3D Scanning With a Mobile Phone and Other Methods

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Degree Thesis
Degree Programme in Plastteknik
2016

DEGREE THESIS	
Arcada	
Degree Programme:	Plastteknik
Identification number:	14118
Author:	
Title:	3D Scanning With a Mobile Phone and Other Mehods
Supervisor (Arcada):	Mathew Vihtonen
Commissioned by:	Arcada

Abstract:

The aim of this thesis was to use a mobile phone for 3D scanning using an application called 123D Catch. Other 3D scanning methods were used to compare different types of 3D scanning. Common 3D scanning methods available and their uses are presented in this work.

A professional 3D scanner was used to get precise scan data on an object which was then used as reference for the lower tech methods. Scanning with a mobile phone means taking 2D photographs of an object from different angles. The photos are then stitched together automatically in the 123D Catch application cloud, from where the data can be downloaded to a computer and manipulated.

A plastic part was 3D scanned and edited to replicate the part with a 3D printer. Equipment available at Arcada was used to test whether this was possible and how well it could be done.

Being a free to use application the 123D Catch was found to create good scans in the right conditions. The result of the scans depend highly on the ambient light and the way the photos are taken of the object.

Keywords:	3D Scanning, 123D Catch, GOM, MakerBot, Meshmixer
Number of pages:	47
Language:	English
Date of acceptance:	

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FOREWORD

The idea for this thesis came from the work practice I have done in 3D scanning. I was offered to write my thesis on this topic for Arcada University of Applied Sciences.

I would like to thank my family and friends for supporting me throughout my thesis work and studies at Arcada. A special thanks to Johan Lundell at Cascade Garum Oy for letting me use their equipment for my work. I would also like to thank the staff at Arcada for making this work possible and big thanks Mathew Vihtonen for patiently supervising my thesis work.

1 INTRODUCTION

These days it is very common that people own a smart mobile phone which is essentially a fairly powerful portable computer which fits in one's pocket. These phones are handy to use as reliable tools for any kind of work and in some cases one could not think of living without one anymore. As useful as the phone can be people do not necessarily know that they are actually carrying a device which can be used for 3D scanning. In fact it is not just very possible it is also quite easy thanks to smart, easy to use, software. Autodesk offers a free software for smart mobile devices and computers called 123D Catch which makes it possible for anybody who has access to a phone or a tablet or a regular camera to create 3D models simply by taking pictures from different angles of an object and uploading them to the 123D Catch cloud. The software processes the pictures and creates a 3D model which can be downloaded to a computer for editing and even 3D printing. The purpose of this thesis is to study 3D scanning with the camera of a mobile device and compare results to alternative scanning methods like professional 3D measuring tools and a more affordable 3D scanning tool called MakerBot Digitizer. There will also be a 3D print of an object scanned with the MakerBot Digitizer in this work.

1.1 Background

3D scanning comes in different shapes and sizes. When something is scanned in 3D it means that the shape of an object or a scene is captured by a sensor which can recognize the location of objects in three dimensions. Depending on the object of interest there are different equipment available for 3D scanning. Small objects or scans which require extremely accurate data for engineering purposes can be scanned with structured light scanners and large scenes like landscapes can be scanned from an airplane with long range laser scanners. The scanners create 3D models of point cloud or mesh data which can be viewed on a computer and used for the necessary purposes.

1.2 Objectives

This work will present different methods of 3D scanning and their uses. The practical part of this work will be concentrated on scans of a selected object scanned by the technique of photogrammetry with a mobile phone camera, MakerBot Digitizer laser scanner and a GOM ATOS structured light scanner for comparison in quality and accuracy. These three methods represent different types of 3D scanning technology and will give an understanding of the possibility with each of them. A given plastic part will be scanned in an attempt to replicate it using the MakerBot scanner and MakerBot 3D printer available at Arcada.

2 LITERATURE REVIEW

3D scanning is in the time being a quite new and unknown tool. However 3D scanning offers great possibilities in many industries for fast data acquisition and allows for reducing the amount of steps in manufacturing like fast identification of defects or any problems which might occur with a product. This is why 3D scanning is widely used in industries such as the automotive and aerospace industries, where precise measuring is crucial, as well as manufacturing industry and even in medicine.

2.1 3D Scanning Applications

2.1.1 Rapid Prototyping

Rapid prototyping, or 3D printing, can be defined as different methods of creating a scale model of a part by using computer aided design, CAD, data fed into a machine which builds the part. Creating a 3D print requires a 3D model either created in a CAD software or by 3D scanning, reverse engineering. 3D printing is very useful in engineering and product design as it is a fast way to create a prototype of the product. This way product developers can save time and decrease the cost of product development by preventing possible costly mistakes at an early stage of product development. The steps of rapid prototyping are, construction of the CAD model, transferring the CAD data to a 3D printing software for settings and constructing the layers of the part, printing of the part and removal of possible excess material from the part such as support material. [1] There are a number of different available 3D printing techniques, of which four are described below.

Fused Deposition Moulding

Fused Deposition Moulding, FDM, is the most commonly known and the cheapest method of 3D printing. An FDM style 3D printer works by feeding a plastic wire, called filament, through a hot nozzle which melts the plastic and extrudes it on the printing bed. The hot nozzle is mounted on an arm moving in x, y and z axes tracing the shape of the part, moving up layer by layer to construct the part. There are a few drawbacks with FDM printing. As the part is created by extruding layer by layer, the surface finish of the part is quite rough. Each building layer can clearly be seen and felt. Also certain features are difficult to create perfectly like overhanging structures. Overhangs and holes may become saggy at the top if the layers do not overlap enough. This can be fixed by having the printer create support material for such features, this requires that the support material needs to be removed when part is finished which makes the finish even rougher. FDM prints are quite easy and cheap to make and a great way to create prototypes but the mechanical properties are not as good as a parts manufactured by traditional methods. [2]

PolyJet Printer

PolyJet printing is another form of layer by layer 3D printing. This method is different from FDM that instead of extruding the PolyJet printer works like an inkjet printer by printing a whole thin layer in one go and curing it immediately with UV-light. Unlike FDM prints there is no sagging in holes and as the a PolyJet printer can build the part in very thin layers, the level of detail and the overall quality and surface finish is in general better than from a FDM printer. [2]

Stereolithograph Apparatus

Stereolithographic, SLA, printing is one of the oldest 3D printing methods and gives some of the best 3D printed parts. SLA printing is different from the other methods as the parts are cured from a liquid photopolymer resin. The resin is held in a tank and an ultraviolet laser traces the shape of the part layer by layer and cures the resin. Depending on the printer the part is either lifted up from the resin or submerged in the resin after each layer is cured. When the part is finished it is rinsed of excess resin and in some cases needs to be cured in an ultraviolet oven to fully cure the part. SLA printers make good smooth surface finish and are able to construct complex parts. [3]

Powder Print

There are various types of powder print technologies of which selective laser sintering, SLS, is one of the most common. In the SLS process a plastic powder is rolled into a smooth flat surface after which a laser melts the powder and solidifies it. Then the printing bed is moved down and another layer of powder is spread on top and melted and so forth. When the part is finished it is surrounded by powder which is removed quite easily. The surface finish of SLS prints is slightly rough, not as smooth as PolyJet or SLA, but the parts made by SLS printing have very good mechanical properties and as the surrounding powder works as support material it makes complex features easy for the SLS process. [2]

2.1.2 Quality Control/Injection Moulding

One of the most common applications of high precision 3D scanning is quality, or shape and dimension control. In, for example, the injection moulding industry the injection moulded parts today are mostly modeled CAD data from which the molds are milled. The CAD data needs to be modified to fit the injection moulding production process, shrinkage needs to be taken into consideration, draft angles added, mould parting lines and so forth. A well-made injection moulding part is designed to be uniformly thick throughout and contains certain features to prevent warping. For a simple part these features can be calculated and should result in not causing any complications. As parts become more complex it is considerably more challenging. Small parts, complex shapes, tight tolerances and schedules set high demands on product developers. [4]

After 3D measurement of an injection moulded part it can be analyzed for warpage and shrinkage in comparison to the CAD model. Different features like holes or other dimensions, if the part fits in assembly with another part, can be measured on a 3D inspection software. Figure 1 shows a part to CAD comparison visualized with color showing the deviation in comparison to the CAD from GOM Inspection software. [4] With the help of 3D scanning technology companies can speed up the first article inspection process on pre-production samples and monitor the quality of their products throughout the production process. If a problem is discovered in a part it can be realized early and it is easy to locate and proceed with necessary measures to fix the problem.

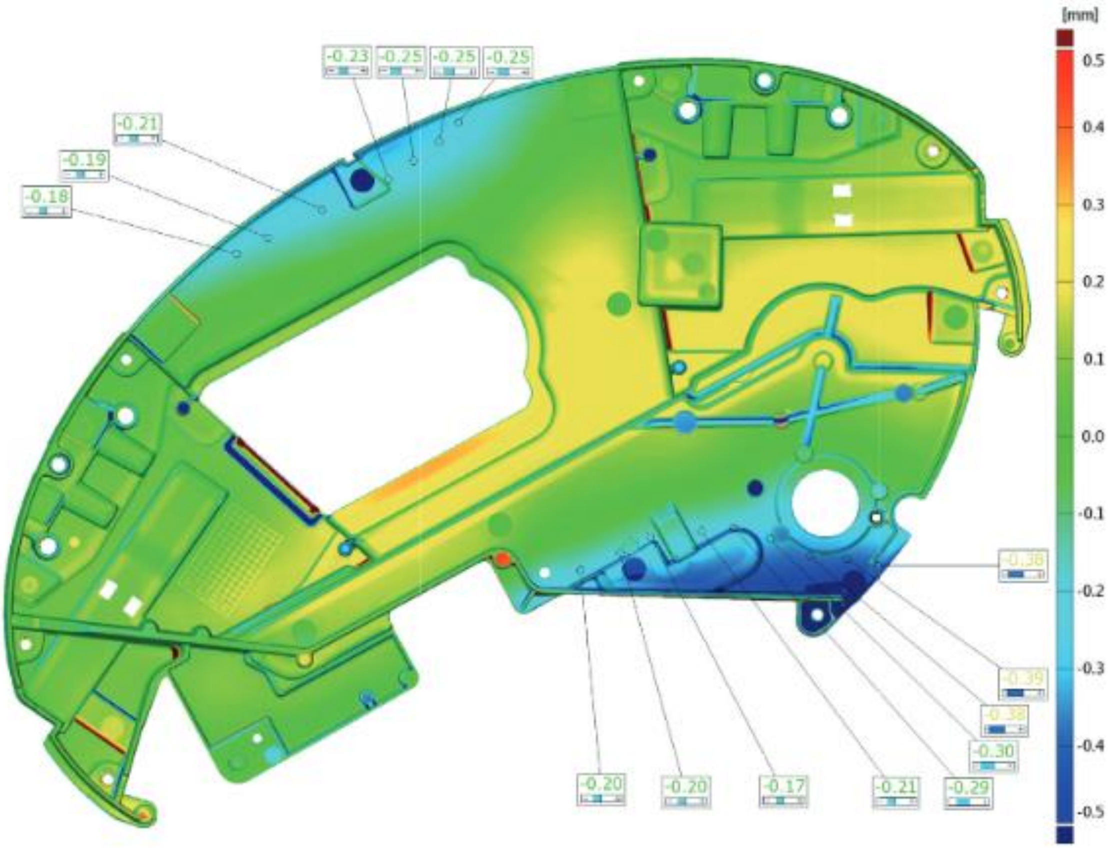


Figure 1: Deviation compared to CAD visualized in color of an injection moulded part [4]

2.1.3 Reverse Engineering

Precise 3D scanning allows for accurate reverse engineering of parts. It is possible to very quickly obtain precise digital copies of objects which can then be manipulated or used to create CAD models. It is especially useful for hand made parts or other freeform objects which are not straight forward to precisely recreate in digital form. The scan data can then be used for computer aided manufacturing in mould making for example. [5]

2.1.4 Wear and Deformation

3D scanning is probably the most useful tool for inspecting the deformation and wear of parts or assemblies. If an object is closely scanned before and after use the damage on the product or simply the effect of a certain use of the product can clearly be observed. Several parts can be tested and for example used in different intensities, this way a product developer can get a quite clear image of the true properties of their product. [6]

2.1.5 Medical Technology and Forensics

In the Institute of Forensic Medicine at the University of Zürich in Switzerland started research in using 3D surface scanning as a tool in forensic medicine in the early 2000s. As an alternative or enhancement to traditional autopsy it is possible to perform virtual autopsy, called Virtopsy, developed at the University of Zürich, with 3D scanning for surface measurement of bodies and other objects for forensic investigation. 3D surface scan of a body can be used together with CT and MRI scans. This way the digital imaging data can be stored in long term and reviewed later if necessary. 3D scanning technology can help to solve tricky cases in medical forensic investigations to find out what kind of object was used to strike a person or matching bite marks to a set of teeth. It is not only useful for deceased victims but can also be applied for living persons. [7] [8]

2.1.6 Computer Graphics

In recent years different kinds of 3D scanning has increasingly been used in the computer game making industry. Creating the gaming environment, objects and characters manually by sculpting and painting is time consuming and requires a lot of skill from the artists. As hardware has grown more powerful game developers' possibilities in game making increase with it and demand on graphic detail has grown at an amazing rate. In the top games of today graphics and attention to detail is very important. Creating a realistic gaming environment is very challenging not just because it is difficult and time consuming to create realistic graphics but the environment of the games are also bigger than ever. This means there is a tremendous amount of objects to create in 3D, and by 3D scanning can be made quickly and with good results. [9]

2.1.7 Aerospace and Automotive Industry

The precision of high-end 3D scanning is recognized in the aerospace automotive industry and can be applied in many areas of production and testing. The aviation industry is especially demanding in precision with very low tolerance for any errors to guarantee safety and reliability of aircraft. As parts need to be perfectly fitting 3D scanning can provide fast and accurate measurements directly after production. An aircraft can be completely scanned and the scan data can be used for computational fluid dynamics, CFD, analysis and other simulations and testing. Turbine blades and housings can be scanned to create digital models for testing and different parts measured for assembly control. In the automotive industry 3D scanning is used in body design and bodywork assembly can be inspected by scanning for example doors or bumpers attached to jigs. [10] [11]

2.1.8 Cultural Heritage Documentation

3D scanning has even been used in cultural heritage documentation, on archeological sites and creating 3D models of artefacts. As most of the target objects in this area of documentation are very delicate it is highly beneficial that 3D documentation is a non-contact approach, which doesn't damage the sites or objects scanned. In cultural heritage documentation different types of 3D imaging are used depending on what is documented. For scanning larger objects or architectural sites topographic LIDAR scanners are used as well as photogrammetry if the area is not suitable for close range scanning. For smaller objects like sculptures and features on surfaces like paintings or carvings close range 3D scanners are used for precise data. [12]

There are many purposes of 3D scanning in cultural heritage documentation. For example historical sites which are being destroyed by mass tourism or war etc. can be precisely documented and preserved in digital form. Digitized models of artefacts allow for virtual examination and research on the objects without having to touch them. Objects can also be replicated by rapid prototyping or CAM, Computer Aided Manufacturing, and especially artefacts too delicate to be moulded. [13]

2.1.9 Surveying

Land surveying is the science of measuring distances and curvature of natural and man-made areas. Before electronic and laser measuring devices surveyors used for example tape measurements and theodolites for measuring. Today modern surveying equipment has made surveying considerably faster compared to surveying with traditional equipment thanks to 3D laser scanners. Today surveyors may use for example LiDAR, Light Detection and Ranging, to get three dimensional point clouds of large areas. LiDAR scanners can be used in both topographic and aerial measuring. LiDAR scanning creates accurate 3D models and is not just useful in large scale topographic measuring, for agriculture, traffic planning, maps, but also in architecture and archeological sites to name a few. [14]

2.2 3D Scanning Processes

2.2.1 Photogrammetry

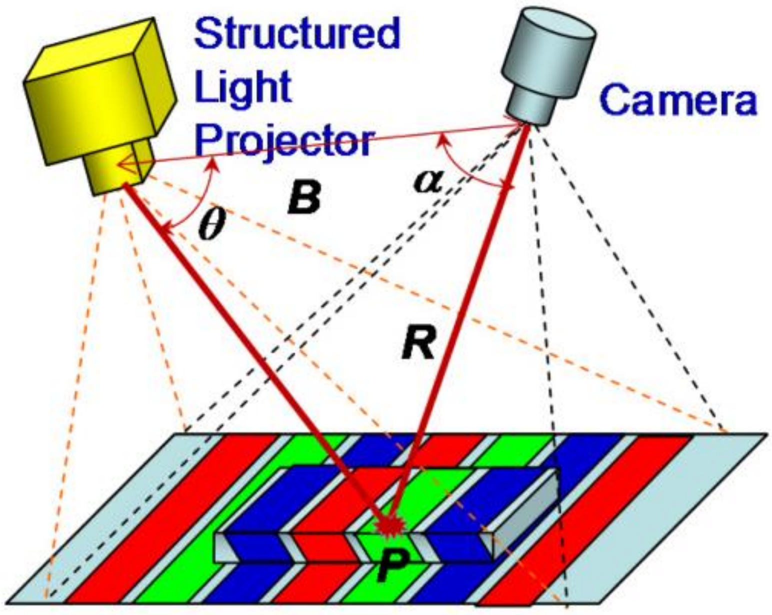
Photogrammetry is the art and technique of extracting three dimensional information from two dimensional photographs. When taking a two dimensional picture, the depth of the three dimensional scene is lost. Photogrammetry reverses this loss of information from photographs from at least two angles of each point desired to capture in 3D.

Photogrammetry uses the principle of triangulation to calculate the location of points. Basically an unlimited amount of points visible in the pictures can be measured at a time and point locations are calculated by mathematically intersecting connecting lines in space. The accuracy of resulting measurement depends on the resolution of the camera, the size of the object in question, how many photographs are taken and layout of the pictures taken. However, the process of photogrammetry is not perfect and therefore the result of photogrammetry is not a perfect depiction of the 3D world. A photogrammetric measurement also has no dimensions. This means that without a known distance in the measurement there is no way of knowing the size of an object depicted. The measurement can be scaled by knowing the distance between actual coordinates and the distance can this way be used to scale the photogrammetric measurement. [15]

Basically any camera can be used for photogrammetry, even a mobile phone's camera can be used. The 123D Catch application used later in this work uses the technique of photogrammetry.

2.2.2 Structured Light Scanning

In structured light 3D surface imaging there is a striped pattern projected on to the target object and the shape of the object is detected by one or two cameras from the distortion of the projected pattern. Structured light scanning uses the principal of triangulation to obtain the distance to the object from the sensor. Structured light scanners come in different versions. The main types of structured light scanner set-ups are scanners with one camera and scanners with two cameras, stereo vision. Stereo vision scanners have the possibility of creating a three dimensional image from one shot because of the two views per image. As more pictures are taken the computer software connects the images to create a 360 degree 3D model of the object, if necessary the part is flipped and scanned again to get the full part. [16]



$$R = B\frac{\sin(\theta)}{\sin(\alpha + \theta)}$$

Figure 2: Structured light scanner with one sensor [17]

GOM ATOS

There are a range of scanners available by GOM (Gesellschaft für Optische Messtechnik mbH), GOM ATOS scanners. They are state of the art high precision structured light scanners designed for demanding measurements. ATOS scanners use narrow band Blue Light Technology for the fringe pattern projection. The Blue Light Technology allows for measuring independently of ambient light conditions. The images are captured by two specially developed cameras with up to 16 megapixel resolution. The ATOS Triple Scan scanner can be adapted to the measurement requirements as the projector and the camera lenses can be changed for different measuring volumes. The measuring volumes range from 38mm for high accuracy on small parts to 2m for large objects. The ATOS scanners use the triangulation principle to determine distance. [18]

As the scanners capture each image from two camera angles at a time and are carefully calibrated, each shot creates three dimensional surfaces individually. Instead of patching the 3D images together only by overlap from the separate shots, reference points are placed on the scanned object through which the software patches the scans together more accurately. This way the system uses both reference points and surface matching to combine the single scans. The reference points are small round stickers with white dots which are of extremely precise diameter. The size of the dots used vary between the measuring volumes. When scanning the bottom side of an object the reference points are used to patch the top and bottom scan together. [16]

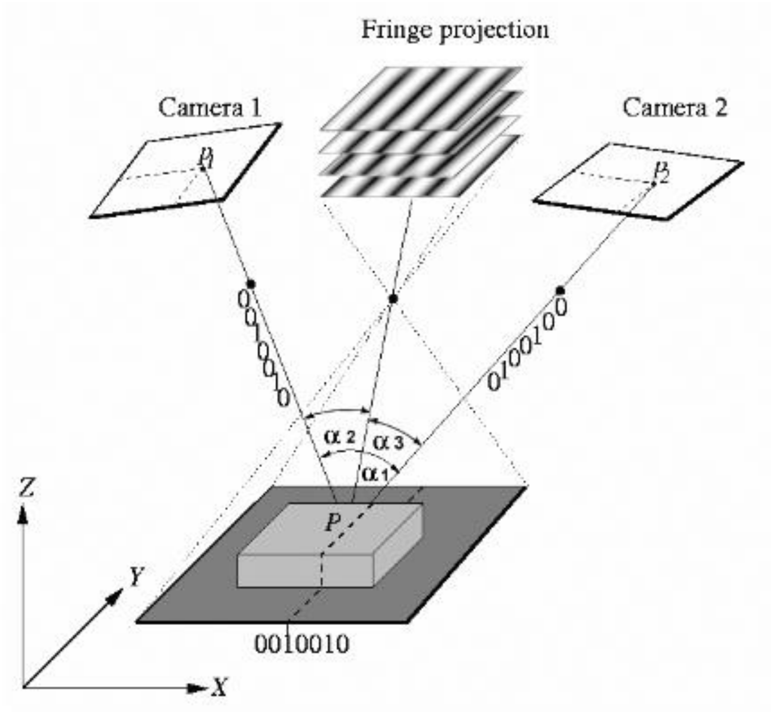


Figure 3: Structured light with stereo vision [19]

TRITOP Photogrammetry

GOM TRITOP photogrammetry is not 3D scanning but a form of 3D optical coordinate measuring. With TRITOP CMM a complete surface point cloud like in 3D scanning is not recorded, only the coordinates of certain reference points placed on the object measured are recorded. TRITOP measuring is used for coordinate measurement of large objects too big to scan or when points placed in specific places on the surface is enough data. It is also used as a tool to map the reference points on large objects for easier and more accurate patching as the software recognizes the points before and during the actual scan. This is for scanning things that are significantly larger than the measuring volume of the scanner. For capturing the reference points a high end Wi-Fi camera with carefully configured settings is used. Creation and identification of a three dimensional coordinate system on the object measured, dimensions and location of the reference points are made possible by coded points located on crosses, scale bars and single coded points. The coded points need to be scattered around the object and captured in the pictures taken of the object. The pictures are sent wirelessly to a computer on which the TRITOP software processes the pictures and creates a 3D coordinate system of the points. Objects as large as 20 meters can be measured accurately with TRITOP. Measurement of plain coordinates on the surface of an object is enough for measuring some shape and position tolerances. When 3D coordinates are captured they can be compared to CAD data for inspection. The equipment is easy to transport to any site for measuring as it only requires the camera along with its accessories, the coded points and the computer with the software. [20]

2.2.3 Laser Scanning

There are a number of different types of laser 3D scanners. The most common ones are time-of-flight, phase shift and triangulation laser scanners. Time-of-flight scanners measures distance by emitting a laser beam and measuring the time it takes for the beam to reflect back from an object, as the speed of the laser is known it is possible to calculate the distance. LiDAR scanners use time-of-flight for sensing. Phase shift scanners on the other hand emits an amplitude modulated beam like a sine wave. The projected beam and the reflected beam are compared by the sensor and the phase difference between the two waves shows the time of the delay. With this information the distances can be calculated. Time-of-flight and phase shift scanning are mid- to long range scanners. [21] For smaller objects and engineering purposes triangulation laser scanners are more accurate. Triangulation scanners use either a line or a point of laser beam to scan across the surface of an object. The laser is reflected off the object and picked up by a sensor. Using trigonometric triangulation the distance to the object can be calculated as the system knows very accurately the distance between the source of the laser and the sensor. [22]

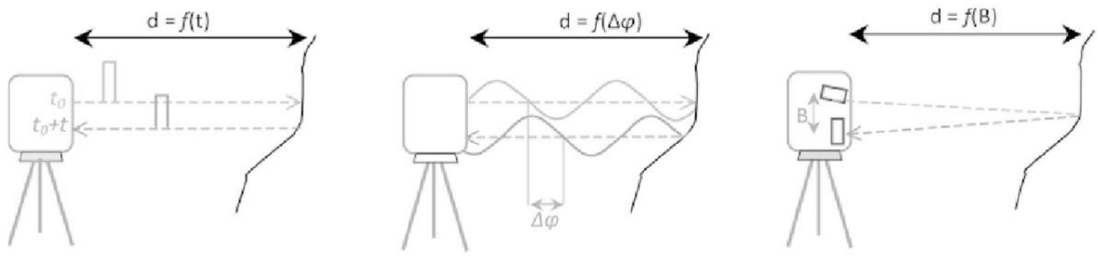


Figure 4: Time of flight, phase shift and triangulation scanners [23]

The main differences between laser scanning and structured light scanners are the density of the point clouds, the accuracy of the scans, how long the scanning takes and the cost of services or equipment. Structured light scanners are able to obtain millions of points taken in a single shot with a very dense point spacing, as low as 0.01mm. Laser scanners sweep across the objects with a point or line and are not able to capture as many points off the surface. Structured light scanners are in general more accurate as in small measurement volumes the accuracy of measurement can be down to 0.005mm or lower whereas small scale laser scanner measurement accuracy can be around 0.02mm. [24] The speed of the scanning depends a lot on the size and shape of the object. Laser scanners have the advantage of sweeping the laser across the surface allowing for fast measuring as the scanners can be operated by hand to aim the scanner. Structured light is on the other hand not necessarily slower. Each shot can be as quick as one second and using rotation table to get all sides rapidly. Complex shapes require more effort and could be faster by laser. Structured light scanners are typically more expensive than laser scanners. [25]

2.2.4 Tactile CMM (Coordinate Measuring Machine)

Tactile CMM, coordinate measuring machine, or probing, is a form of three dimensional coordinate measuring where a probe connected to an arm moving in three Cartesian axes measures coordinates on the surface on an object by physical contact. Before modern optical metrology tactile CMM was the most accurate form of measuring in precise engineering applications, but as optical metrology allows for faster measuring and complex geometries being much easier to acquire with high accuracy without having to touch the parts, optical metrology is a good alternative. Contact CMM machines are different depending on the size and other features of the measured objects. [26]

2.2.5 Polygon Meshes

A polygon mesh, or simply mesh, is an assembly of points, called vertices, connected by lines, or edges, which create faces, mostly triangular or quadrilateral. Together these elements represent the surface and define the shape of a digital object in 3D. The triangles, or faces, in a mesh are flat which means that any curved or organic shape for example is an approximate description of the shape. Objects like perfect squares can be perfectly represented as a mesh. The accuracy of the mesh depends on the density of the faces. The more faces there are the closer the features resemble the true shape of an object. A 3D scan creates a point cloud which is not mesh before the points are connected with edges to create the faces of the mesh. [27]

There are many different formats available for displaying 3D models. The 123D Catch scan creates an OBJ, Object, file and the MakerBot Digitizer creates the files in STL, Standard Tessellation Language. Files in OBJ and STL are easily converted from one to the other as they are very similar. The ATOS scans can also be converted to STL and in this thesis files were mainly used as STL files.

3 METHOD

3.1 Equipment

Scanning was executed in three different methods. The means of scanning were a mobile devices' camera using Autodesks free to download 123D Catch application with a Sony Xperia Z1 Compact mobile phone, GOM ATOS Core scanner using GOM ATOS Professional software and the third method was a MakerBot Digitizer with their own MakerWare software for MakerBot Digitizer. For mesh editing another free sofware by Autodesk called Meshmixer was used. Inspections were made with GOM Inspect.

The object scanned to compare the different scanning methods was a plaster cast of a head. The reason the plaster head was chosen for this experiment was that it was light in color and had a smooth but matte surface, which is optimal for 3D scanning. The head is a sculpture designed by the Finnish artist Heikki Nieminen and the copyrights are owned by Kehittämiskeskus Opinkirjo, which is an organization working for supporting wellbeing and growth of children and youth in Finland. [28]

The other object scanned was a white plastic part for holding a roof drain pipe. The objective was to 3D scan and then 3D print the drain holder part to copy the original part using the MakerBot equipment available at Arcada University of Applied Sciences.

3.2 Scanning with Mobile Device

3D scanning is made possible for anybody with a smart mobile device or a camera and a computer with 123D Catch software. Creating a 3D representation of almost any kind of object is not only possible, but very easy thanks to the mobile application or computer software. All one has to do is simply take a series of pictures with the device of choice and uploading the pictures to the application cloud where the rest of the work is done automatically. The process is photogrammetry.

First of all the application needs to be downloaded to the mobile device used. When taking pictures with a regular camera the pictures should be uploaded to the application with a computer. The software is available for free at http://www.123dapp.com/catch for PC. For mobile devices it can be downloaded from Google Play, App Store and

Windows Store, so it is basically available for any PC or Android, Apple or Microsoft mobile device.

Before starting a scan there are a few things to take into consideration. First of all finding a good spot where it is easy to move around the object for taking pictures. To get as clear data from all sides of an object as possible it is important to have even and sufficient lighting all around the object. Direct sunlight is too bright on one side and creates a shadow on the other side which leads to poor scanning results. Shiny or transparent objects may not work at all. It is also really important that the object does not move during the photographing, so the object scanned should be placed on a steady surface. If the object moves the scan should be restarted. For best possible result some points of reference around the object, like placing the object on a newspaper or a checkered pattern for example. This makes it easier for the photographs to be patched together. When uploading the pictures a good internet connection is required.

The scans were carried out as follows:

- A platform for the part was prepared and adjusted to be as comfortable to photograph as possible for steady pictures, and space was cleared around the platform to ensure the part was easily reachable 360 degrees around.
- A patterned piece of cloth or a page of newspaper was placed on the platform for reference points. Then the part put on top of the patterned base.
- The 123D Catch application was opened on the mobile phone and “Start a New Capture” was clicked to start taking pictures.
- The scanning was executed by shooting photos around the object from every direction and from two different heights. First at a low angle taking ca. 20 photos all around, and then again at a higher angle. Then additional pictures were taken of details.
- When the pictures were all taken and considered as good as possible they were uploaded to the app cloud for calculation. This process takes several minutes and requires a decent internet connection to work.

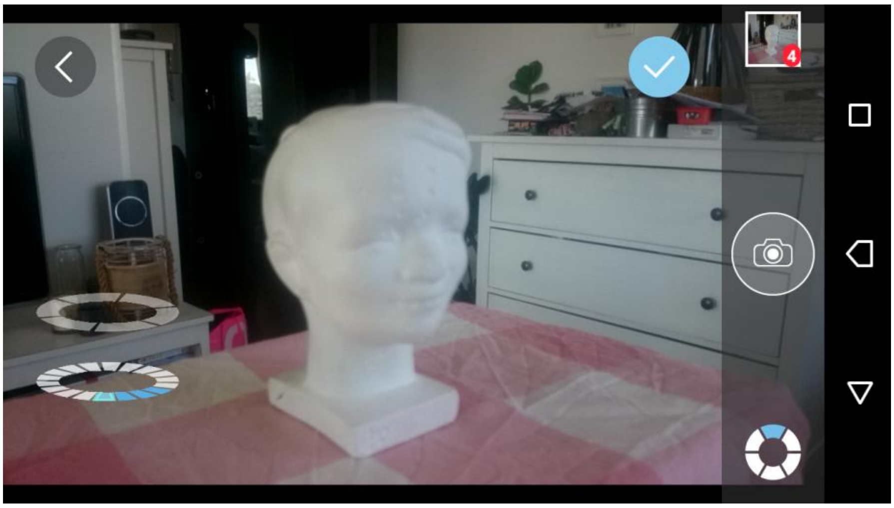


Figure 5: Screenshot from 123D Catch (Picture by Author)

When the pictures have uploaded and the model is calculated it can be reviewed on the device used or by logging in to the 123D Catch website. From the website it is possible to download the model to a computer for editing of the mesh created. As the photogrammetry method captures not only the object which is scanned but also some of the surroundings, the unnecessary data needs to be removed.

Figure 6: Photographing plaster head (Picture by Author)

3.3 Scanning with MakerBot Digitizer

The MakerBot Digitizer is an easy to use desktop 3D scanner optimized for 3D printing. It consists of two lasers emitting beams in the shape of a line, a camera sensor and a turntable. The scanner works automatically and does not require much work for the person scanning as the object is rotated automatically on the turntable allowing for capturing all angles of the object without moving it. The scanner is quite affordable compared to professional scanning equipment and can be purchased at a price somewhere under 1000 euro.

Figure 7: MakerBot Digitizer (Picture by Author)

Scanning with MakerBot Digitizer:

- The scanner was plugged to a computer with the MakerBot MakerWare software and switched on.
- The software was opened and the scanner was automatically activated through the software.
- Before starting a new scanning session it is important to calibrate the scanner with the calibration tool which comes with the scanner. The software instructed how to place the calibration tool on the turntable for calibration. The calibration consisted of two steps. The first was for calibrating the sensors and the second for calibrating the turntable. The scanner was ready for the actual scanning.
- Next the object was placed on the turntable. The software asks whether the objects color is light, dark or something between. Shiny objects should be scanned with the dark mode. In this case the head was light. Light color mode was selected.
- The scanning was started, and the software showed that it takes nine minutes to perform the scan. Two different methods were used for scanning the head object.

The first was a single scan with the head standing up. As the head was high enough for the scanner to not get data from the very top, a second scan was executed of the head. The second time the head was first scanned laying on the left and using the “multiscan” function scanned a second time with the head laying on the right side to scan all sides of the head. This process then took nine minutes twice, and when the second part of the scan was complete the software automatically combined the scans from both sides. The difference of these scans will be displayed in the results section.

- When the scans were complete the software generated the 3D model which was ready for editing or even directly 3D printable.

3.4 Scanning with ATOS Core

The ATOS Core is a high-end 3D scanner by GOM (Gesellschaft für Optische Messtechnik mbH). The scanner is compact at the size of a thick laptop computer and designed for scanning of small to medium sized objects like injection moulded plastic parts. For scanning the device has a projector which projects fringe patterns using a special narrowband blue led light and two cameras which record the fringe patterns projected on the object. The Blue Light Technology allows for measurement independently of ambient lighting. The system uses special reference points which are applied as small stickers around and on the object for identifying the position of the scanner and to connect the individual scans to each other. [29]

- The scanner was turned on and connected to the computer. The scanner required about 20 minutes to warm up during which time is used for preparing the object to be scanned.
- Reference points were applied to the object in such spots that they could be captured from two sides of the object to capture the whole object. This required two scans, one from the top and one from the bottom side.
- The object was placed in the center of a rotating table facing up and the table was checked for reference points and some more points were applied to the rotating table around the object to make sure there were enough reference points for the scan.

- As the scanner was warmed up and ready it was placed in optimal position for performing the scan.
- A scan was performed using the rotating table scanning 360 degrees from eight different angles and additional shots were taken of features not obtained from the first scanner position.
- The scan was examined on the computer to make sure all necessary data was obtained.
- The object was then flipped with the bottom side up on the rotating table. Some adhesive putty was used to keep the object securely in place.
- A new scan was executed as before.
- When the scans of both sides were complete they were examined on the computer to make sure all necessary data was collected of both sides.
- Using the common reference points from both scans the top and bottom scans were connected in the computer software.
- The scans connected properly and the final step was initiated which was polygonization and recalculation of the mesh.
- As the software finished calculated the scan was ready.

3.5 Mesh Editing

When scanning any object usually some unwanted data is collected which needs to be trimmed off. The objects scanned might be positioned on some sort of surface which can be seen in the scan or background objects can be captured as well. If one wishes to edit a mesh for any reason the mesh can also be sculpted and altered.

3.5.1 Meshmixer

Meshmixer is a free software by Autodesk which allows for editing of meshes created by 123D Catch or any 3D scanner as long as the mesh is imported in a compatible format, STL for example. The Meshmixer software is fairly easy to use for mesh editing and sculpting and also works as a tool for preparing a mesh for 3D printing. [30]

Plaster Head - 123D Catch

The 123D Catch photogrammetry scan of the plaster head was scanned in a space where objects in the background were close enough to be caught in the scan. The extra data was to be trimmed off. The mesh was downloaded to a computer from the 123D Catch website and opened in Meshmixer. [31]

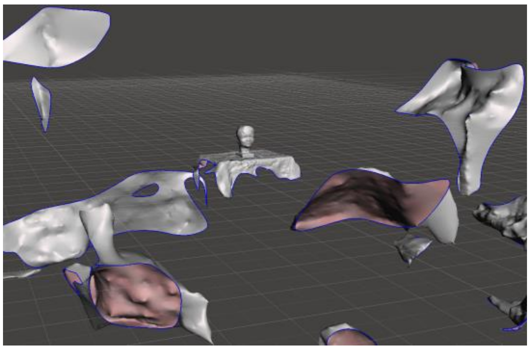
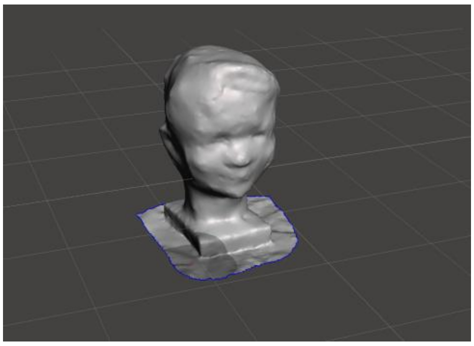
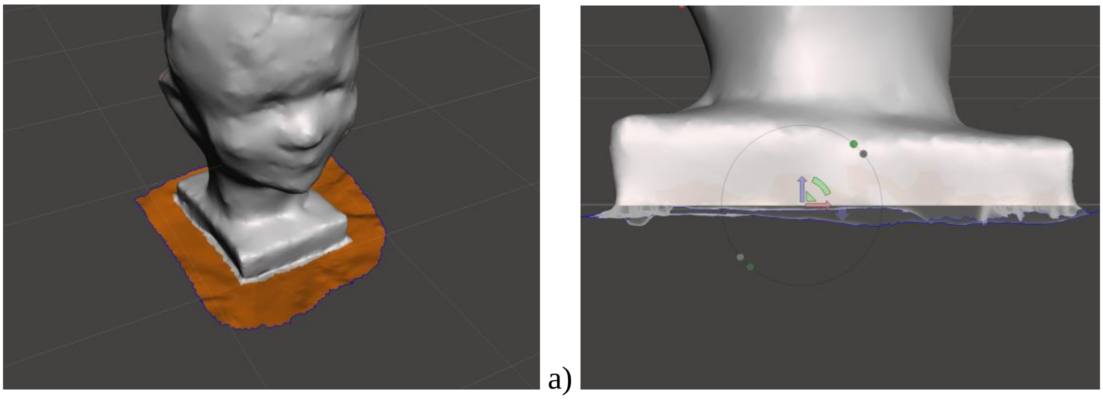

a)

b)

Figure 8: a) Mesh as downloaded, b) Rough edit (Picture by Author)

First a all excess material was roughly trimmed around the head part to prepare for discarding the base area around the part. By using “Select” and “Discard” (x key) all extra material could be easily removed. As the scan only covered the part in one poisition standing up there was no scan data of the bottom which meant that a flat cut and filling of the bottom would be the bottom of the head. This was done by carefully trimming off as much as possible of the material not belongning to the part itself and then cutting at a plane to make the bottom surface flat. The hole left after the plane cut was filled. There are different ways to fill the hole, the “Plane Cut” command can cut and fill directly or the hole can be manually filled afterwards. It was found that the “make solid” command filled the hole smoothly without a sharp edge as it made the mesh “solid”. The only thing left was to dimension the part. As the meshes created with 123D Catch are dimensionless the mesh was not of correct size. A measurement was taken on the ATOS mesh of the head from the tip of the nose to the back of the head and the distance was used to scale the plaster head in Meshmixer.



a) b)

Figure 9: a) Colored area selected, b) Plane cut (Picture by Author)

After filling the bottom the editing of the part was finished as no extra editing of the part was desired. The part was to be compared to the other means of scanning without altering the mesh data of head.

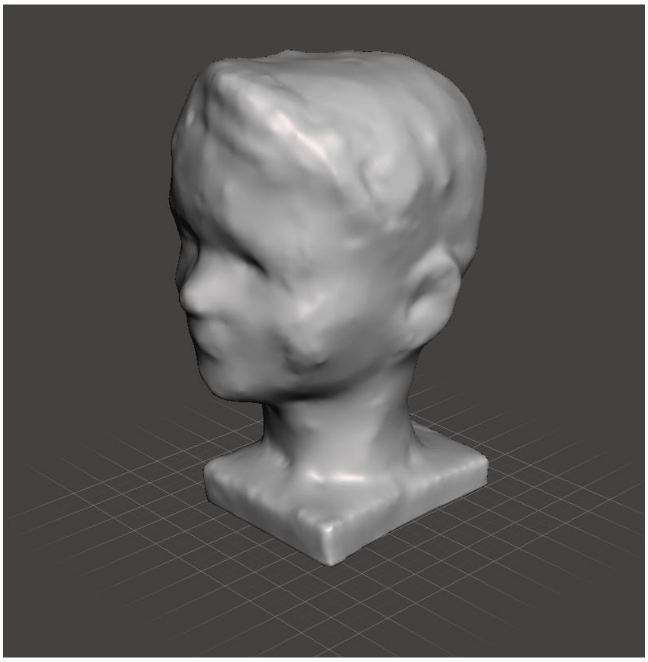


Figure 10: Finished edit of head part (Picture by Author)

Drain Holder – MakerBot Digitizer

The drain part was scanned with the MakerBot Digitizer to be 3D printed to “copy” the original part. Due to the shape of the part being quite complex for the MakerBot Digitizer and surface a bit shiny, it was challenging to acquire a decent scan of the part, even several “multiscans” did not improve the scanning result. It was necessary to edit it the part quite dramatically.

At first the task of scanning the part was found very difficult. Scanning the part laying down and standing up there were always large areas of the part that the scanner could not reach. The finished scan would always be impermeable all over even though some areas were not actually scanned which resulted in undesired “bubbles” in these areas.

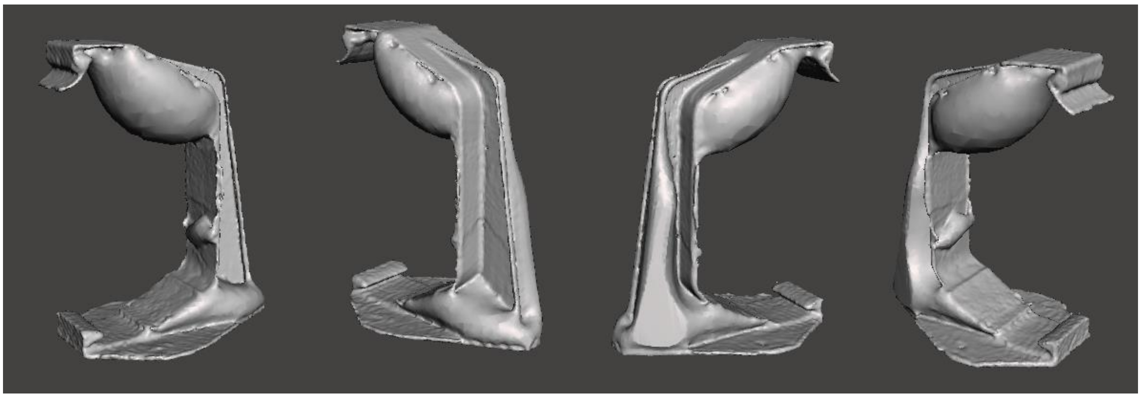


Figure 11: Bubbles in hard to reach areas (Picture by Author)

Scanning the part in any positions where the drain part could stand on its own did not work very well. Some adhesive putty was acquired and used to try to scan the part at an angle. The scan improved significantly and was considered good enough to work with. The process of the scanning was performed the same way as described in the Scanning with MakerBot Digitizer section with the difference being that the positioning of the part required some help from the adhesive putty.

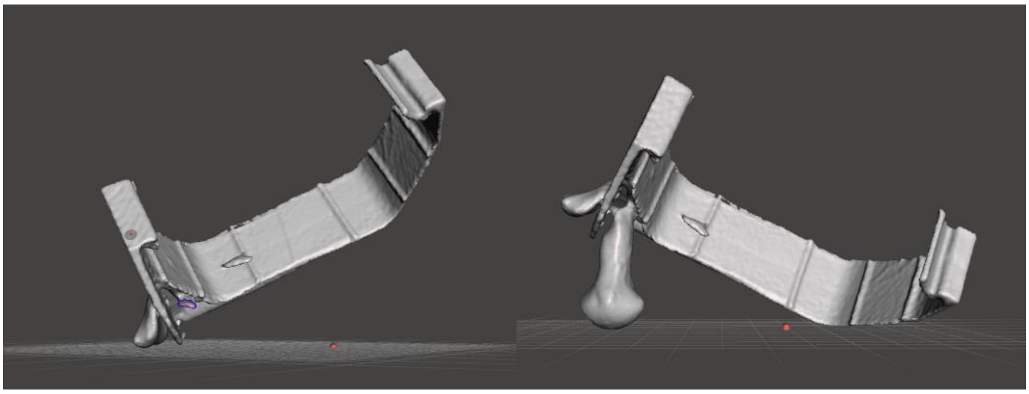


Figure 12: Scanning positions of drain part (Picture by Author)

Most of the part was captured but some detail like slim edges, small features and corners were rough or “bubbles” appeared in these places. A third scan was attempted to try to reduce some bubbles, but did not result in an improvement and was discarded. The mesh was then opened in Meshmixer to edit the mesh to prepare it for 3D printing to create a copy of the original part.

First the pieces of adhesive putty, which were also captured in the scan, were removed by selecting and discarding. Any holes created by the removal were filled. The big bubbles which were not part of the desired shape were removed and filled to make the part look as much as the original as possible. Some of the holes created required a fair amount of effort to close, especially holes which cover surfaces of different angles.

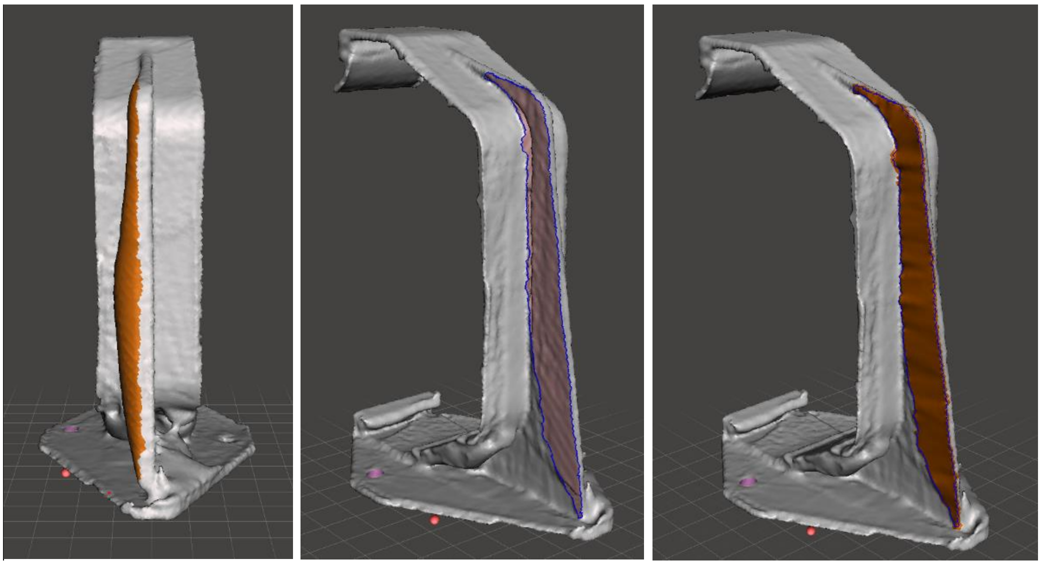


Figure 13: Deleting a bubble and filling the remaining hole (Picture by Author)

Some of the features of the part came out very thin in some places and needed to be filled up a bit using the sculpt tools like “Inflate” and “Draw” to increase the mesh volume. The surface of the mesh was in general bumpy from the glossiness and multiscan overlap. The roughness was smoothened out with “RobustSmooth” tool.

The shape of the part was symmetrical, and one side of the mesh was looking better and easier to edit to the proper shape which led to testing a mirroring of the better half of the mesh. The result of the mirroring was considered a good solution as it saved editing time and made the part look significantly better and symmetric.

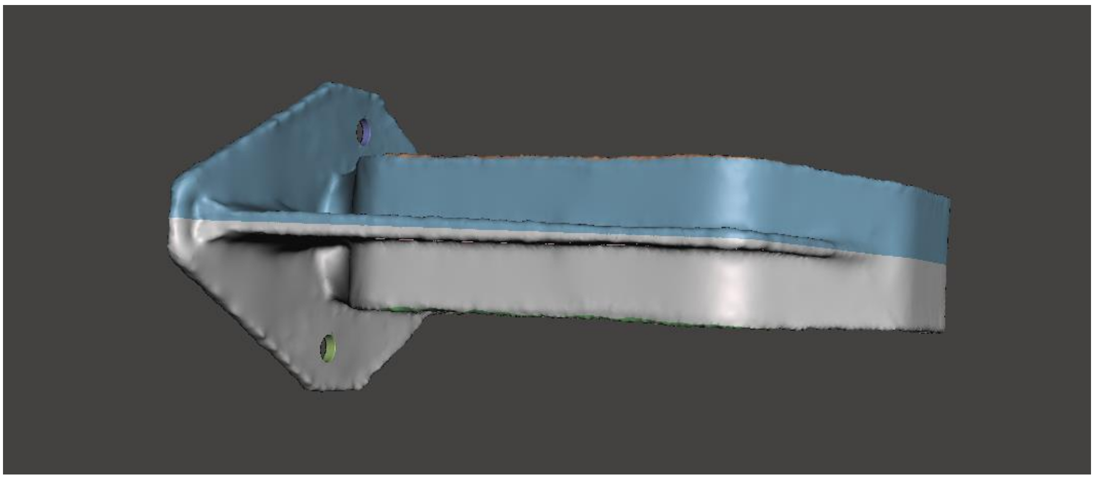


Figure 14: Part mirrored (Picture by Author)

After mirroring, the holes in the base were created and surfaces and edges were cleaned up to obtain a smooth as possible finish.

3.5.2 Plaster Head - ATOS Professional

Like in the 123D Catch scans usually some of the base surface on which the scanned object lies will be caught by the ATOS scanner. A couple of procedures need to be carried out on the scan data before the scan project can be completed.

When the plaster head was scanned some of the surface on which the object was standing was captured in the scans. The extra data was removed in the software by creating plane from three points on the base surface and deleting everything below the plane. If for some reason this would not have been possible or in the case of other unwanted data it could have been manually removed. The head was scanned from two sides and the same was done for the other side. When the scans were cleaned up they were connected by using the common reference points captured from both scans.

The reference points themselves were not captured as part of the mesh, which meant there were small “holes” in the mesh at the places of the reference points. These holes can be filled either automatically by the software as it makes the mesh calculation, or filled manually after the calculation. In this case the holes were filled manually because of the possibility to make sure the fill is done properly. The automatic filling may give a less smooth result.

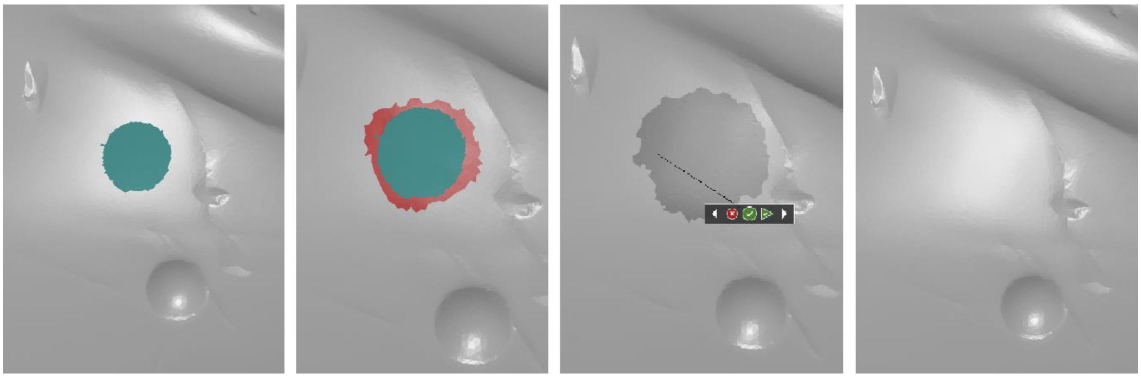


Figure 15: Patching a reference point hole in ATOS software (Picture by Author)

3.6 3D Printing Drain Holder

The drain holder part scanned with the MakerBot Digitizer was edited in Meshmixer to resemble the original part as closely as possible to be 3D printed. When the mesh was edited, saved in STL format and ready for printing it was copied to a memory stick and moved to a computer controlling the 3D printer, MakerBot Replicator desktop 3D printer. The 3D printer was an FDM printer.

First the part was scaled down 50 percent in the settings of the MakerBot to make a test to find out if the part could be printed in one piece standing on its base. Printing standing up meant that there would be a quite big overhang and the printer was set to build support material. The preview was examined and settings adjusted to not make too much but also not too little support material. When everything was set the command was sent to start the printing. Printing of the miniature version took around one hour.

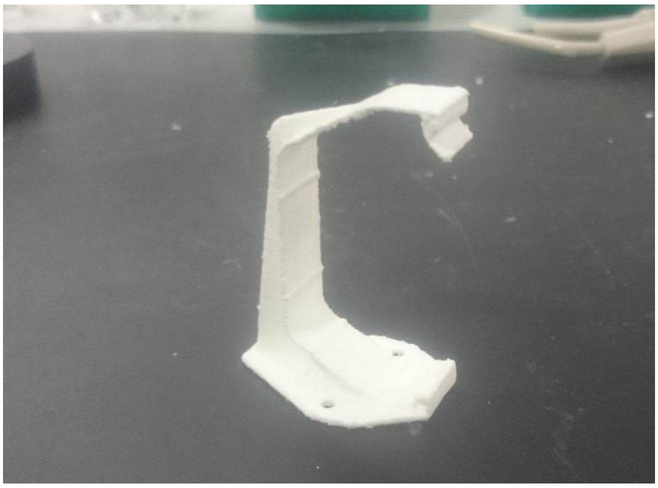


Figure 16: Miniature print scaled down 50% (Picture by Author)

It was decided that the full size print would not be printed in the same position as the miniature test version, but rather splitting the part through the middle and printing it in two halves to be glued together. The reason for this was simply to be able to 3D print the part without using much support material.

The part was split in Meshmixer and two separate new files were created, one of the left and one of the right half of the part. Again, the files were transferred to the computer connected to the 3D printer and the meshes oriented properly in the MakerBot 3D printing software. The printer was set to create support material to support the holes in the parts. Then the parts were printed one by one.

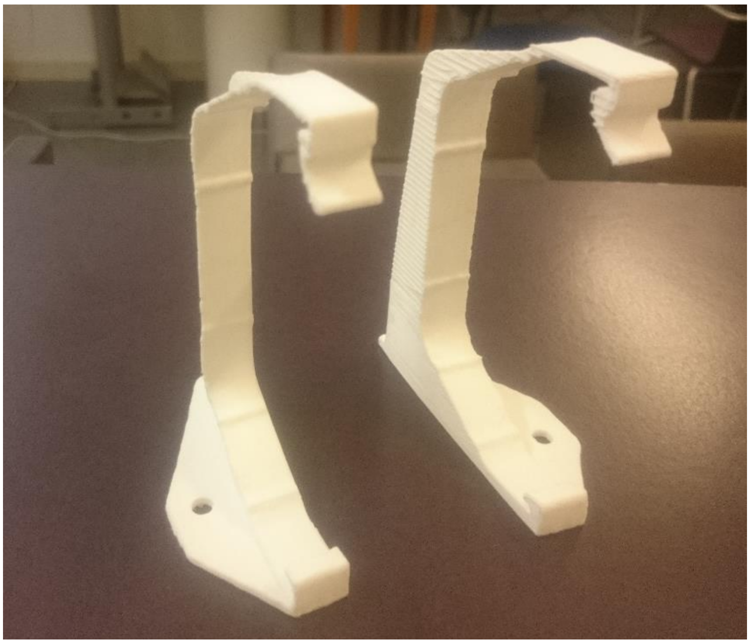


Figure 17: Both halves of drain holder printed (Picture by Author)

Once the halves were both printed they were removed from the printing bed and extra material torn off. To prepare the parts for gluing the contact surfaces were prepared by sanding roughness off. The two halves were then glued together with a cyanoacrylate superglue by Biltema. Once the glue had set the 3D printed replica of the drain holder was ready.

Figure 18: Part finished (Picture by Author)

4 RESULTS

4.1 Plaster Head

It was known beforehand that the ATOS Core scan of the head would be the most accurate of the three different scans. The scan data from the ATOS scanner was therefore the closest to the true shape of the actual physical object and was used as the reference for inspecting the success of the other scans.

4.1.1 ATOS Scan

Figure 19 and 20 show the ATOS mesh beside a photograph of the real plaster head. The level detail of the mesh is very high and even the smallest grooves can be observed.

Figure 19: ATOS scan and a photograph of the actual part (Picture by author)

Figure 20: Close-up of ATOS mesh (Picture by Author)

The big indent in the mesh picture in figure 20 is about 0.5 mm in diameter.

4.1.2 123D Catch

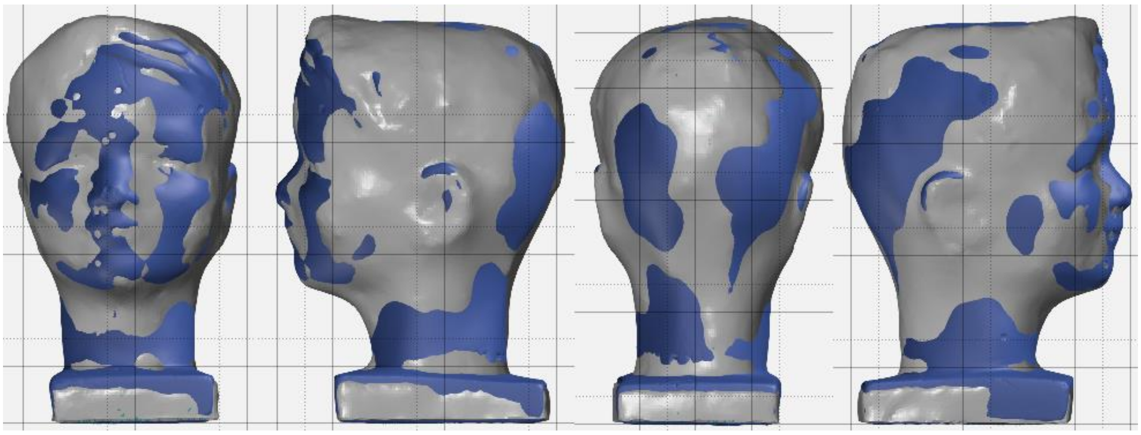


Figure 21: 123D Catch scan comparison on top of ATOS mesh (Picture by Author)

The blue mesh in figure 21 represents the reference body and grey mesh is the 123D Catch mesh. It can be seen that the overall shape is 123D Catch mesh is close to the reference mesh. However, the level of detail in the 123D Catch mesh is poor.

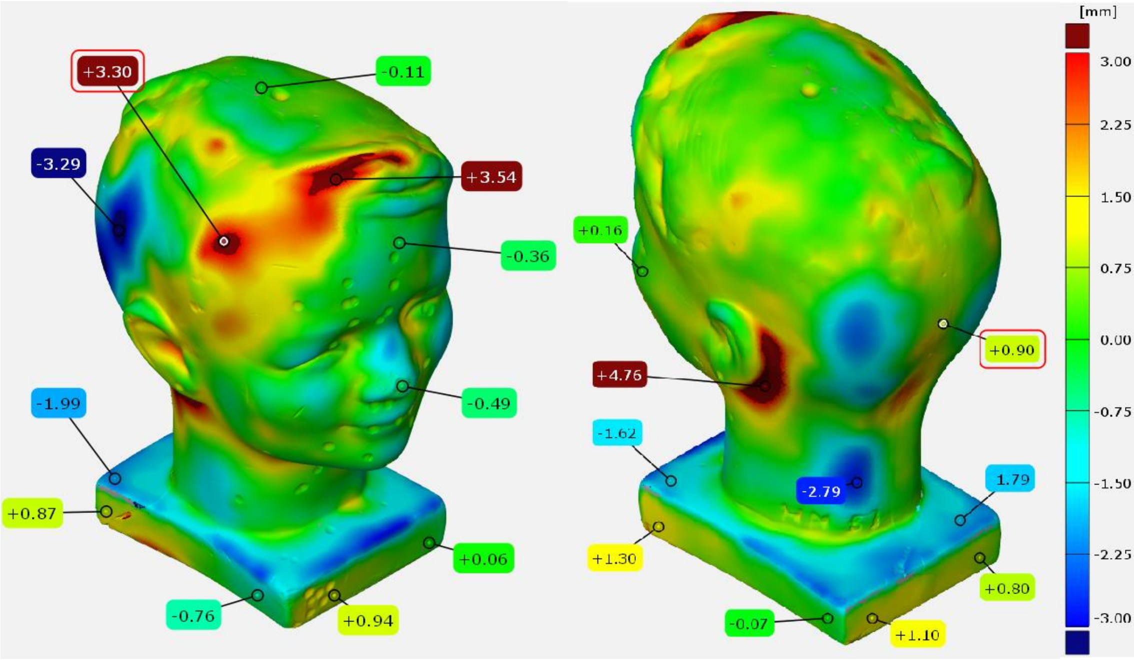


Figure 22: Surface comparison on the reference head (Picture by Author)

Figure X shows a color scheme of the deviation of the 123D Catch scan in comparison to the reference mesh. Only the reference mesh is visible and the color at any given point shows how much the 123D Catch scan differs from the reference in millimeters. The color scheme goes from red to blue. Red when the part is bulging out and blue when the surface of the part is within the reference mesh. Wherever the color is green the difference is small, within around 0.7 mm. It can be stated by the look of the color scheme that the 123D Catch mesh is bumpy and not very smooth, but in general close to the ATOS mesh.

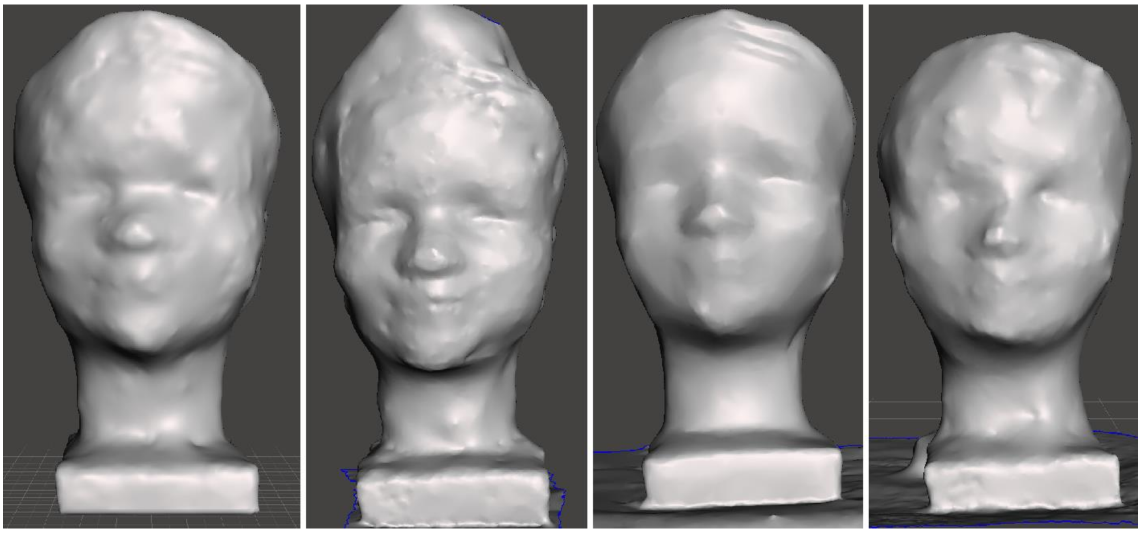


Figure 23: Different 123D Catch scans compared to each other (Picture by Author)

Figure 23 shows four examples of different scans of varying quality. The one on the left is the one used for the measurements being the best overall. The second picture from the left shows a very detailed face but the top of the head was not captured properly.

4.1.3 MakerBot Digitizer

As it was mentioned in the method part regarding the MakerBot Digitizer scans, the head part was not completely captured standing upright. A second scan scanning from two different angles to cover all sides was carried out. These two methods also gave information about effect of the “multiscan” feature compared to just a single scan.

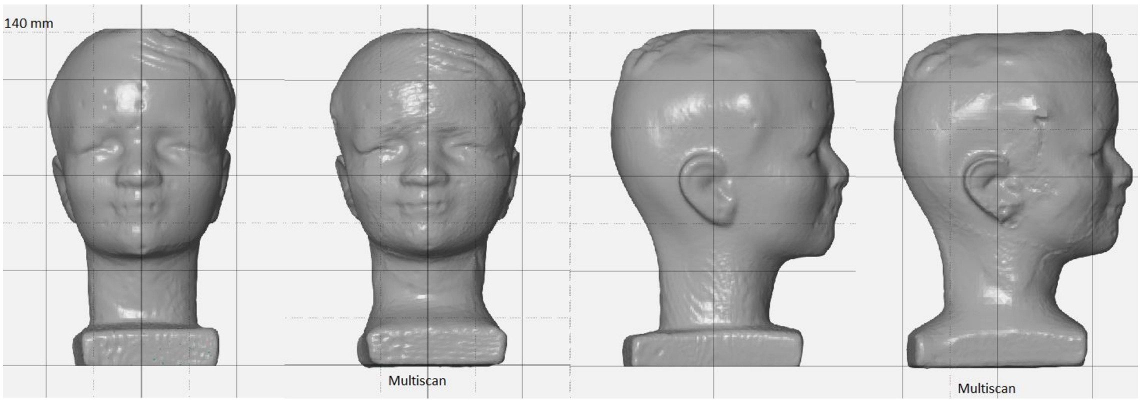


Figure 24: Single scan compared to multiscan (Picture by Author)

Figure X shows the different scans side by side. Some difference between the scans can clearly be detected. The overall look of the multiscan part is rougher and some difference in general shape can be seen. The single scan part is missing part of the top of the head and it seems that scanning the part on the sides made a great difference at the base of the neck. The shape of the face looks rounder in the multiscan.

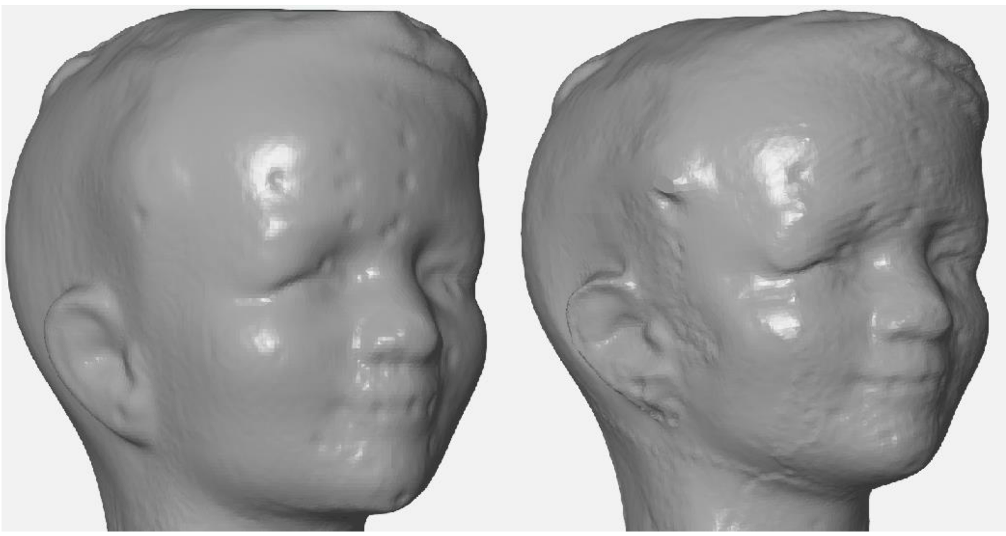


Figure 25: Close up of surface quality, multiscan on the right (Picture by Author)

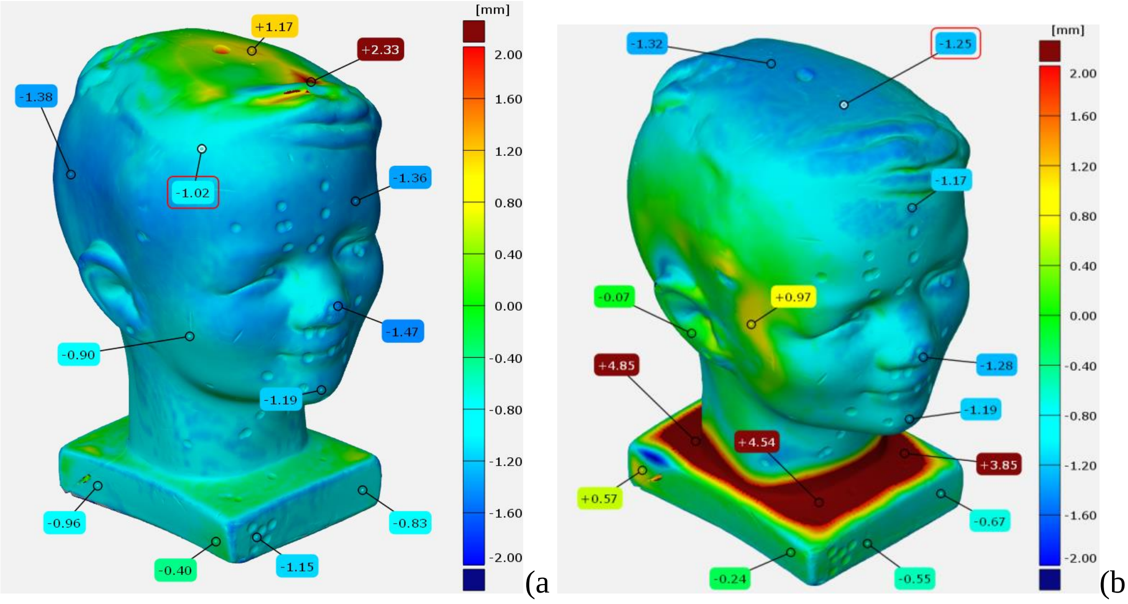


Figure 26: Surface comparison to reference part, a) Single scan, b) Multiscan (Picture by Author)

The surface comparison, figure 26, shows that both the single scan and multiscan meshes are in general smaller than the reference ATOS mesh. Almost all around the MakerBot scans are within the surface of the reference. The multiscan part is slightly wider at the sides of the face area. The base of the neck on the multiscan clearly diverges as it is almost 5mm above the reference mesh at certain locations.

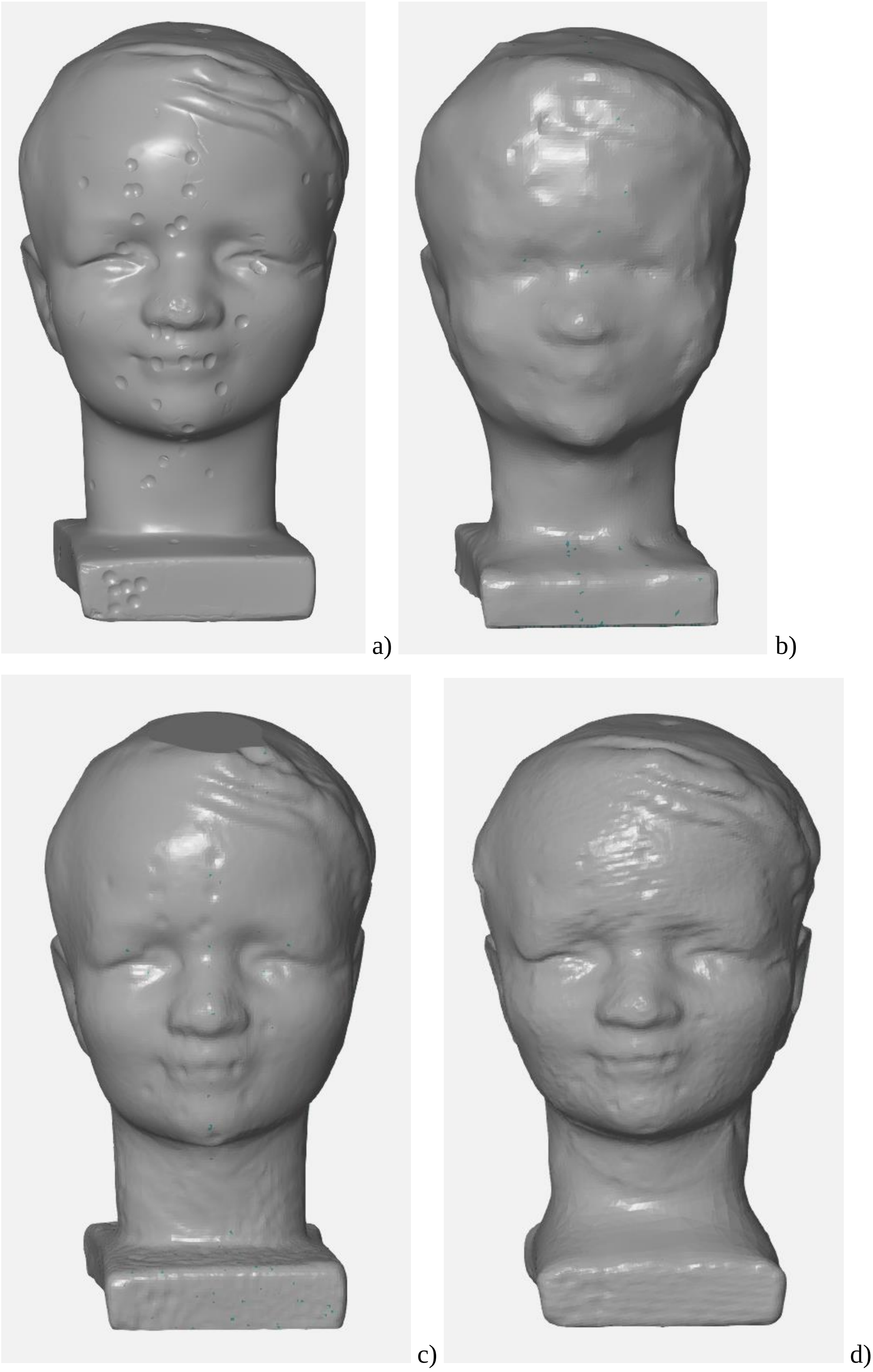


Figure 27: Close-up on a) ATOS scan b) 123D Catch scan c) MakerBot scan d) Makerbot multiscan

4.2 Drain Part

The finished 3D print of the drain holder resembles the original part fairly well. The 3D print is in its wholeness slightly smaller than the original when examined side by side. Overall thickness is also slightly minor in comparison to the real part. The hook shapes at the top and bottom of the part, which also were the hardest to capture with the scanner, is also somewhat narrower than in the original even after heavy editing.

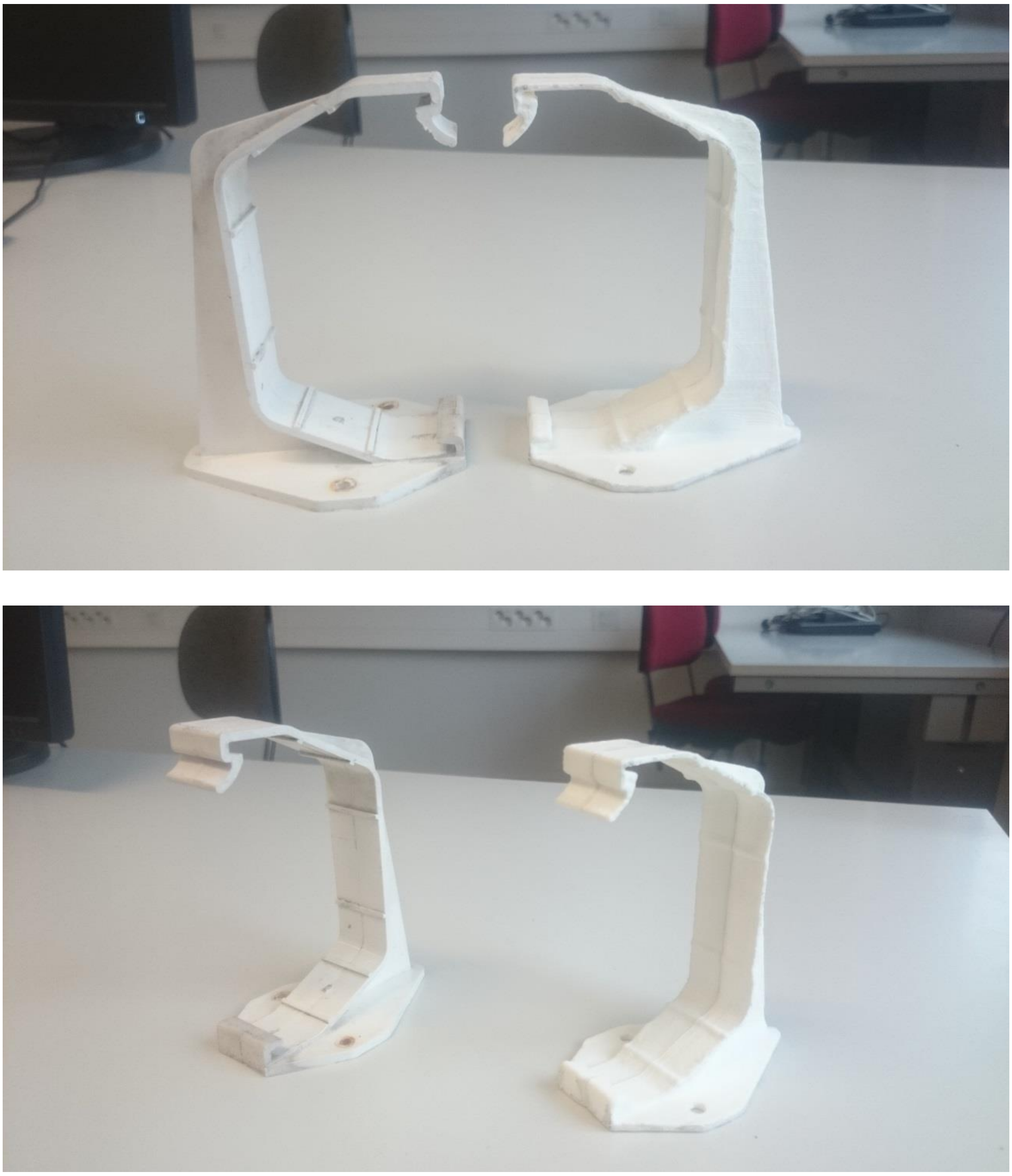


Figure 28: The original and the 3D printed drain holder side by side (Picture by Author)

5 DISCUSSION

At this point is should be mentioned that 3D scanning for 3D printing and unauthorized copying, distribution and selling of any object protected by copyright law is illegal. [32]

The plaster head object was chosen to compare the different scanning methods because it was light in color with a matte surface and enough details which would show in the comparisons between different scans. The object had small indentations which were caused by shooting the object with an airsoft gun (which fires small plastic pellets) which were small and good for displaying the detail of the scans. Light colored objects which are not shiny, reflective or transparent work the best for 3D scanning in general, they do not require any surface treatment. The object did however show to be tricky to capture with 123D Catch as overall accuracy varied from one scan to another. Variations in lighting conditions showed to have significant impact on scanning results.

Scanning the plaster head with 123D Catch gave nice scans in the right conditions. The overall shape could be captured surprisingly close to the true object. It was found that it is quite hard to get consistently good detail in the meshes created by the 123D Catch application. At best the detail of the mesh was impressive, figure 23 the second face from the left. That mesh was detailed enough to spot the small indentations, and looks almost as detailed as the MakerBot scan. Unfortunately such detail was found to be hard to keep consistent around the whole part. This is most likely because of insufficient lighting, shadows in certain angles, not good enough photography and that the shape of the part is a bit tricky. Unlike in other 3D scanning, the white color of the part gave some difficulty as there was a thin line between over and underexposing the photographs. If the light was brighter from one side the photographs were easily too bright from the light side and too dark on the other. Taking pictures around the part to capture the complete shape of the part was difficult as the pictures needed to be taken from many angles also from below to get overhanging features like the chin on the part.

The MakerBot scanner is capable of making fairly good scans but only in the case where the scanning specimen fills certain requirements. The laser beams emitted are fixed across the center of the turntable and the laser source is at a fixed height. This means that features which are not visible from an angle viewing at the center of the specimen (if it is placed in the middle of the turntable) will go overlooked. Also the top of a part will not be caught by the lasers if the part is too high.

The head part was scanned in two different ways, standing upright and two scans from either side laying down. Scanning the part in one scan standing up caught the part well with the only drawbacks being that the part was just a bit too high which meant some of the top was missed. The other thing being that there is no scanning data of the bottom, the software simply creates a flat surface under the part parallel to the turntable. This may not be a problem if the bottom is not important or a completely flat bottom is desired, but the object is not a hundred percent scanned which could be a flaw if precise data is desired. In the other case where the head was scanned from two sides all surfaces were covered using the multiscan feature. This in turn creates another problem which is the combination of the two scans. By looking at figure 24 and figure 25 it is quite clear that the results differ from each other. The general surface of the multiscan mesh is not as smooth as in the first scan. The face is also distorted and clearly wider with multiscan. At the base there is a clear bulging, figure 26, which was caused by a similar problem described in the method section with the drain holder. Both scans are also clearly overall a bit smaller in comparison to the reference scan with an exception of the multiscan part which is wider at the sides. Figure 26 displays a surface comparison with labels showing the deviation in millimeters. The scan accuracy is quite good as the small indentations can be spotted, but not very sharply. Smaller details are not however visible.

The drain holder part replication using the MakerBot equipment was not a straight forward task. Scanning the part was difficult due to a too complex shape for the MakerBot Digitizer. Figure 11 displays an example outcome of scanning the part laying down in different possible positions. A better result was achieved using some adhesive putty to get the part into an angle off the scanning turntable. The result however was far from perfect and to get a better resemblance of the original part, the scanned mesh required considerable manipulation. The part is too complex for the MakerBot Digitizer.

A substantial amount of time was used to learn basics in mesh editing and simultaneously editing the scanned part. The finished mesh was still not a perfect replication of the original part. That in mind, the quality of the printed version of the mesh can, of course, not be any better than the digital version as the 3D print comes out a bit rough. The purpose of the experiment was to scan the part and print it as it was scanned. This meant that it was not supposed to be changed too much in the editing, it was meant to try to stay as true to the scanned data as possible.

6 CONCLUSION

Considering that the 123D Catch application is a free and easy to use the scanning results it is capable of is impressive. And above all it can be done with a mobile phone by anyone. The only discouragements being insufficient or too much light, objects with complex shapes and the fact that the models created are unitless. Measurements can be added later by for example measuring the actual part and scaling the part according to the measurement.

The MakerBot scanner managed to create a good scan of the head part, better and more detailed than the ones made with the 123D Catch application. If as good surface finish as possible and accuracy is desired by the MakerBot it is best if the part in question is scanned only once, in one position if enough data is obtained that way. The multiscan feature where more sides of a part can be scanned reduces the final quality and accuracy and distorts the mesh. However, that is not necessarily a problem if accuracy is not crucial. The mesh can be edited and smoothened in software like Meshmixer.

Although the drain holder was successfully scanned and modified to create a decent replica of the original part, the process was more complex than expected. Due to the MakerBot scanner not being suitable for such complex parts it was clear that the drain part revealed to be too much of a challenge for the scanner. A simpler part on the other hand would work perfectly. For a part such as the drain holder it could have perhaps been easier to manually create the whole part in a solid modeling software instead.

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