the key points”* (Piratelli-Filho, Jobim Souza, Valdes Arencibia, & Anwer, 2014)

On the other hand, destructive method is useful for reverse engineering small and complex objects in which both internal and external features are scanned.

Normally, “a CNC milling machine is used to slice 2-D cross-sectional images, which are then gathered by a camera”. (Raja & Fernandes, 2008) Obviously, the disadvantage of this method is the destruction of the object. Therefore, it is not possible to use for art sculpture, pieces of art, etc.

2.3 Measurement: Non-Contact Technique

The main principle of this technique is that the sensor and the object to be measured are separated from each other. An important factor to be determined is the distance between the two elements, since it will determine how well the 3D acquisition is performed and the level of quality you will receive from it.

“Passive scanners do not emit any kind of radiation; they rely on detecting reflected ambient radiation. In most cases, passive methods are generally inexpensive because they do not require particular equipment except for digital cameras”.

They provide low accuracy, typical tolerance ± 0.025 to 0.2 mm. Nevertheless, due to its strong relation with the ambient light, sometime it is difficult to acquire some surfaces, then it is needed it to somehow prepare those surfaces (powder coating) prior to the acquisition. Still, the non-contact methods give you a wide variety of advantages: no physical contact, good accuracy, relative low cost, etc.

2.4 3D Acquisition: Active Methods

The main concept of these techniques is that active scanners emit a type of radiation (X-ray, ultrasound) or light and detect the reflection or radiation passing through a specific object.

“The light emitted by the scanner is reflected by the object scanned and sends back the information to the scanner, recording the surface distance” (CreaForm Inc., 2014).

Nonetheless, these scanners have some restrictions: any reflective or transparent surface will originate difficulties with the information acquisition.

2.4.1 Triangulation

One of the most common active techniques is the triangulation, in which a sensor releases a laser light that hits the object at some incidence angle, reflects from it and detected.

“Since light moves in straight lines, a triangle is formed between the laser source, the measured object, and the detector. By measuring the exact location the laser hits the detector we can calculate the distance to the object using simple geometry”. (Halevy, 2015)

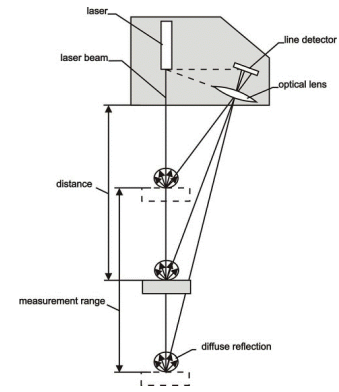


Figure 2.1 Triangulation Method

2.4.2 Time of Flight

The time-of-flight 3D laser scanner uses a laser light to explore the subject. This type of scanner, equipped with a time-of-flight laser rangefinder, finds the distance of a surface by timing the round-trip time of a pulse of light. The accuracy of a time-of-flight 3D laser scanner depends on how precisely the t time can be measured: 3.3 picoseconds is approximately the time taken for light to travel 1 millimeter.



Figure 2.2 Time of Flight Scanner

2.5 3D Acquisition: Passive Methods

Passive methods normally use the light that is already existent in the scene, then the sensor just record the way it is. *“By controlling the illumination of the scene in which the object is present, the accuracy of these methods can be increased.”* (Malik, 2015).

One of the special and interesting characteristics of these techniques is that they can be really cheap, since they use normal and not specialized equipment in order to perform.

2.4.1 Photogrammetry

Photogrammetry is one of the most famous image-based techniques, allows the construction of an accurate 3D model based on photographs. Hence, photogrammetry is based on the conversion of 2D elements (images) into 3D information, commonly resulting in a CAD 3D Model (point cloud)

“The advantages of photogrammetry stay in the fact that a. images contain all the information required for 3D modeling and accurate documentation (geometry and texture); b. photogrammetric instruments (cameras and software) are generally cheap, very portable, easy to use and with very high accuracy potentials; c. an object can be reconstructed even if it has disappeared or considerably changed using archived images” (Gruen, Remondino, & Zhang, 2004) Nevertheless, it is necessary to master specific types of skills in order to have the best results.

Nowadays, photogrammetry has been widespread in all over different disciplines, not only because of it is comfortable and easy to use, also because it is relatively cheaper than other 3D acquisition methods, either passive or active. Photogrammetry applications can be found in the most diverse environments. For example:

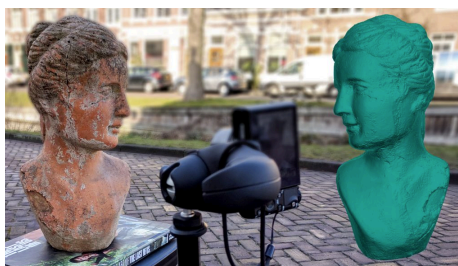


Figure 2.3
Ancient Sculpture Photogrammetry

1. Art and Museum. Since ancient sculptures do not have any 3D model background, photogrammetry could be used in order to acquire size and features for further analysis and investigation, without even touching the piece.

2. Accident Car Reconstruction. Forensic measurements are needed when a car accident happened, Photogrammetry is ideal due to managing and moving parts is not an easy and comfortable task for the police departments or insurance teams.

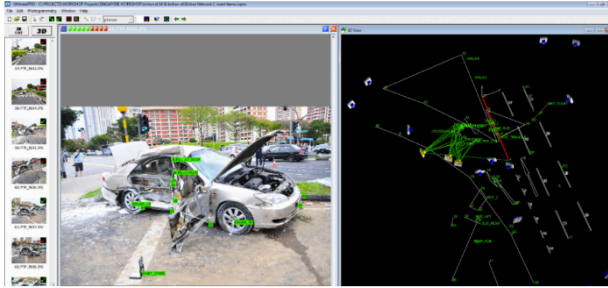


Figure 2.4
Mapping an accident scene from ground-based photography

3. Human Body Reconstruction. We are living in the time of 3D reality, live action videogames, high-end special effects films, etc. All of them need specific model of human body in order to run their renders.



Figure 2.5
Human Body Photogrammetry

Here are more examples of Photogrammetry Applications:

- Automobile Construction
- Mining Engineer
- Machine Constructions
- Objects in Motion
- Shipbuilding
- Structures and Buildings
- Traffic Engineering

3 EXPERIMENTATION

As mentioned before the aim of this thesis is to confirm if the photogrammetry is suitable for the Class A Surfaces Acquisition. Two 3D acquisition tests will be performed: 3D Scanning and Photogrammetry, in order to compare results between these 2.

3.1 Methodology Definition

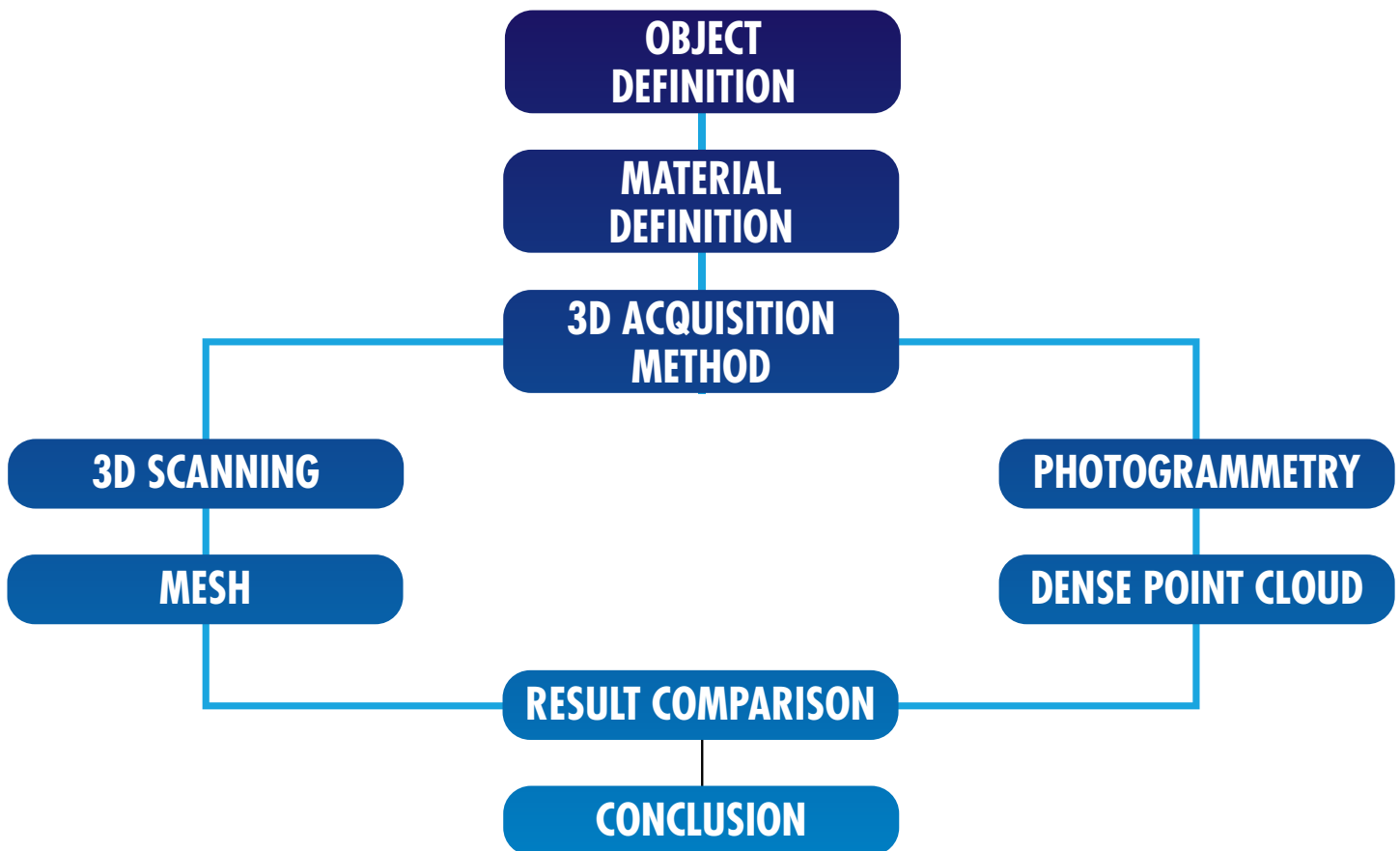


Diagram 3.1 Experiment Methodology Flow Diagram

3.2 Object Definition

The model used for this test was a prototype used in the Transportation and Automobile Design (TAD) Master Course imparted by Politecnico di Milano, as part of the project for Audi.

Figure 3.1
Experiment Car Clay Model



3.3 Material Specification: Clay

Sometimes, the type of material will define how complex 3D acquisition technique will be; this is because all these processes play with day or artificial light, therefore if the material is opaque or translucent (reflects light or not) it will impact on the collected image. A provisional solution for this issue is to cover with matte paint all those surfaces that can generate these reflection problems. For these tests, the material used in the prototype was Industrial Clay Type. Here are some characteristics:

CHARACTERISTIC	ADVANTAGE
Sulfur free	Reduces potential corrosion
Lightweight	Reduces transportation and shipping cost when models are finished
Excellent Milling Qualities	Clay fragments do not stick to milling bits or model surface
Resistant to Shrinking and Cracking	Saves time on no needed reparation time
Workable at 130°f (55°c)	Quicker heat up time making it comfortable and more easy to apply
Exceptional cohesion and adhesion	Adheres to foam, wood or any existing painted surface

Table 3.1 Industrial Clay Type Characteristics (Chavant, Inc, 2017)



Figure 3.2 Modeling with Clay

3.4 Scanning 3D Test

3.4.1 Set Location

Reverse Engineering 3D Lab was a set as a location for the 3D scanning test; one of the first usage recommendations for this test was to be performed in an indoor space.

3.4.2 Scanning Process

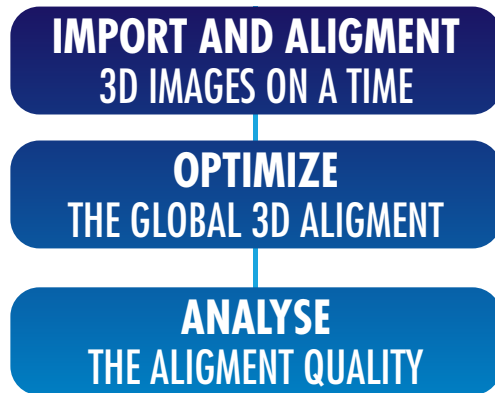


Diagram 3.2 Scanning Test Methodology

3.4.3 Shooting

For this specifically test, it was decided to take as many scans as possible, in order to assure high level of accuracy and precision at the end of the test. Finally, 21 scans were taken (used time 30 minutes approx.), assuring an overlapping of at least 60%, this is needed since a sufficient number of points is required to describe the part and also because those common features are used to properly mate the different images.

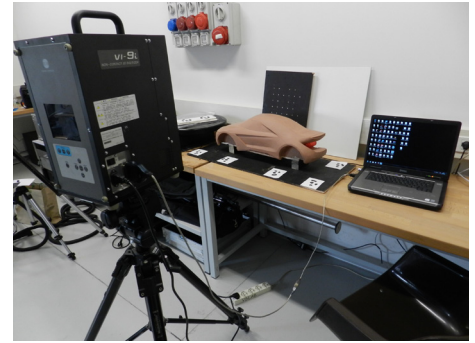


Figure 3.3 Scanning test Location (Reverse Engineering Lab)



Figure 3.4 Scanner Shooting

3.4.4 Import & Alignment

Scanned were imported one at a time, converted to 3D Image format, and then aligned to the other 3D Images. One of these scans was fixed, in order to set a coordinate system and then continue with the alignment based on that fix point.

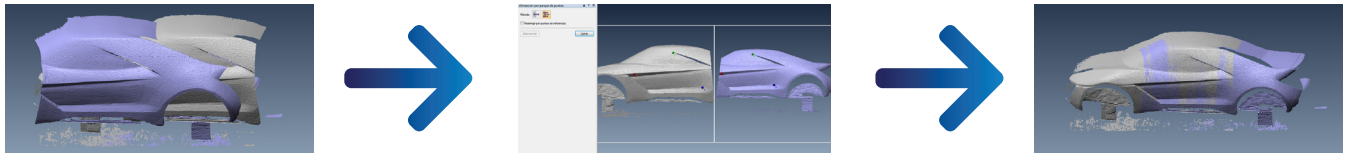


Figure 3.5 Images Alignment

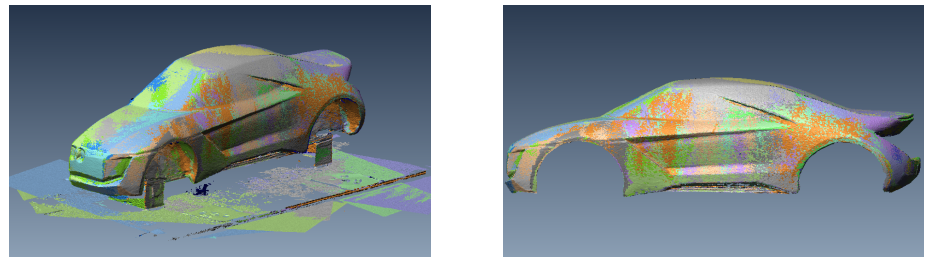


Figure 3.6
Scanned Images Aligned

3.4.5 Optimization

The next step is to refine that alignment; this is done by applying “best-fit image alignment” software feature to the entire set of 3D Images to reduce the alignment errors.

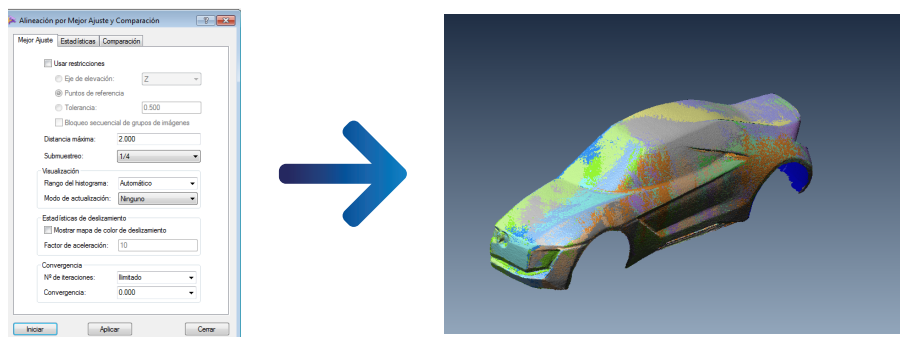


Figure 3.7
Best-Fit Image alignment feature

3.4.6 Alignment Quality Analysis

Finally, Polyworks allows us to create a series of histograms that show which was the performance of our scanning. This graphs display histograms showing the distribution of points with regards to their distance from all overlapping 3D Images.

Afterwards, the aim of these graphs is to show whether the scanning was nearby zero error value and a standard deviation value relatively close to the digitizer accuracy ($z = 0.322$ mm, $SD = 0.096$ mm).

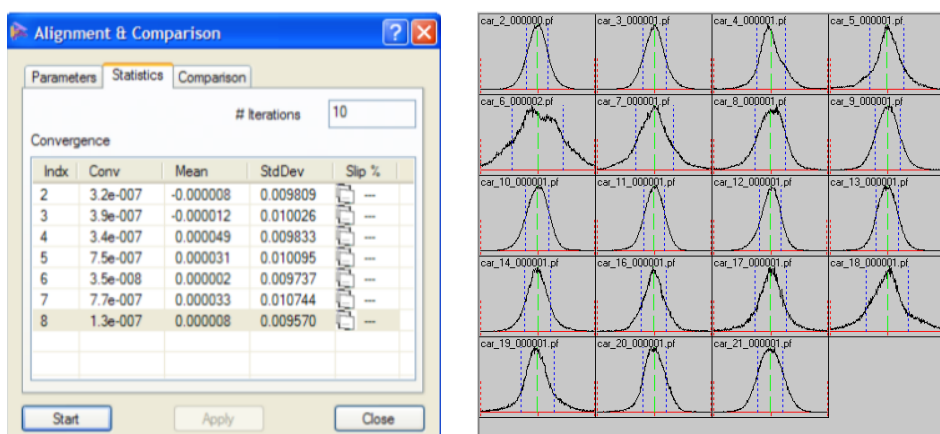


Figure 3.8
Alignment and Comparison Statistics

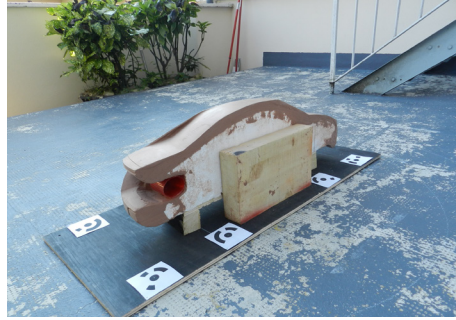
3.5 Photogrammetry Test

3.5.1 Set Location

My own terrace apartment was elected to be the location of this photogrammetry test, due to 2 main reasons. 1) Easy Location. The place was supposed to have a free and easy access location. 2) Outdoor Space.

In order to prove that photogrammetry can be performed even if it is not possible to have a specialized laboratory.

Figure 3.9 Setting Location



Place:

Milano, Lombardy, Italy

Surface:

9 m²

Main Characteristics:

No Controlled Temperature

No especial equipment

3.5.2 Set Geometrical Targets

In order to generate an accurate measurement of 3D data for this Clay Model, it was necessary to define a correct geometrical target arrangement.

One of the main assumptions was to set the geometrical targets nearby the area of interest of this car mockup, and make sure that your set of overlapping images extends beyond the placement of these targets. This overlapping should be well covered. Therefore, once properly calibrated, they can provide an accurate scale for the whole photogrammetry test.

Figure 3.10
Geometrical Targets Lay Out

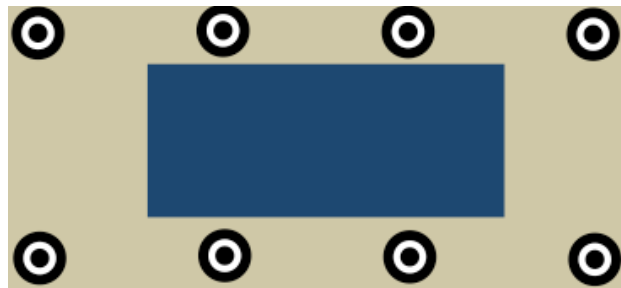
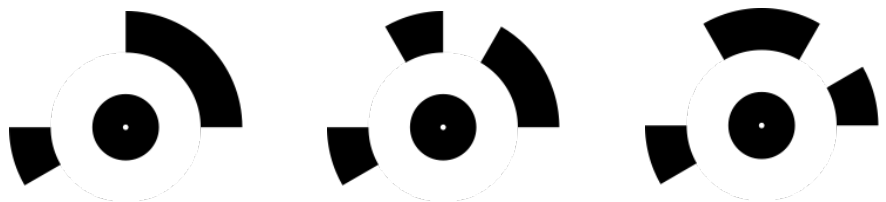
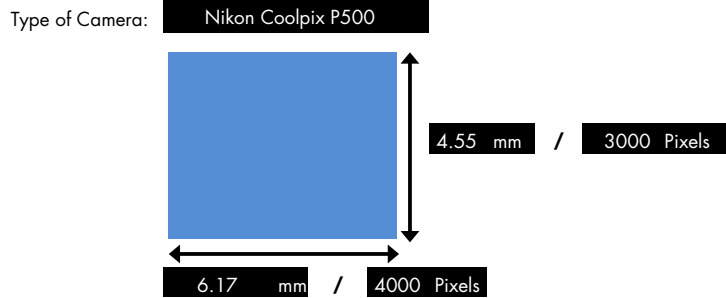


Figure 3.11
Geometrical Targets Shape



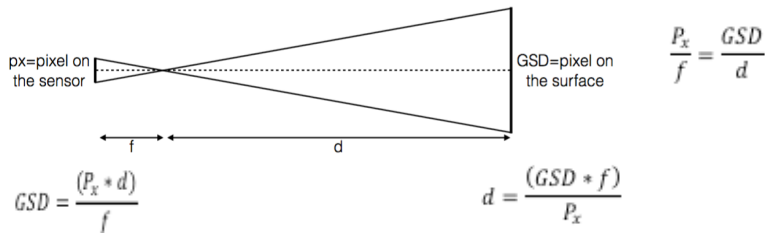
GROUND SAMPLING DISTANCE [GSD]



2. Evaluate the pixel size as:

Px_horizontal 0.0015 → 1.5 μm
 Py_Vertical 0.001517 → 1.516667 μm

3. Evaluate the GSD considering these Similar Triangles:



Distance to Object [d] 1000 mm GSD 0.1 mm
 Focal Distance [f] 23 mm Focal Distance [f] 23 mm

GSD → 0.067 mm d ← 1491.1 mm

Table 3.2
 Ground Sampling Distance Calculation (GSD)

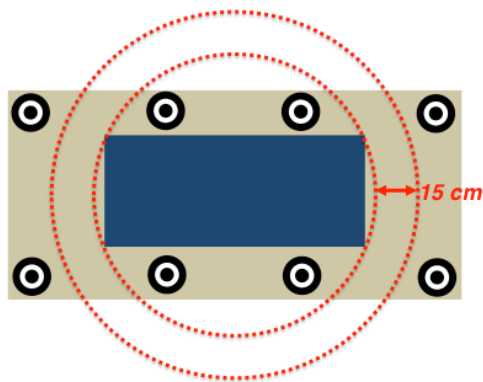


Figure 3.12
 Geometrical Targets Lay Out with GSD marks

3.5.4 Photogrammetry Tests General Characteristics

9 different photogrammetry tests were performed along this experiment. Initially, the first test was run based on the previous and basic knowledge. Then, the 2nd phase was executed with control parameters, such as GSD and camera specific fixtures. Finally, the 3rd phase was run with an even more controlled parameters and even helping the test with other software to make this final phase more precise.



Diagram 3.3 Photogrammetry Test Sequence

On the other hand, during shooting process, it was decided to test 3 different settings; the intention was to study the positive or negative impact. These settings were:

a. Device Type

Device 1

Camera: Nikon Cool Pix 500
 Sensor: CMOS 12Mpx
 Sensor Size: 6.17 X 4.55 mm
 Image Quality: Fine
 Image Size: 3264 X 2448



Figure 3.13 Nikon Cool Pix 500

Device 2

Camera: Iphone 4 Camera
 Sensor: 5 Mpx
 Sensor Size: 4.52 X 3.42 mm
 Image Quality: Fine
 Image Size: 1936 X 2592



Figure 3.14 Iphone 4

b. Partial/Full shooting, where Partial means, shooting was just considering the car visible surfaces (neglecting Car B-side) and full means a complete 360 shooting of the object

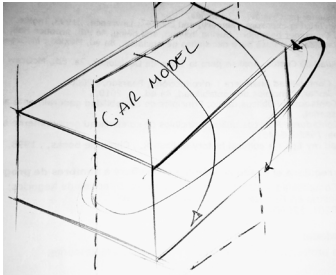


Figure 3.15 Partial Shooting
(Half Model)

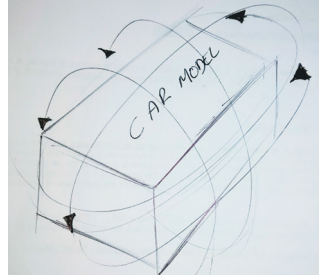


Figure 3.16 Full 360 Shooting
(Complete model)

c. Floor/Table Base, due to experimenting purposes, it was decided to have 2 bases with different height, in order to verify if it impacts on test result.

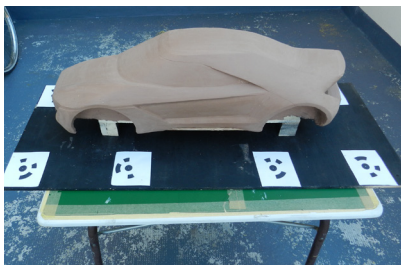


Figure 3.17 Table Base

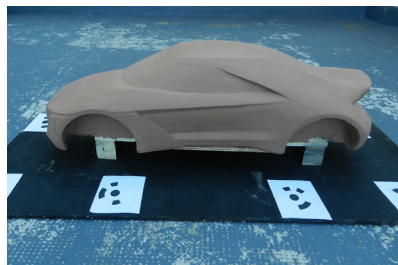


Figure 3.18 Floor Base

3.4.5 Phase 1. Photogrammetry (Test1 – Test5)

Phase 1 General description:

- T1: 65 (Nikon CoolPix500, partial 360 shooting, table base)
T2: 71 (Nikon CoolPix500, partial 360 shooting, floor base)
T3: 56 (Iphone 4, partial 360 shooting, floor base)
Chosen Test T4: 41 (Nikon CoolPix 500, full 360 shooting, floor base)
T5: 65 (Iphone 4, full 360 shooting, floor base)

1.Alignment

At this process PhotoScan finds the camera position and orientation for each photo and builds a sparse point cloud model. For thesis purposes, it was decided to pick Test 4 to be analyzed, due to its better result at Test Phase 1.

All pictures (41) were added to Photoscan, filtering and removing those ones that had an issue like focal, external elements, etc. For the alignment action, “Medium” Accuracy was picked in order to avoid an over information. The result of this is a sparse point cloud - 3D representation of the tie-points data.

Figure 3.19
T4 Photoscan Agisoft Alignment Action

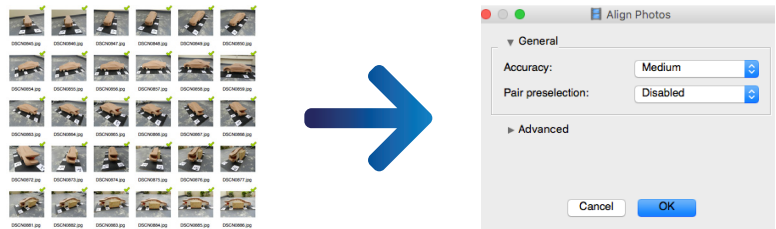
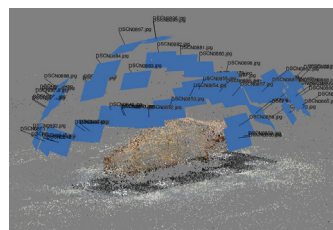


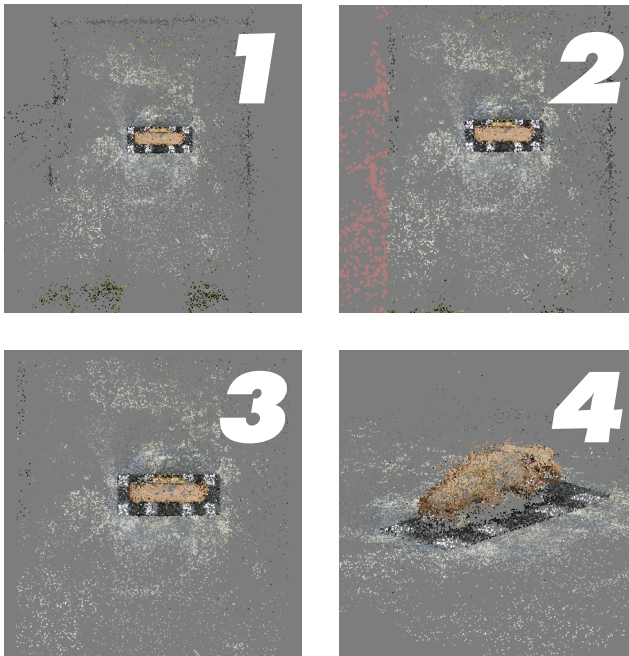
Figure 3.20
T4 Photoscan Agisoft Total Cameras



**Figure 3.21***T4 Photoscan Agisoft Final Alignment*

2. Useless Points Cleaning Up

At this stage, the Point Cloud was partially cleaned up. External elements such as building walls, stairs, handrails, etc. were removed. Although, PC was including several elements (Floor and Wood Base) those were not part of the Object.

**Figure 3.22***T4 Pointcloud Cleaning-up*

3. Dense Cloud Build Up

PhotoScan allows to generate a dense point cloud. Based on the estimated camera positions, the software defines depth information for each camera and other parameters in order to be joined into a single dense point cloud. Depending of the number of used images, it will impact on the dense cloud generation time. The more pictures to be analyzed, the more time.

Chosen Settings
Quality: Medium
Depth Filtering: Aggressive
Approximate Time: 3,5 hrs.

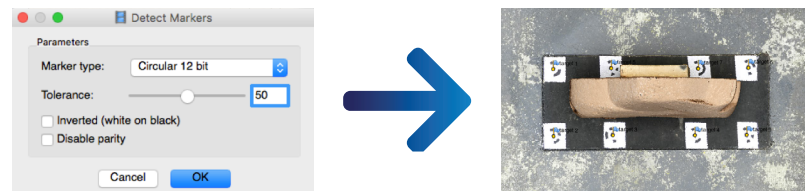
Figure 3.23 T4 Dense Pointcloud Building-up



4. Detecting Geometrical Targets (Markers)

Marker Type: Circular 12 Bits
Approximate Time: 40 s

Figure 3.24
T4 Detecting Geometrical Targets



5. Creating scaling Bars & Error Calculation

For this step, it was needed to go back to the real object, in order to measure the real distances between geometrical targets. A measuring tape was used to define the largest distances between the targets. Once gathered all actual measurements, back on Photoscan, it was created 4 different scaled bars, the 4 longest distances between the targets. Then, real measurements were introduced into the Scale Bar Table. Finally, the table is updated, giving the Total Error at the end of the Table, which is nothing more than distance between the input (source) and estimated positions of the camera.

Measurement 1: 915 mm

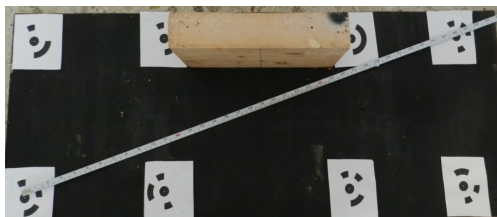


Figure 3.25
Measuring Real between Geometrical Target Distance 1

Measurement 2: 901 mm

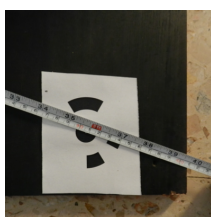
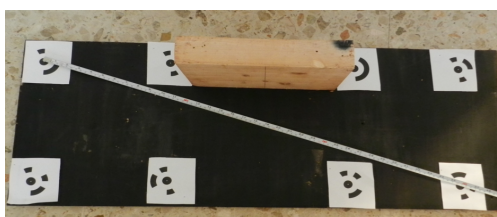


Figure 3.26
Measuring Real between Geometrical Target Distance 2

Measurement 3: 861 mm

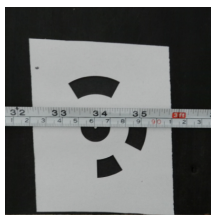
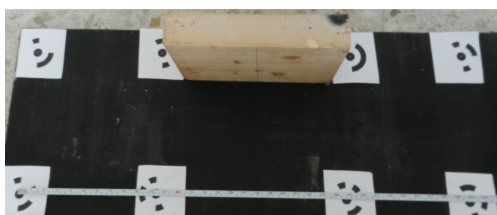


Figure 3.27
Measuring Real between Geometrical Target Distance 3

Measurement 4: 870 mm

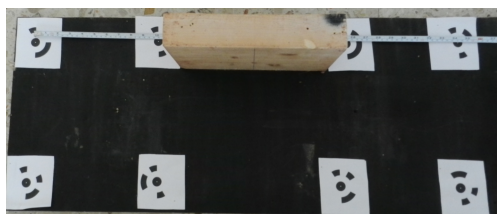
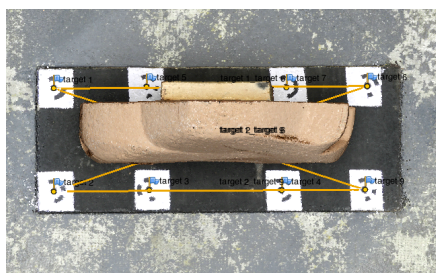


Figure 3.28
Measuring Real between Geometrical Target Distance 4



Scale Bars	Distance (m)	Accuracy (m)	Error (m)
<input checked="" type="checkbox"/> target_1_target 6	0.870000	0.001000	-0.000994
<input checked="" type="checkbox"/> target_1_target 9	0.907000	0.001000	0.000318
<input checked="" type="checkbox"/> target_2_target 6	0.915000	0.001000	0.000614
<input checked="" type="checkbox"/> target_2_target 9	0.861000	0.001000	0.000016
Total Error			
Control scale bars			0.000605
Check scale bars			

Figure 3.29 T4 Scale Bars Creation

6.Dense Point Cloud Clean Up

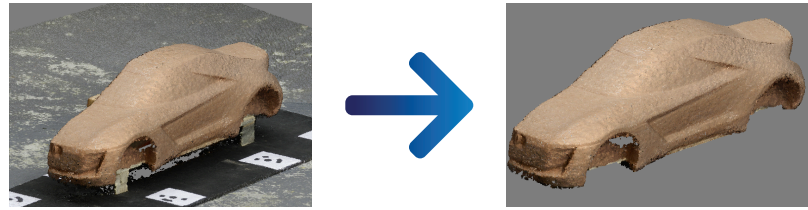


Figure 3.30
T4 Dense Cloud Clean Up

7.Mesh Build Up

When the dense point cloud has been generated it is possible to generate polygonal mesh model based on the previous modified dense point cloud. Compared to Dense Point Cloud, this process usually is faster, since the points just need to be connected and create mesh triangles.

Approximate time: 30 seconds

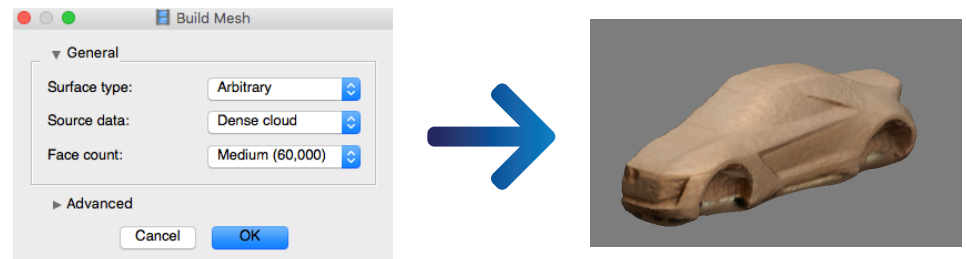


Figure 3.31 *T4 Mesh Build-up*

8.Cloud Compare: Alignment & Translation

Cloud Compare Software was used in order to compare both techniques: Scanning & Photogrammetry. Scanning was used as the Master, due to its better theoretical accuracy and precision. Then Photogrammetry models were aligned to the Master. This alignment process took several previous steps because Polyworks and Photoscan have a different axis system references. Once aligned, a comparison tool was run and then the results were obtained.

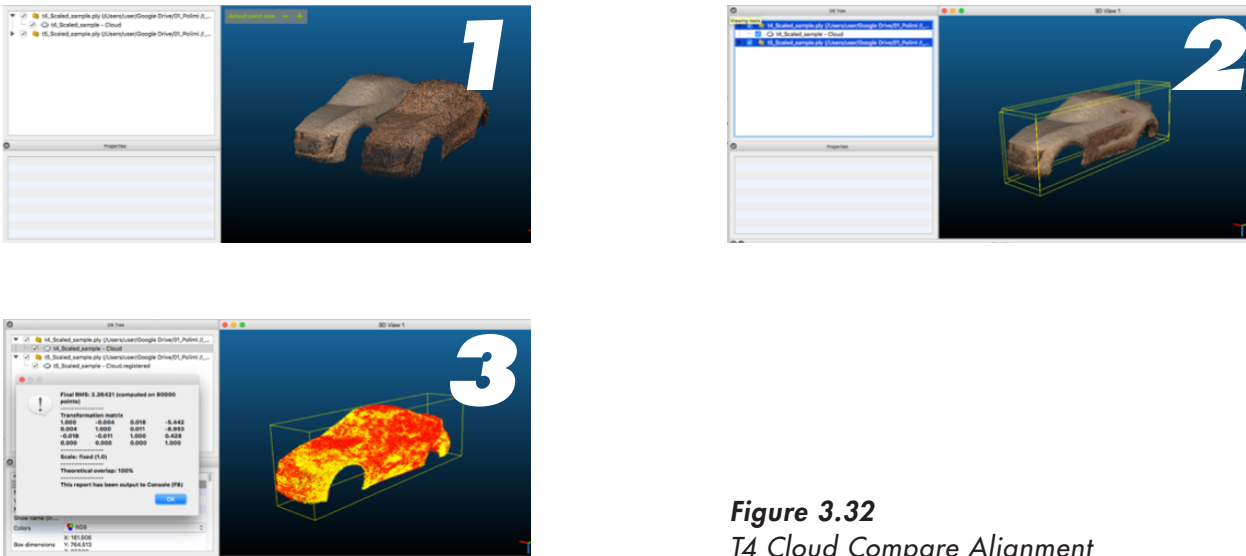


Figure 3.32
T4 Cloud Compare Alignment

9.Cloud Compare: Comparison Results

For this 1st photogrammetry test, it is possible to detect an almost 1 mm of Mean variation and approximately 4.6 mm of Standard Deviation, which in terms of photogrammetry is not that high. Nevertheless, in terms of Class A surface, something bigger than 1 mm is a considerable amount. The standard deviation is almost half centimeter.

Mean: 0.755 mm SD: 4.6144 mm

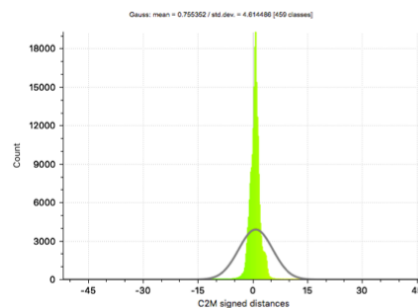
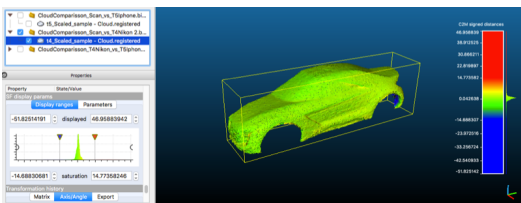


Figure 3.33 T4 Cloud Compare Comparison Result

3.4.6 Phase 2. Photogrammetry (Test7 – Test8)

1. Shooting Especial Features

Closer GSD for Specific Features (100 mm approx.)

Make Farer GSD for Scaling Purposes (form 8 to 10 pictures)

Camera Settings:

Number of photos:

Chosen Test T7: 179 (Nikon, full 360 shooting, floor base)

T8: 152 (Nikon, full 360 shooting, table base)

Exposure < 1/400

Fixed Aperture (F8)

Fixed ISO 160

2. Alignment

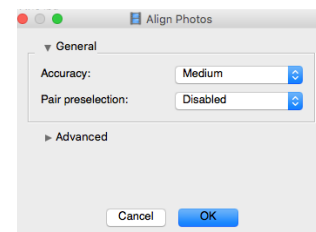


Figure 3.34 T7
Photoscan Agisoft Alignment Action

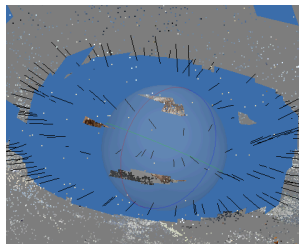


Figure 3.35
T7 Photoscan Agisoft Total Cameras



Figure 3.36 T7
Photoscan Agisoft Final Alignment

3. Useless Points Cleaning Up

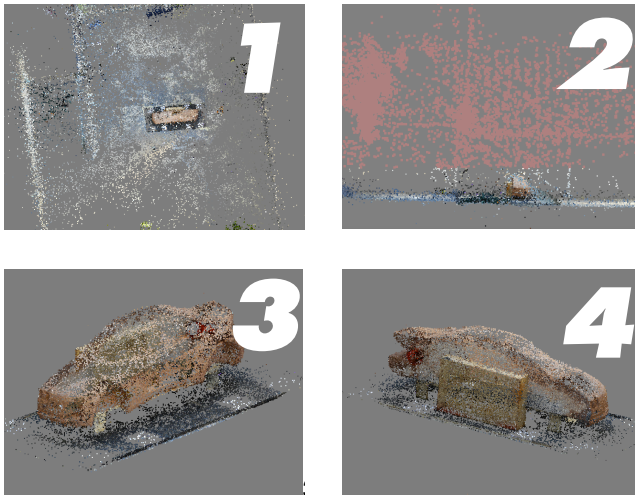


Figure 3.37
T7 Pointcloud Cleaning-up

4. Camera Optimization

The Software calculates internal and external camera orientation parameters during alignment. This calculation is performed using only image data, and then this process may create issues in the approximations. In consequence, non-linear deformations are originated in the final model.

These model deformations can be removed by optimizing the estimated point cloud and camera parameters based on the known reference coordinates. This is possible using the software feature called “Optimization Camera Alignment”. After this process is done, it is possible to detect some improvements on the point cloud.

For this test, it was decided to use all parameters, except K4, P3, P4.

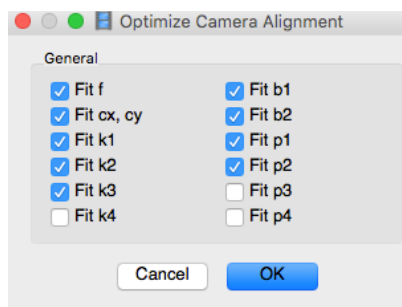


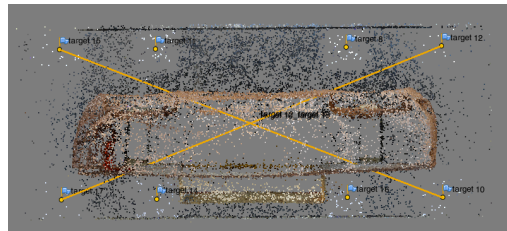
Figure 3.38
T7 Camera Optimization

5. Detecting Geometrical Targets (Markers)



Figure 3.39
T7 Detecting Geometrical Targets

6. Scaling & Error Calculation



Scale Bars	Distance (m)	Accuracy (m)	Error (m)
<input checked="" type="checkbox"/> target 10_target 15	0.861000	0.001000	0.000620
<input checked="" type="checkbox"/> target 12_target 17	0.861000	0.001000	-0.000621
Total Error			0.000620
Control scale bars			0.000620
Check scale bars			

Figure 3.40
T7 Scale Bars Creation

7.Resize Volumetric Box

Figure 3.41 represents how the volumetric box is resized in order to exclude the points that are not needed for the Dense Cloud creation. This process makes easier and faster the process, since the points that are not properly located give unnecessary noise. The intention is to size the box a near as possible to the area of interest.

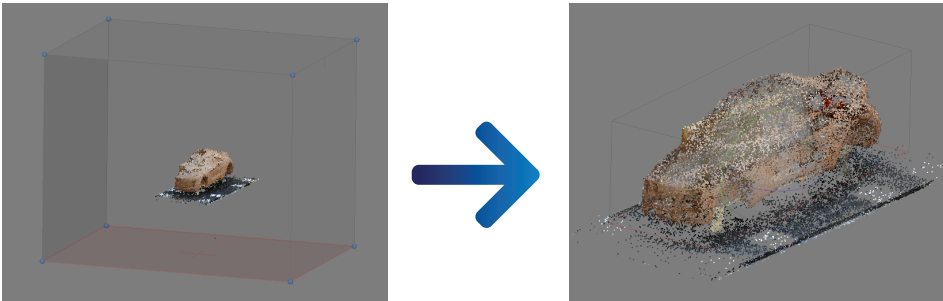


Figure 3.41
T7 Resizing Volumetric Box

8.Remove all Far Pictures



Figure 3.41
T7 Removing Far Images

9. Dense Cloud Build Up

Approximated Time: 4.5 hrs.

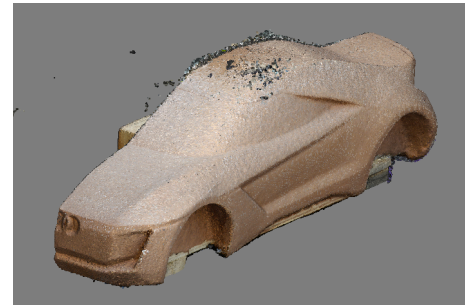
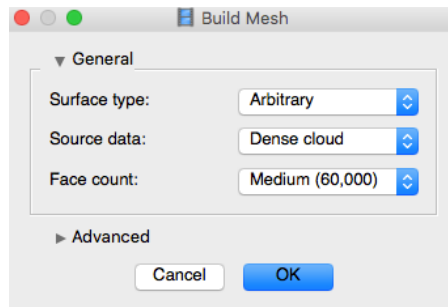


Figure 3.42 T7 Dense Cloud Clean Up

10. Comparison

Mean: 0.057 mm SD: 2.522 mm

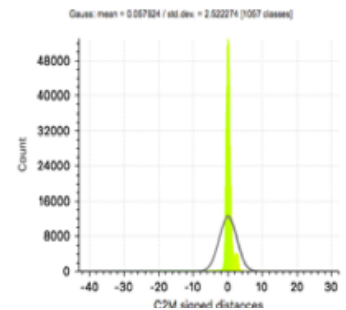
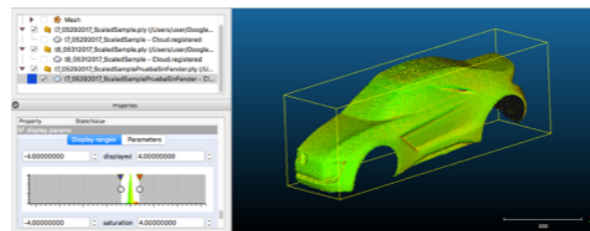


Figure 3.43 T7 Cloud Compare Comparison Result

3.4.7 Phase 2. Photogrammetry (Test9)

1. Shooting

T9: 234 pictures (Nikon , full 360 shooting, floor base)
Features and Specific Zones Zooming

2.Alignment

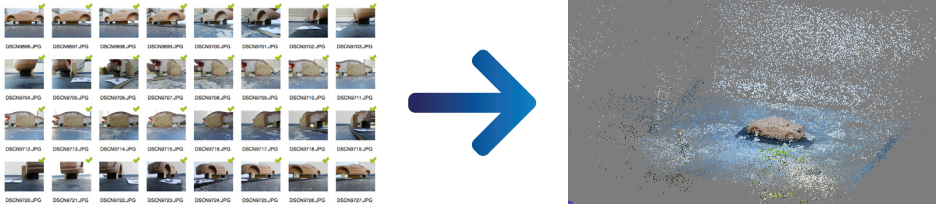


Figure 3.44 T9 Alignment

3.Gradual Selection (0.4)

Sometimes, it is more convenient to find out where the points with high error are located, and then with Photoscan tools it is possible to remove these “noisy” points. “Gradual Selection” filtering helps to select such points, which usually are supposed to be removed. This tool has 4 different types of criterion:

- 1.Reprojection error. Corrects Localization Accuracy.
- 2.Reconstruction uncertainty. Point deviated out from the cloud.
- 3.Image Count. Corrects points that are visible only on 2 photos.
- 4.Projection Accuracy. Correct Poor Projections points due to their bigger size.

Then, “Projection Accuracy” criterion was used for this test. Afterwards, Gradual Selection Threshold was adjusted using the slider, in order to have 0.4 range, this means almost 12,000 points that were selected and then deleted. The assumption is that this process will help the point cloud to be cleaner and more accurate, then the dense cloud would be more suitable for surfacing.

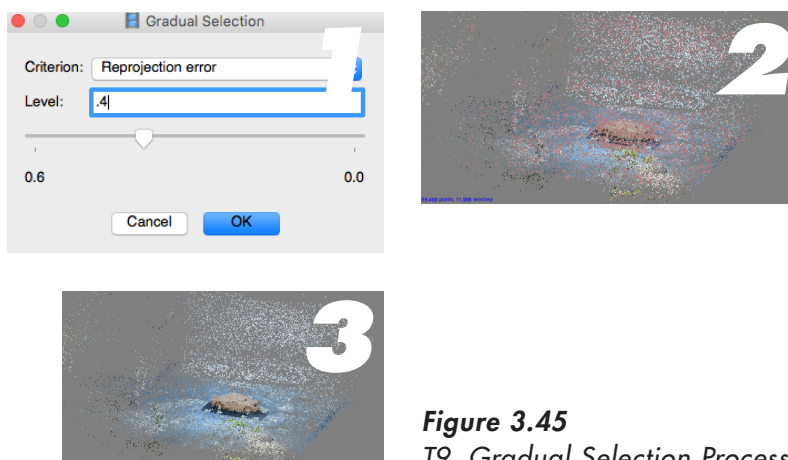


Figure 3.45
T9 Gradual Selection Process

4. Detecting Geometrical Targets (Markers).

Same as Phase 1 & Phase 2

5. Optimizing Cameras.

Same as Phase 1 & Phase 2

6. Scaling & Error Calculation.

Same as Phase 1 & Phase 2

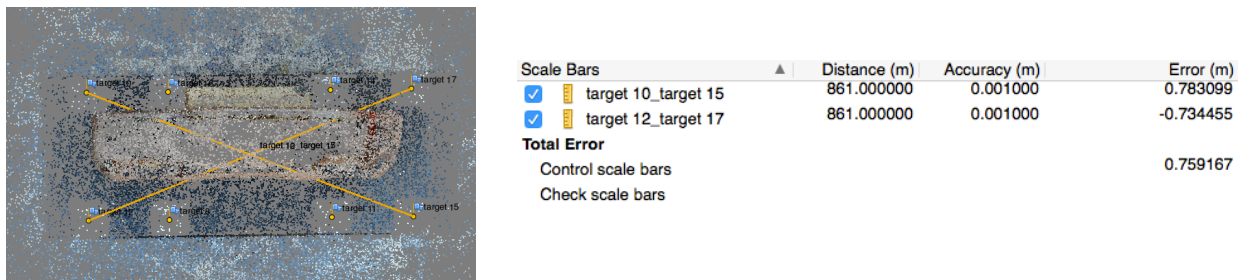


Figure 3.46 T9 Scaling & Error Calculation

7. Resize Volumetric Box.

Same as Phase 2

8. Remove all Far Pictures.

Same as Phase 2

9. Dense Cloud Build Up.

Same as Phase 2

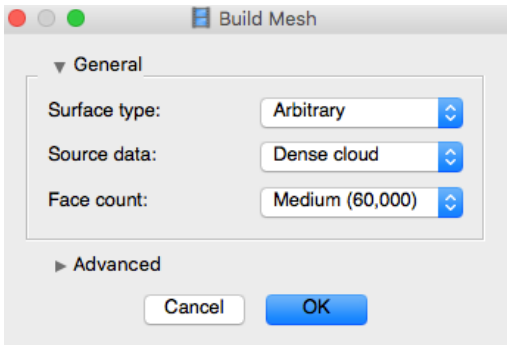


Figure 3.47
T9 Dense Cloud Point Build Up

10.Comparison

Mean= 0.1274 SD=1.9275

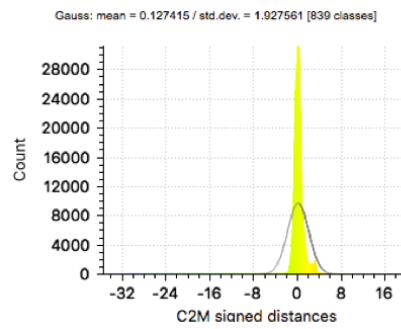
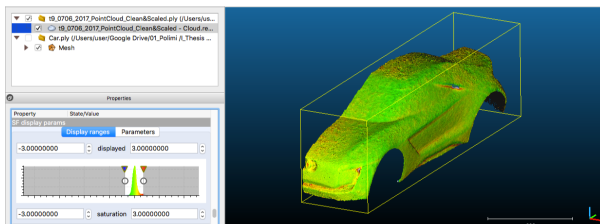


Figure 3.47 T9 Scaling & Error Calculation

4 RESULTS

4.1 Scanning VS Photogrammetry Comparison (CloudCompare Analysis)

Finally, five tests were brought to CloudCompare Software (CC), the aim of this comparison was to compare these 5 dense point clouds against our Master (T6 Scanner Point Cloud). Once aligned and compared, the software computed the mean and the standard deviation of each one of the exercise.

Based on this exercise, we can get different conclusions. Those ones referred to the shooting. The more taken pictures, the better Mean and Standard Deviation. Full 360 Shooting helps to get a better alignment and Dense Cloud build up. Moreover, changing Camera settings noticeably enhanced test 7 and test 8 pictures, comparing Mean and Standard Deviation results between Phase 1 and Phase, it is possible to see approximately up to 10 times lower mean and 50% lower standard deviation. It is important to mention that number of taken pictures also dramatically impacted on the results.

The base, where the object was located, was an important factor because the table height negatively impacted on the acquired information. In other words, the height turned into test noise, due to software could not properly detect deep, height and external element differentiation.

Even tough, it was possible to perform a photogrammetry and get ordinary results with an Iphone 4, it is worth to conclude that a newer phone with a more powerful camera and sensor could have help more in terms of this thesis.

On the other hand, Gradual Selection tool improved photogrammetry test after alignment, by removing all those noisy points that negatively affected Mean and SD. Also, by consequence, the re-alignment and the Dense Cloud point build were faster than before, making it a more time effective workflow.

T4 (M=0.7553, SD=4.6144)

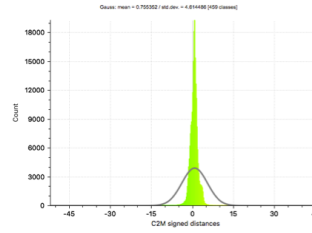
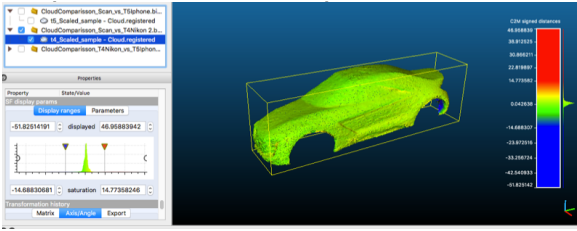


Figure 4.1 T4 Comparison Result

T5 (M=0.2706, SD=4.6144)

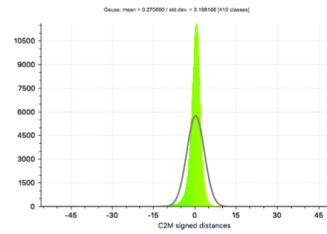
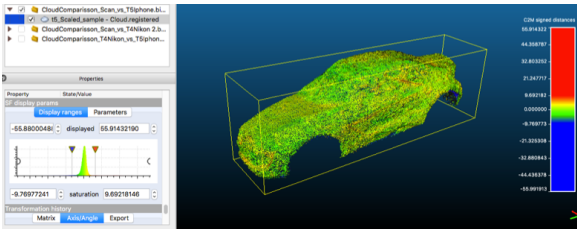


Figure 4.2 T5 Comparison Result

T7 (M=0.0672, SD=2.2767)

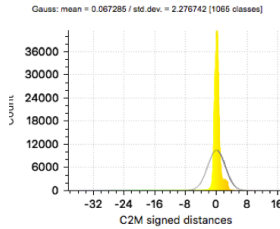
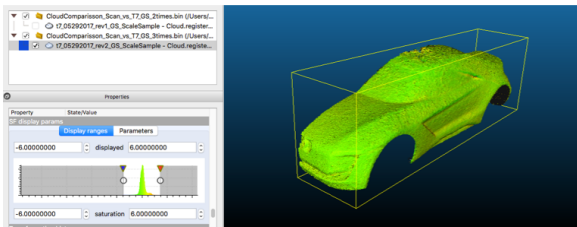


Figure 4.3 T6 Comparison Result

T8 (M=0.166, SD=1.603)

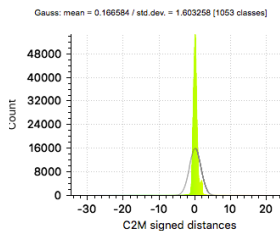
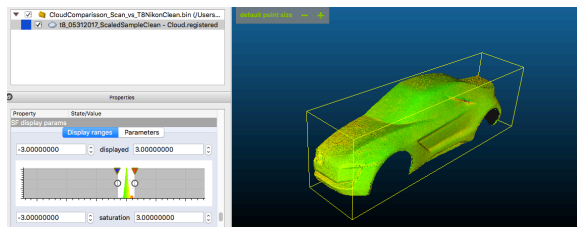


Figure 4.4 T8 Comparison Result

T9 (M=0.1274, SD=1.927)

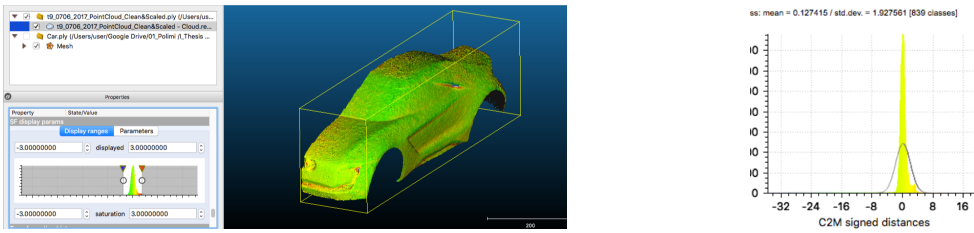


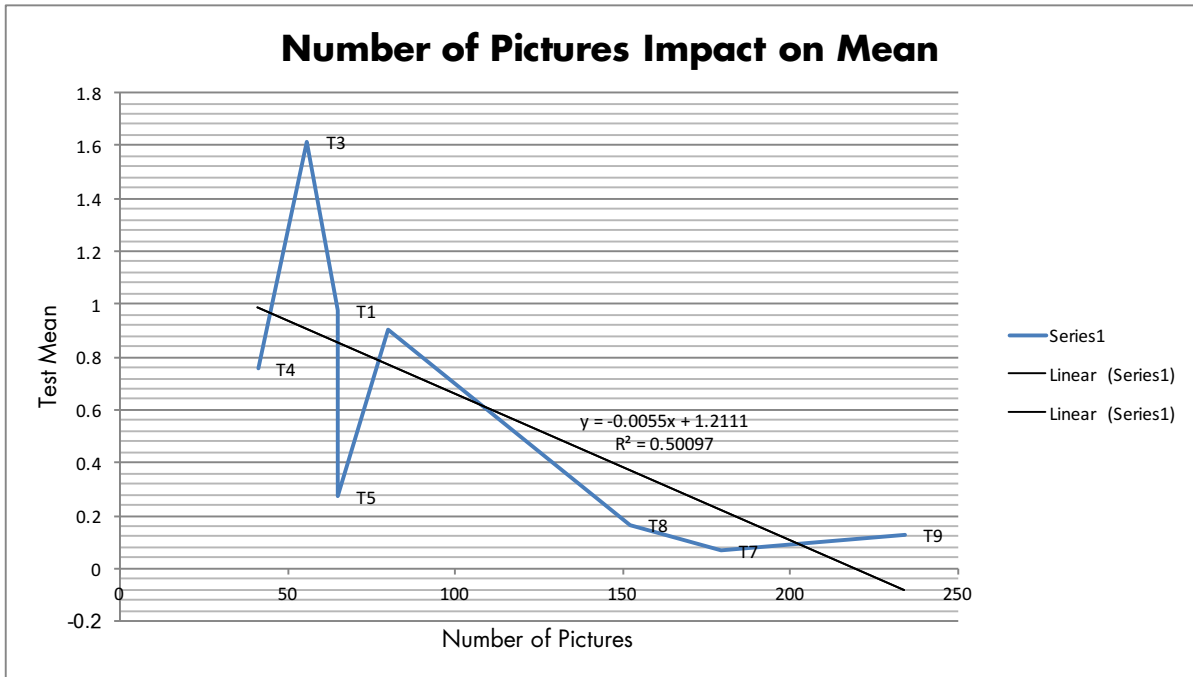
Figure 4.5 T9 Comparison Result

4.2 Photogrammetry Tests Summary

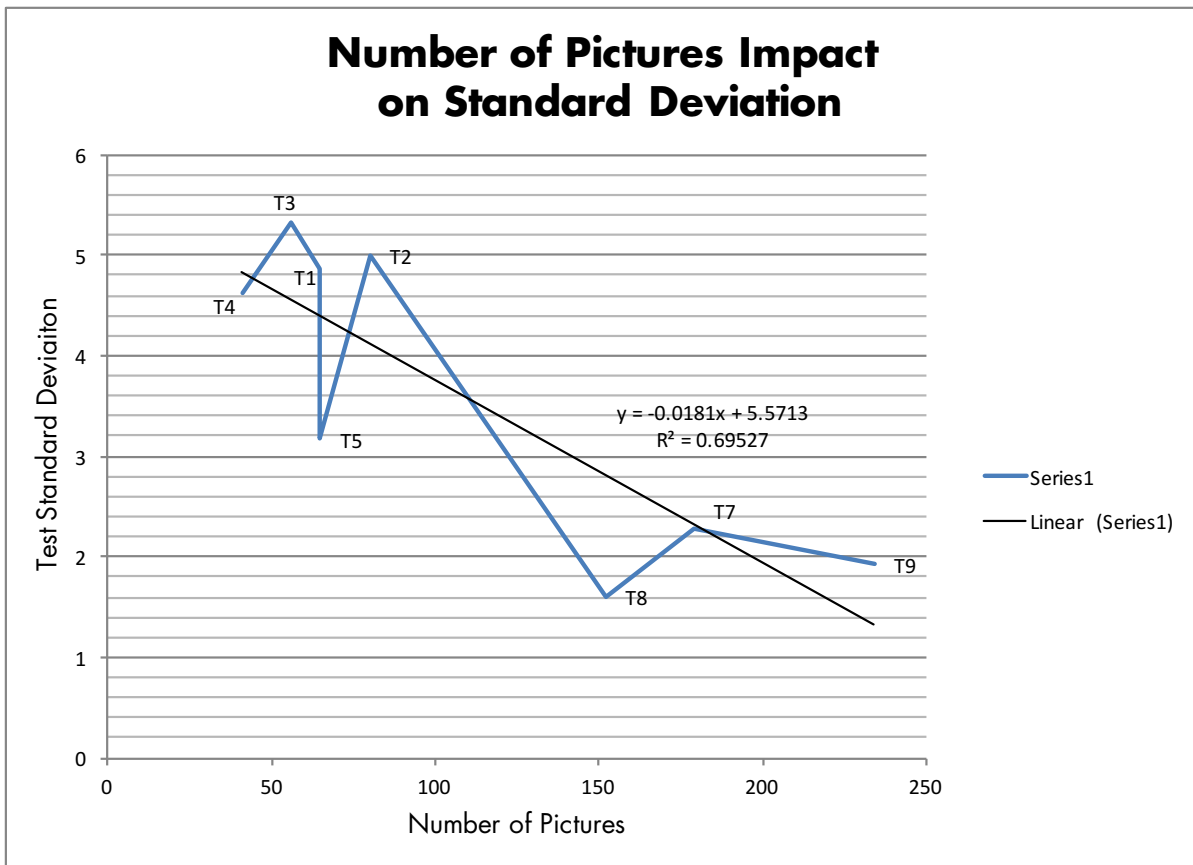
This is a Table summary that aims to show progression of the experiment, depicting which were the modified parameters and how they affected the final results (Mean and Standard Deviation). Moreover, two graphs (graph 4.1 & graph 4.2) are showed on this study, these two elements showed that there is a strong relationship between the number of pictures and the final comparison results, the more pictures taken the better mean and Standard deviation.

# Test	Device	# Pictures	Full/Partial Shooting	Table / Floor	Camera Settings	Features	Scaling ictures	Error after scaling [mm]	Mean	Standard Deviation
Test 6	Konica Minolta VL-9i	21	Full	Base	-	-	-		NA	NA
Test 4	Nikon Cool Pix 500	41	Full	Floor	No	No	No	0.605	0.7553	4.6144
Test 3	Iphone 4	56	Partial	Floor	No	No	No	NA	1.617	5.326
Test 1	Nikon Cool Pix 500	65	Partial	Table	No	No	No	0.627	0.9766	4.861
Test 5	Iphone 4	65	Full	Floor	No	No	No	0.611	0.2706	3.1681
Test 2	Nikon Cool Pix 500	80	Partial	Floor	No	No	No	0.907	0.9012	5.001
Test 8	Nikon Cool Pix 500	152	Full	Table	Yes	No	Yes	0.436	0.166	1.603
Test 7	Nikon Cool Pix 500	179	Full	Floor	Yes	No	Yes	0.621	0.0672	2.2767
Test 9	Nikon Cool Pix 500	234	Full	Floor	Yes	Yes	Yes	0.759	0.1274	1.927

Table 4. Photogrammetry Tests Summary



Graph 4.1 Number of Pictures Impact on Mean



Graph 4.2 Number of Pictures Impact on Standard Deviation

4.3 Class A Surfacing

4.3.1 Dense Point Cloud Import

“Meshlab is open source system for processing and editing 3D triangular meshes. It provides a set of tools for editing, cleaning, healing, inspecting, rendering and texturing” (MESHLAB, 2017).

As mentioned, Meshlab is a powerful tool, it was chosen not only for its mesh edition features, but also it was used as a tool for cloud conversion. Comparing it against Photoscan Agisoft, Mesh had a complete variety of export file types, which are compatible with many CAD Creation Software, such as CATIA, UX, etc.

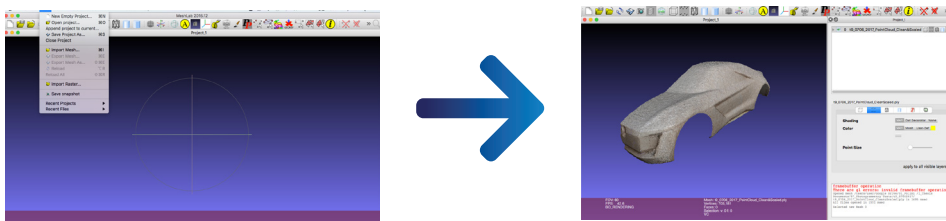


Figure 4.6
T9 Dense Point Cloud Import

For this study case, Object File Format (.OFF) was chosen for the export point cloud file, this format typically contains description of composing polygons of the 3D object, such as: XYZ coordinates, edges, faces, etc. Once defined the format, we proceed to export the Point Cloud.

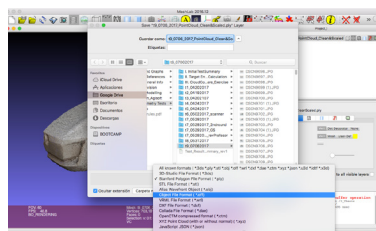


Figure 4.7 T9 Type of Format

4.3.2 Point Cloud Import Process

CATIA was selected as the 3D Modeling Software to use for Class A Surface Generation. There are many reason why CATIA that backed up this decision. It has one of the most powerful tools for style & design on the market. “From 3D sketching, surface manipulations, Class-A modeling, 3D printing features, reverse engineering, among others. CATIA Design/Styling provides all the solutions for design creativity, surface excellence and product experience.” (DASSAULT SYSTEMS, 2017)On the other hand, CATIA has the possibility to import and then manipulate different type of file format; likewise it gives you the opportunity to export diverse type of files to be used in other applications.

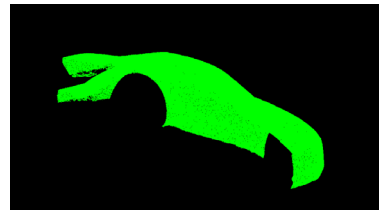


Figure 4.8 T9 OFF of Format

4.3.3 Point Cloud Manipulation

After Point cloud import, it was necessary to realign it, in order to be mated with the absolute axis system (XYZ), on the CATIA Digitized Shape Editor workbench, it was possible to position the cloud point in such a way that it was easier to modify it.

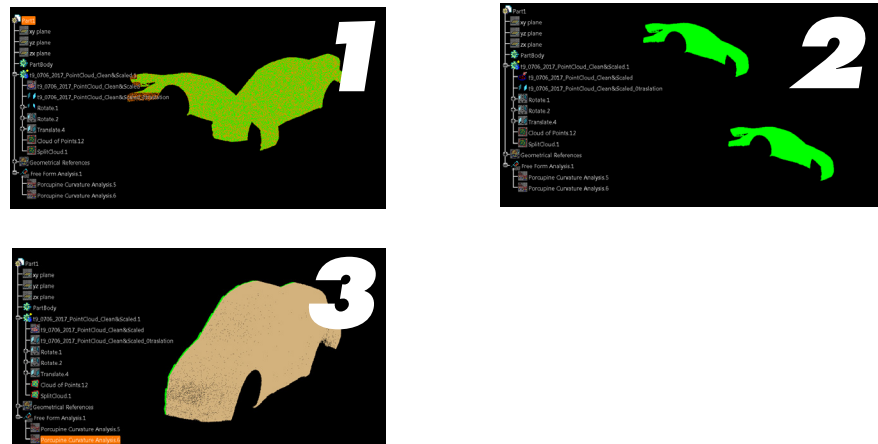


Figure 4.9
T9 Point Cloud Manipulation

4.3.4 Point Cloud Sectioning

Once properly aligned with the axis system, it was decided to create a Section arrangement along X, Y and Z axis, in order to extract more detailed information about the point cloud. Also, it helped to detect some errors and irregularities in the 3D acquisition and when detected it was possible to define a strategy to mitigate those issues on the surfaces creation.



Figure 4.10
T9 Point Cloud Sectioning



Figure 4.11
T9 Point Cloud Sectioning

In addition to the XYZ sections, a series of “auxiliary” sections were defined in order to collect the small and hidden features of the clay model. For example: Front fascia inner zones, Pillar C zones and Rear Headlamp area.

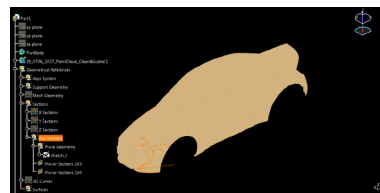


Figure 4.12
T9 Point Cloud Auxiliary Sections

4.3.5 Character Lines Definition

Typically, a character Line is defined as “a line creased into the side of a car to give it visual interest. Character lines will directly create vehicle’s image.” (Car Design Academy, 2017) In other words, these lines provide the car appearance and finally they give the appealing that will cause hypothetical sales. Furthermore, there are secondary lines that possibly do not have the specific weight of Character Lines, but they also contribute to the car final shape.

“Door Parting Line Door Parting Line is an indispensable element of car and door mechanics. Simply it is a line dividing door and body, or front door and rear door. Cross Section Lines It is an imaginary line to show where cutting plane divides the car body.” (Car Design Academy, 2017)

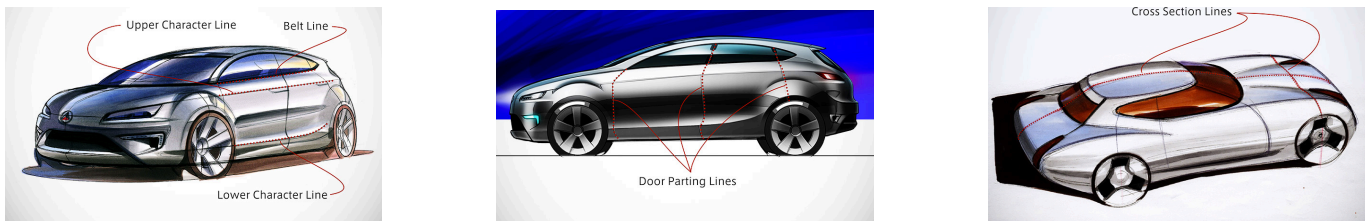


Figure 4.13 Types of Character Lines

For this experiment, the Clay Model has some defined character lines and some others were vague. Therefore, my experience and personal preferences delineated the missing lines.



Figure 4.14 Clay Model Proposed Character Lines

Once hypothetically defined the Clay Model Character Lines on paper, they were recreated on CATIA, using the created section as support for this action.

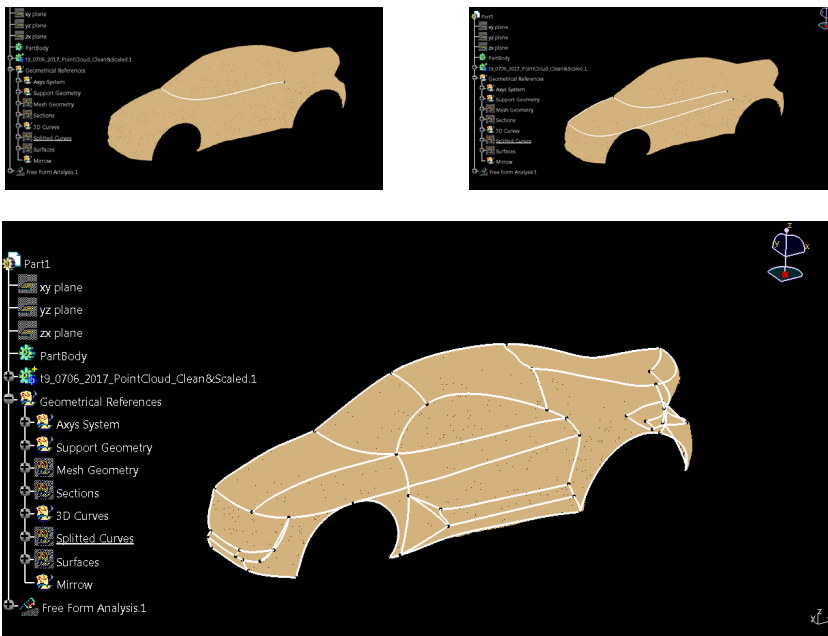


Figure 4.15
Character Lines on Point Cloud

4.3.6 Class A Surface Creation

Final Surfaces were created using Generative Shape Design workbench; different features were used such as sweep, fill and multi-section. All of them using the character and secondary lines previously created. More than 30 surfaces were created, in order to fill out the line skeleton.

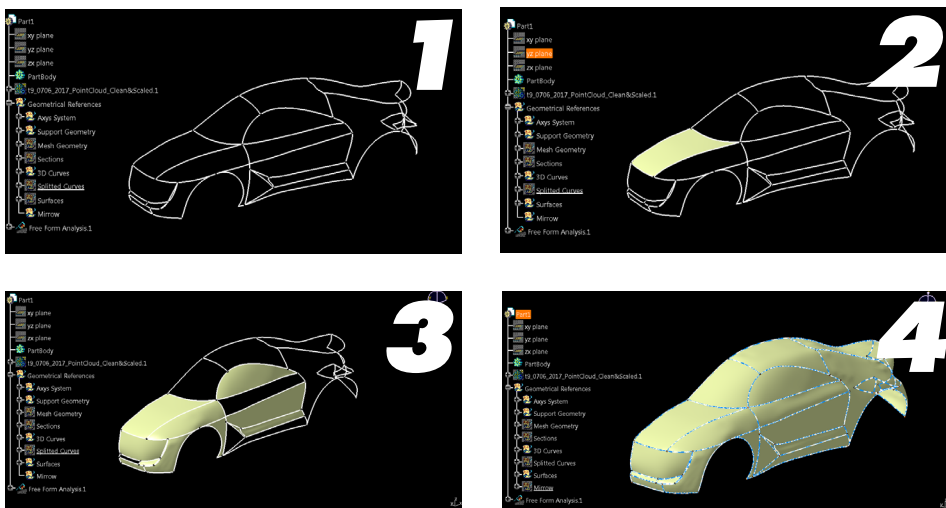
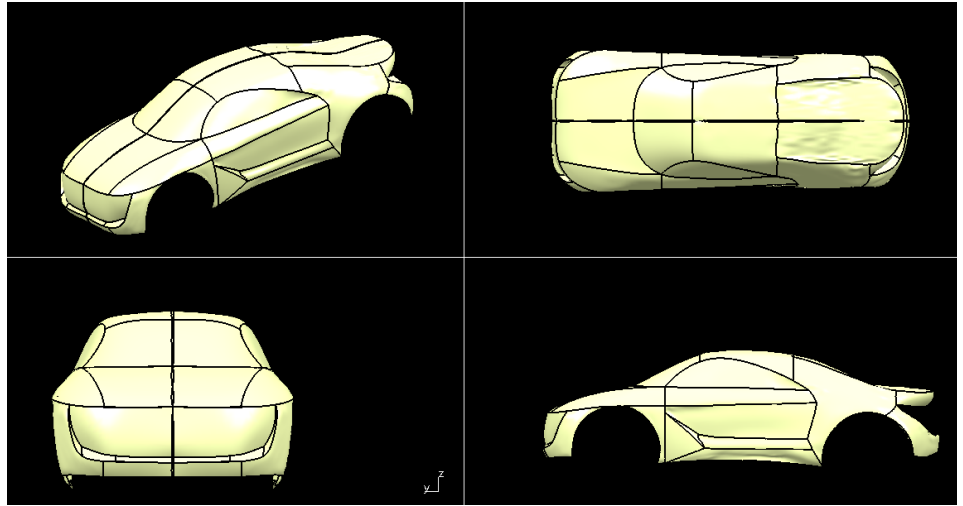


Figure 4.16 Class A Surface Creation

Figure 4.17
Class A Surface Completion



4.4 Class A Surface Quality Analysis

a. There are zones with some evidence of misinformation and poor surface quality, showing wrinkly finish and lacking of smoothness. This will directly impact on light reflection and appearance.

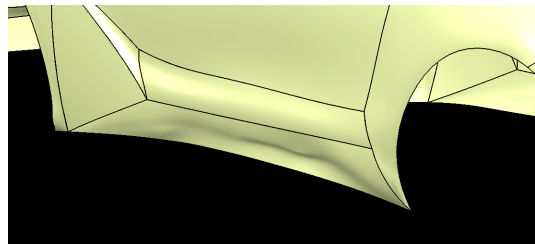


Figure 4.18
Appearance Issue a.

b. At these zones, rear fascia is showing bumpy surfaces, this means that there was lack of point, and the software did not know how to fill this vacancy.

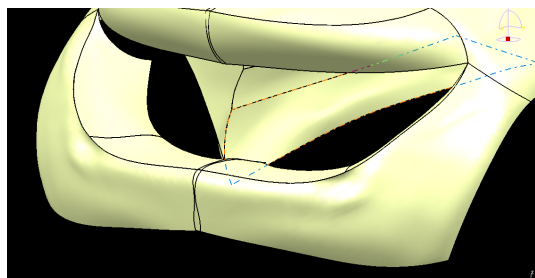


Figure 4.19
Appearance Issue b.

c. One of the final steps of the test was to generate a mirror operation in order to complete the Car Clay Model, as the picture shows, both half surfaces are not mating at the very middle. Photoscan could not recognize where the edge of the model was ending.

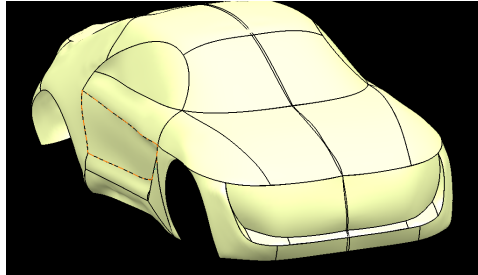


Figure 4.20
Appearance Issue c.

d. Zones, where 3 or more surfaces converged, were not properly generated, creating bumpy and wrinkled finishes.

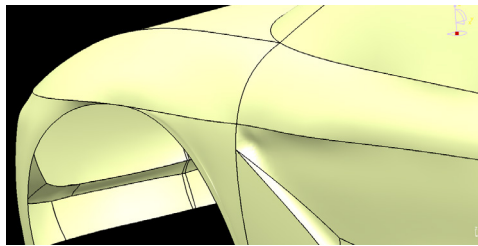


Figure 4.21
Appearance Issue d.

e. When joining all surfaces, it was detected that they did not even have Class 0 condition (touching condition) at .001 mm merging distance. Subsequently, when we increased merging distance up to 0.1 mm (maximum allowed) most of no touching condition disappeared.

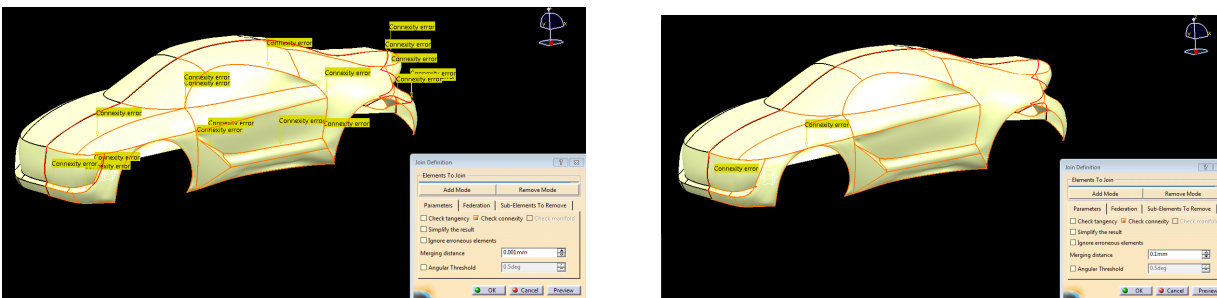


Figure 4.22 Appearance Issue e.

f. Sections of joined surfaces were done, therefore Curvature analysis were performed, showing that surface are not achieving, in some cases, touching, tangent, curvature and acceleration condition. In other words, they cannot be considered as a Class A surfaces.

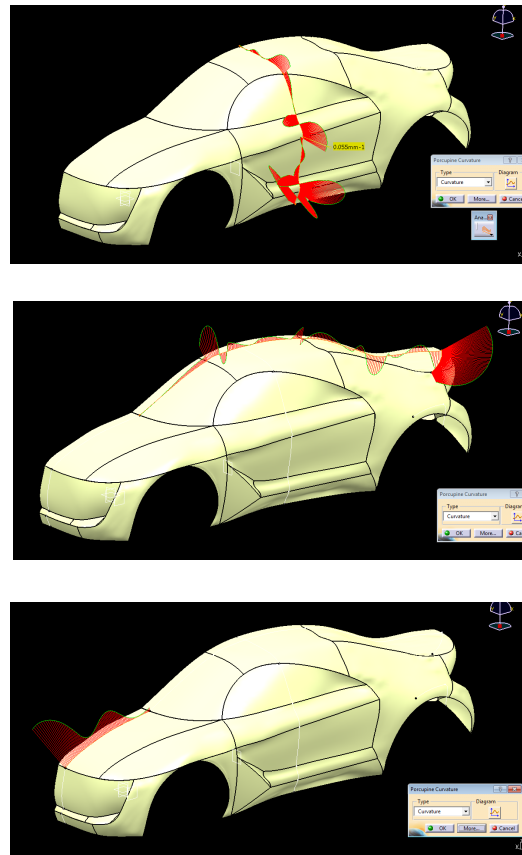


Figure 4.23 Appearance Issue f.

4.5 Class A Surfaces: Photogrammetry v Scanning

After the Photogrammetry Class A Surface was analyzed, it was decided to recreate the generation process; the only difference was to use the scanning cloud point instead of the first one. The intention of this exercise is to compare the results between each other, in other words, to compare both Class A surface and then obtain some deductions.

First of all, it is important to note that it was used the same software tool (CATIA), features and methodology. Also, the same engineer with previous experience executed these new activities. The aim was to not introduce other variables that could have modified the final results.

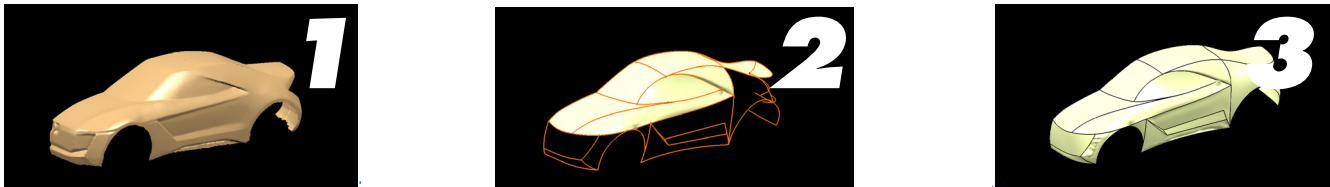


Figure 4.24
Scanning Class A Surface Process

Once finished, the next step was to analyze it. First, Class A Surface was compared with the original Scanning Cloud Point, to define how much they varied. As it can be seen on Figure 4.25, it is possible to say that the generation of the surface is not that precise and accurate respect the cloud point. For this thesis purposes, this variation was neglected, since this process normally takes months to be performed and this process tried to mock up that time, finally this was performed in 4 hours. Therefore, that variation could be considered as normal due to the regular design cadence was not followed.

Afterwards, issues and imperfections of these new surfaces were highlighted. It is important to note that it was found that they had similar conditions as the ones of photogrammetry surfaces. Some zones were lacking of information and then surfaces tried to correct that, resulting in surface deformation, bumps or coarse conditions.

Figure 4.25
Scanning Class A Surface Comparison

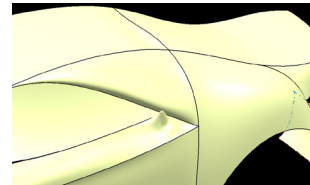
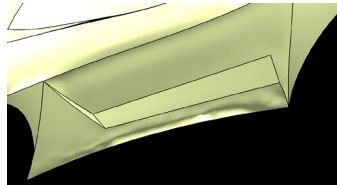
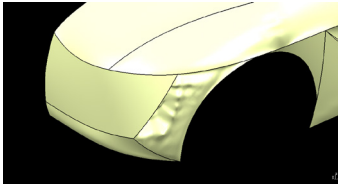
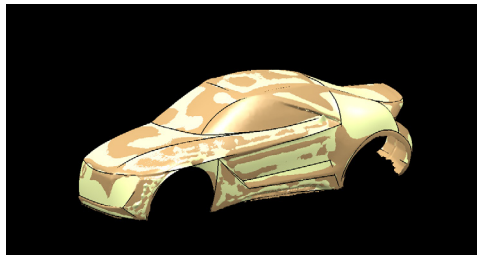


Figure 4.26 Scanning Class A Surface Deformation

The final step of this comparison was to overlap both generated surfaces (photogrammetry & scanning). First, the analysis was just performed by sight; in other words, after the surfaces were put together in different colors (yellow and green) and then the biggest variation zones were just identified. Afterwards, some sectioning was done, and then the biggest identified variations were measured. Finding that in some zones, the differences were varying between 4 to 6mm, determining these ranges as one on the largest (door and rear fender). Some other zones (fender and hood) presented smaller ranges from 0.5 to 1 mm. These results could be originated because of the complexity of the surface zones (more features).

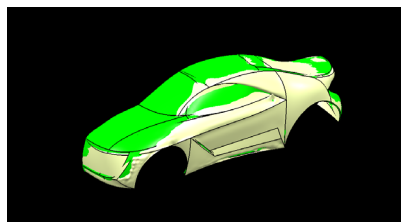


Figure 4.27 Scanning Class A Surface Deformation

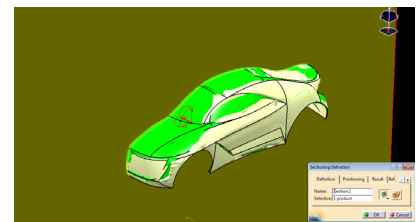


Figure 4.28 Scanning Class A Surface Sectioning

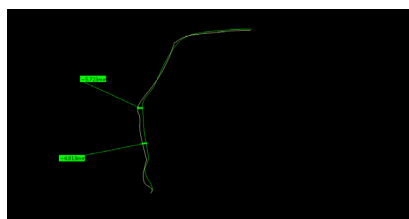
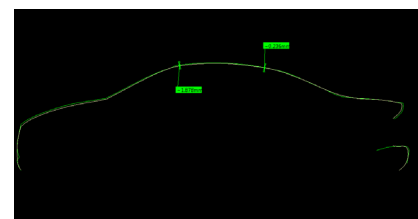


Figure 4.29 Scanning Class A Surface Section Measurements



5 CONCLUSION

Finally, after one scanning test and 9 different photogrammetry tests, several conclusions can be generated, in very different aspects (Space, Time, Human Resources, Cost & Quality). This thesis will try to segment these different points of view and then propose a general conclusion about the entire experiment. Trying to solve the initial aim of this thesis, which is to prove that Photogrammetry technique could be a suitable (and also cheaper) option for 3D info acquisition in the Car Industry.

5.1 Space

So far, we know that Scanning technique needs a specific space in order to perform correctly its tasks. The Konica Minolta Vivid I9 is designed only for indoor spaces, because sunlight really interferes with the result of the acquisition. Besides, this specifically scanner has some temperature (20 c) and humidity (65%) requirements in order to execute in a proper way. Not to mention that it is necessary to have a power installation capable enough to handle this scanner size and needed computer. On the other hand, for the photogrammetry test, an apartment terrace was used in order to accomplish all 9 tests. It was not needed any specific requirement. Although, it was preferable to have a cloudy day or wait for the sun to move in order to avoid unnecessary sunlight in the pictures.

5.2 Time

In this case, it is pretty straight forward that, in general, scanning took less time to be finished than the photogrammetry. In simple numbers, scanning took only 21 images (25 minutes) to have satisfactory results. Photogrammetry spent more time, taking 234 pictures (40 minutes). Besides, in terms of alignment, Polyworks alignment job was considerably less time than Photo Scan Point Cloud Creation (2 hours average) and talking about building dense point cloud this time can reach up to 5 hours, depending of the number of pictures. Then, cleaning process is

more complex on photogrammetry since more points are gathered, this means that external elements were captured such as stairs, bicycle, etc. which will take more time to be deleted.

5.3 Human Resources

At this very aspect, it is possible to say that both techniques can use the same headcount (1 person). From experiment point of view, all activities could have been done by one person, starting from the shooting and then with information development. Although, scanning was performed by two people.

5.4 Cost

Moneywise point of view and just comparing equipment, it was found that definitely the equipment of scanning technique is more expensive. On the market, a Konica Minolta Vivid 9i is budgeted in a range from 25,000 USD to 55,000 USD, depending on included features. Then, comparing it with a 200 USD Nikon Coolpix P500, it is more than 100 times of equipment cost. Nevertheless, as it was mentioned before, it takes more time and headcount to perform the photogrammetry.

5.5 Quality

Ultimately, quality must be the main driver of all these techniques, if the pointcloud or mesh is not good enough to work with it and then generate surfaces, it is not worth it. Scanning technique is a very useful tool and depending on the used scanner, this technique could be even more powerful. That is why this procedure is widespread all over the industry. Now, in terms of this experiment, there is no doubt that scanning technique gave the best precision result ($M=0.0008$, $SD=0.0095$). If we compare it to our best photogrammetry result ($M=0.0672$, $SD=2.2767$) there is a big gap between both of them. Neverthe-

less, this thesis detected that the more parameters set on photogrammetry and the better equipment it was used, the better results we obtained. Actually, from T1 to T7; it was detected an improvement of more than 1000% in terms of mean and standard deviation.

As final words, it is right to say that Scanning would be a more accurate technique. However, even if this numbers are not that “good” in terms of metrology, we can state the obtained results are good enough in terms of 3D Surface acquisition, since the intention of this experiment, from the very beginning, was to generate a base model or 3D support, in order to start generate the first Class A Surface of a Car Clay Model. Moreover, it was found that the Photogrammetry is an improvable procedure, which once mastered it could give positive results This means that, If we are able to detect which we are the parameters and settings that impact the most in results and then modify them in our convenience, it is possible to get satisfactory results with less money, no expensive and specialized equipment and in which anybody can handle these tasks.

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