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Assembling and maintaining a 3D scanning workstation

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The purpose of this thesis is to describe how three different 3D scanning methods were implemented for building a small workstation that would be easy to use to produce 3D models that can be applied in further computer-aided design or 3D printing.

3D scanning technology, which uses sensors that collect light, is still developing. Most of the literature about it is from blogs and software websites, giving short introduction to it and tutorials about home-use 3D scanners. Thus, further research needed to be done when choosing which programmes and sensors to work with.

The practical part of this thesis was to do 3D scanning tests of objects that would vary in size, colour, and material and that also have different lighting settings. It was important to find out what the smallest and biggest size of an object was which could be scanned. As well as that, one of the key focuses was to learn how well the scanned objects could interact together with other computer-aided design programmes which have been used in Helsinki Metropolia University of Applied Sciences.

The programmes that were used in this project gave ordinary results. One of the programmes that was originally chosen for this project did not work with the sensor. Therefore other programmes had to be used. Some of the objects could not be scanned, because they were too dark, too bright, and too transparent or were scanned in poor lighting. 3D scanning is not as time consuming as the conventional technology, where the objects would be modelled from scratch, but it had fewer details and sometimes was lacking information, such as texture, once it was imported to other software. This could have happened due to lack of skills and time with computer-aided design programmes.

In conclusion, the low cost 3D scanners are promising and could bring interesting applications, but do not yet deliver an excellent outcome. However, they can be used as research and introduction technology for students that show interest in this area.

Keywords	3D scanning, 3D printing, cloud point, CAD

Contents

Abbreviations

3D	Three dimensional
CT	Computer tomography
LIDAR	Light detection and ranging
RGBD	Red Green Blue Depth
CAD	Computer-aided design
USB	Universal Serial Bus
PC	Personal computer
MAC OS X	Macintosh operating system X (ten)
STL	Stereolithography file format
PLY	Polygon file format is a format for storing graphical objects
OBJ	Geometry description file format
CPU	Central processing unit
SDK	Software development kit
VRML	Virtual reality modelling language
RCM	Reality computing mesh
FBX	Filmbox
RCP	Rich Chart Builder (project)
AVI	Audio Video Interleave
MKV	Matroska Video file
4K	High resolution picture format: 3840 x 2160 pixels per frame
PNG	Portable Network Graphics
CAM	Computer aided manufacturing

1 Introduction

The term 3D has been in technology for a while. It is seen everywhere — in movies, commercials, games, and quite recently, even in printing. The industry is getting bigger every day and the choices of 3D printers are increasing but so are the 3D scanners and their software.

The purpose of this thesis is to research available 3D scanning technology and describe how a workstation was built with already existing programmes and equipment from Microsoft, Autodesk and Occipal. A comparison will be made to other software and methods used for 3D scanning and the future for 3D technology. The final product is a working 3D scanning workstation for students and staff of Helsinki Metropolia University of Applied Sciences.

Prior to writing this thesis, the media department of Helsinki Metropolia University of Applied Sciences only had one 3D scanning device which was used together with 3D printing in the printing laboratory which was only available as of winter 2015. There is not a lot of information provided so far about 3D scanning technology and its possibilities, and for that reason media engineering students have not had an opportunity to use it during their courses. Consequently, this project is a good introduction to how 3D scanners function and where they can be implemented.

The topic of 3D scanning is broad. This project only concentrates on commercial and home-use scanners and what kind of results they can achieve. There are many advantages that can be accomplished by this technology, which will be discussed in the last parts of this paper.

2 3D scanning

2.1 Definition

To understand how 3D scanners work, they can actually be compared to cameras. Many people have a camera nowadays, either in their pocket on their phone or a professional mirror camera in their bag. Both scanners and cameras have field of view, the difference is that the sensor on the camera gathers colour whereas the scanner sensor collects the distance from the surface in every single point of many pictures. This way they create point clouds or polygon meshes of data that are in a 3 dimensional coordinate system. [1.]

3D scanning is a technology which gathers the information of an object using a camera that collects light, laser beams or even x-rays. There are various ways to call 3D scanning devices like 3D digitizers [2], laser scanners [3], white light scanners [4], industrial CTs [5], LIDARs [6] and more. Laser scanners project a line of laser light, while at the same time the cameras are capturing the distance and shape of laser line and making point clouds in the computer. [7.]

In this thesis mostly light scanners and the post-production will be discussed. The scanners have RGBD (Red, Green, Blue, and Depth) sensors. The depth part of the sensor plays a major role, because it tells how close or far the object is. The camera compiles the data about the object's shape and appearance and sends the information to the computer, which then makes a render of the object in 3D. A lot of computing power is needed for this process, since not all the computers can do the rendering in real time. The minimum requirements for the computer using each 3D scanning programme are mentioned in section 2.3 Different scanning methods.

2.2 History of 3D scanning

3D scanning is a relatively new technology but it has been around for a while and the term is familiar to people working in research and design. Back in the 17th century Snell von Rojen studied the laws of optical triangulation, which is the base of how 3D scanning works. However, it still took decades of theoretical research and laboratory tests about image processing systems that could bring people closer to a 3-dimensional image. [8.]

The very first technology for 3D scanners was developed in the 1960s. That was in the time when Lidar technology began, just after Arthur L. Schawlow and Charles H. Townes invented the laser in 1958 [9] and Theodore H. Maiman operated the first working laser in 1960 on May 16th [10]. At that time, three variables were needed to perform 3D scanning — light, cameras and projectors. Only after 1985, when computers started to be used throughout the industry, scanners that used white light, lasers and shadowing were made to perform scanning of the surfaces. [7.]

At the very beginning there was a physical probe, which took too much time to create the object and further measurement needed to be done. Additionally, after scanning, the object should be left intact and the physical probe worked only by having contact with the surface. To solve this problem, optical scanning technology was developed. There were three types of optical scanning - point, area and stripe. Stripe showed the most promise and was elaborated further. [11.]

Laser scanning was developed in the last half of the 20th century. It played a major role in technology, helping engineers and designers to find accurate information of model surfaces. Lasers and camera tubes that collected white light took still too long time and were not very cost efficient. There was also understanding that not only the scanning methods but software for them had to be created and improved. Making a scan of the object took a few times which resulted in having a big number of images. Those images needed to be merged together and all the duplicates had to be deleted. [7.]

In the seventies and eighties the sci-fi and special effects took over Hollywood and the movie industry. *‘Star Wars’*, directed and written by George Lucas, used wireframe imagery for the *‘Death Star’* plans and ‘*Millennium Falcon’* spacecraft. That was the third movie to use this technology [12]. The very first use of 3D CGI in a full feature film was Walt Disney’s *‘Tron’* in 1982 [13]. In the same year *Autodesk Inc* was founded by John Walker, who was making design software for computers. *Cyberware Laboratories* in Los Angeles have made new 3D scanning technology which allowed scanning a head, as can be seen in figure 1 [14]. *Cyberware Laboratories* collaborated with the *Industrial Light & Magic* visual effects company owned by George Lucas to create a dream sequence in *‘Star Trek IV: The Voyage Home’* [15]. Later in the nineties *Cyberware* made a full body scanner [16]. In 1995 *Disney-Pixar* made *'Toy Story'*, which was the first feature film that was made using only computer animation. The film was directed by John Lasseter who was one of the co-founders of *Pixar* [17].

Figure 1. Cyberware head and body scanner. Reprinted from cyberware.com [14; 16].

3D scanners was another company that started making scanners and in 1994 they released *REPLICA* which made fast and quite accurate scanning possible and it was using laser stripe technology. *Digibotics*, *Faro Technologies* and *Immersion* also failed to make faster scanners available, those were a great push but still nothing like the industry standards we have today. [11.]

3D scanners were getting closer to the finish line and in 1996 they released a manually operated arm with a 3D stripe scanner which worked with *ModelMaker* and produced fast scanning which also captured colour. Nevertheless, the future was ready for camera and sensor based 3D scanners. The only disadvantage they had was capturing shiny objects, reflections and transparent objects. However the optical scanners are now the cheapest to make and have been commercialized. [7.]

There are very many different ways to use 3D scanners. It is very popular in the movie industry and video games, as more and more of them are using 3D technology. It is also being used in more important fields such as “industrial design, orthotics and prosthetics, reverse engineering and prototyping, quality control/inspection and documentation of cultural artefacts”. [18.]

2.3 Different scanning methods

This section will be reviewing four software available for 3D scanning and reconstruction.

2.3.1 Occipital Skanect

Skanect is software which together with *Structure Sensor*, *Microsoft Kinect* or *Asus Xtion* cameras can scan objects. In addition to capturing shapes, this system also captures the colour of the scanned object. It creates 3D meshes within few minutes. It scans in real time, so it is possible to see the scanned object in the screen immediately during the scan. Then it just takes a few minutes till the rendering is done and the object is in the programme. There is possibility to modify the mesh within the programme, but it is best to export it and edit it with *Meshlab* and *Meshmixer*, free software from Autodesk. It is also possible to export the file as OBJ and edit it with *Autodesk 3Ds Max*. Usually the meshes have so many vertexes and faces that it is very hard to edit them with *Autodesk 3Ds Max*. Vertexes can be reduced in *Skanect* before the export or optimized in *3Ds Max*. *Skanect* together with a sensor makes a low-cost 3D scanner affordable for every-one. It is easy to use, the system requirements are not too high as can be seen in table 1 and it is rather simple to use.

Table 1. Hardware requirements for Occipal Skanect. Data gathered from skanect.com [19].

CPU Reconstruction	2GB RAM, Quad core processor
GPU Reconstruction	Intel Core 2, Cuda 2.0 compatible graphics card, with 1Gb of memory
Recommended PC	Windows 7 or later (64 bits), Intel i7, 4GB RAM, NVIDIA GTX 560 or higher
Recommended Mac	OS X 10.8 or 10.9, Macbook Pro 2012 or Macbook Air 2013

Skanect offers some predefined scenes for the scan like body, object, room, and half room. It is also possible to customize the settings according to specific needs.

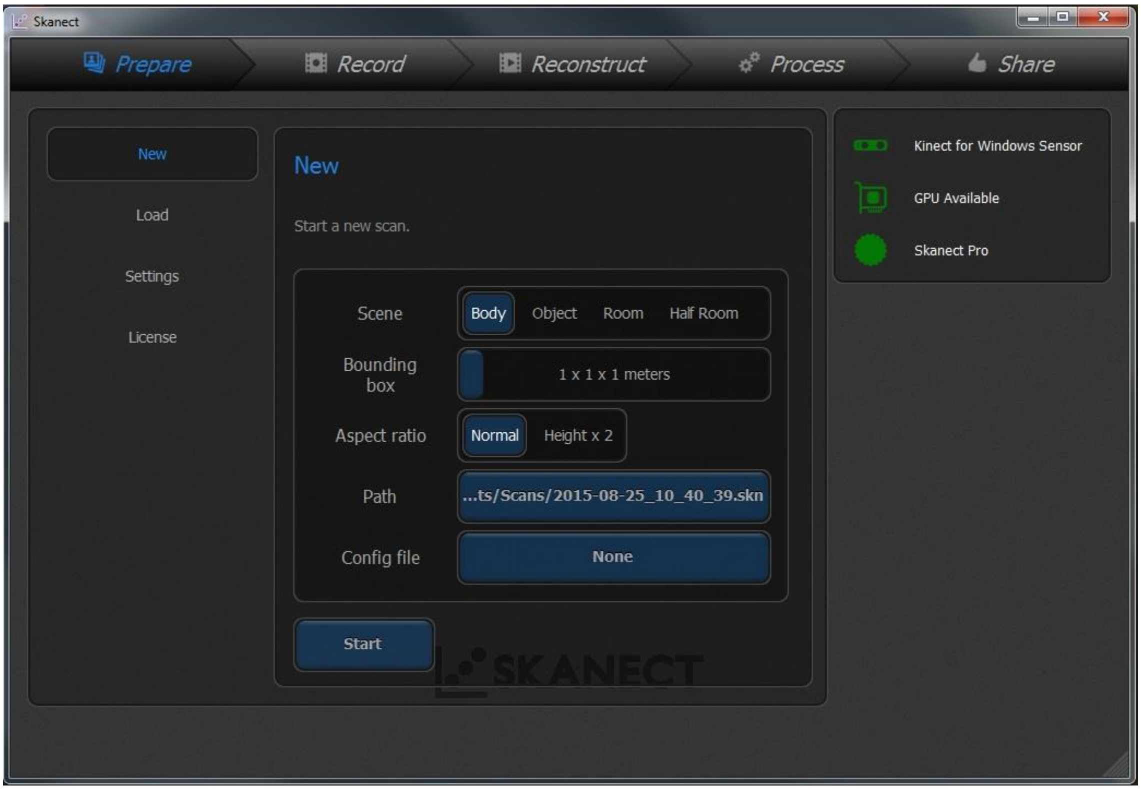

Figure 2. Skanect interface screenshot [20].

Figure 2 shows that there is also an option to make customized settings and save them for later use. On the right corner there is an indicator to show that a sensor is connected, if the GPU is available. The indicator also shows which version is used, for this case it is *Skanect Pro* with full license.

2.3.2 Sense Sculpt

While most of the 3D printing companies have focused only on making the 3D printers affordable and easy to use, *Cubify* did not forget the people who do not have extensive knowledge of how CAD works. They made an affordable, handheld scanning device which is only €329 and can scan up to 3 by 3 meters. Although, it is not actually as good as it sounds. Once trying to make some scans it appears that it is rather unstable. It is promoted as a portable device but it is still connected with a USB cord, which is not that easy to navigate. It does not work all too well on smaller than 30cm objects, which deducts major possibilities for the user. A *Sense* scanner has two cameras and an infrared sensor, just like *Kinect*. It also has a tripod mount, for a steadier scan. The scanner comes together with the software called *Sculpt*, which can be used on PC and MAC OS X. It is quite user friendly and simple to use, but there are some drawbacks.

Table 2. Sense hardware recommendations. Data gathered from cubify.com [21].

Operating system	Windows 7 or 8, Mac OS X 10.8 or later
CPU	Intel Core i5 or equivalent processor
Memory	2GB RAM minimum
Screen resolution	1280 x 1024
Colour	32-bit
Storage	4GB available hard disk space

For example, if accidentally chosen to scan some bigger object instead of a smaller one, there are no back buttons, so the scan has to be made from the start. In case it is not possible to get a full scan and there are some parts missing, the software has a tool called *Solidify* which helps to fill in the gaps and have a good object ready to be printed. If there are still problems with the edits which were done with *Sculpt*, meshes can be saved and exported as STL or PLY files. [22.]

2.3.3 Autodesk Memento

Autodesk Memento is a powerful tool that can turn photos or scans into high quality 3D models. It can generate up to two-billion-polygon meshes. It is also possible to edit the models, smooth them out, fill in the gaps, detect any bugs and have it ready for 3D printing or 3D interaction in videos or web. No previous CAD experience is needed in order to use the programme. It is a simple to use, user friendly app, which opens up the doors for everyone to make the 3D world possible. It does however require quite a lot of computing power. The beta version for *Memento* is for *Windows* and *Mac* users. Below the system requirements for both operating systems can be seen. Similar tools as in *Memento* are in another app of *Autodesk* called *123D Catch*. Unlike *Memento*, it limits the amount of pictures that can be uploaded, and the photos go to the cloud, whereas in *Memento* it is part cloud based part computer based for processing the images. *Memento* also works well with other software rom *Autodesk*. That allows objects to be exported in many different paths. *Autodesk* also has a 3D scanning programme called *ReCap.* [23; 24.]

Table 3. System requirements for Autodesk Memento for Windows. Data gathered from memento.autodesk.com [25].

Operating System	Microsoft Windows 7, 8 or later
CPU	64-bit Intel or AMD multi-core processor
Graphics Hardware	NVIDIA or AMG graphics card with a minimum of 2GB VRAM
Memory	12GB system RAM
Storage	SSD recommended
Pointing Device	Three-button with scroll wheel mouse

As seen in the table an average computer that is up to date should be enough to run the programme.

Table 4. System requirements for Autodesk Memento for Macintosh. Data gathered from memento.autodesk.com [25].

Operating System	Apple Mac OS X v10.10.0 or later (Yosemite)
CPU	Quad-core Intel Core i7
Graphics Hardware	NVIDIA or AMD graphics card with a minimum of 2GB VRAM. Graphics card should support OpenGL 3.2 or newer and DirectX10 or newer
Memory	16GB system RAM
Storage	SSD or PCIe Based Flash
Pointing Device	Three-button with scroll wheel mouse

Windows based computer was used in Helsinki Metropolia University of Applied Sciences Leppavaara premises. That campus is also equipped with a *Macintosh* computer laboratory, and therefore giving specifications of them might be useful for further use.

2.3.4 Reconstructme

Reconstructme is a software that allows scanning objects in real-time. It can make models of relatively small objects like cats or lamp and scales up to a whole room. It can also get colour information if the sensor supports it. Following sensors can be used: *ASUS Xtion* Family, *PrimeSense Carmine* Family and *Microsoft Kinect* family. The scanned object can be later exported in STL, OBJ, 3DS and PLY and used with other CAD software for further modelling.

Table 5. System requirements for Reconstructme. Data gathered from reconstructme.net [26].

CPU	Intel Core 2 Duo E6600 or AMD Phenom X3 8750 processor or better, 2GB of RAM
Video Card	ATI Radeon HD 5700 or NVIDIA Geforce GT 240 or better Updated Driver, NVIADIA, AMD, INTEL
Sensor Type	Asus Xtion Family or PrimeSense Carmine Family or Microsoft Kinect family Updated Driver ASUS Xtion, PrimeSense, Microsoft Kinect
OS	Windows XP, Vista, 7, 8

The most important thing is to have all the drivers installed correctly and have updated drivers for graphic card and sensors. As well as that, the sensor should have SDK drivers and the graphic card should support OpenCL.dll.

3 Initial approach

3.1 Planning

Beginning with chapter 3 the thesis will be concentrating on the practical work that was conducted after theoretical research. This whole project started from one simple idea - animated documentary. After finding an old small portable projector the first thought was to make a real-time animated documentary projection in the actual space where some historic event took place. Some research had to be done in advance, from which the very first thing was to figure out how to make projection mapping. It seemed to be very simple based on the tutorial provided by Peter Kirn. All that was needed was a *Kinect* device together with a computer, *Reconstructme* and the *VVVV* mapping tool software. Figure 3 shows *Kinect* how the device looks. However, at the very beginning it was clear that this idea might not work as easily as described.

Figure 3. Kinect xbox 360 device. Copied from commons.wikimedia.org [27].

Although *Reconstructme* is advertised as easy to use “plug and play” software, it is actually not as easy to make it work. First of all, it needs to have a very powerful computer to support the real-time modelling. Also, with many of the usual graphic cards the programme just cannot work. Even though it says on *Reconstructme* website that it should work with *NVIDIA* Geforce GT 240 or better, it is not always true. Even with *NVIDIA* GeForce GTX 750 Ti or some other graphic cards that they say the scan should work it does not and they do not provide the best customer support for indicated problems. There is a forum on their website and many people have similar problems, but they do not provide answers for that. For example, it is actually very hard to get all the drivers installed correctly. Even when installing the sensors it might not be possible to just plug them to a computer and do automatic installation. Many users actually advise to install the drivers manually since then it should not select the wrong version of the drivers, otherwise it could result in the scan simply not working. As mentioned before, one needs to have *Kinect* SDK drivers and also the graphic card has to support OpenCL.dll.

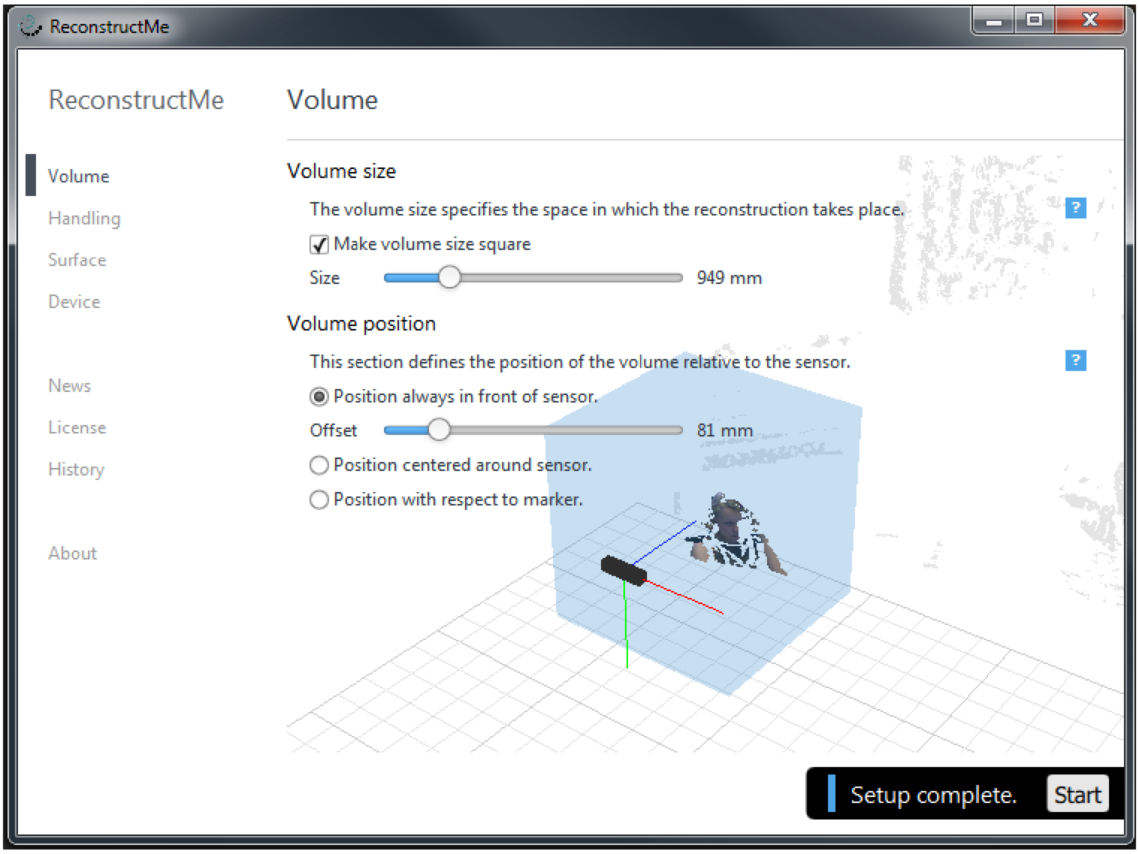

Figure 4. Reconstructme setup interface screenshot [28].

While trying out the software there were two major problems — first, the programme could not find the sensor, even though all the drivers were installed correctly. In attempt to solve this issue a better graphic card was purchased. After the sensor problem was solved there was another error. The software did not start the scan at all. Figure 4 shows the interface image of the programme when it says that the setup is complete. However once the start button is clicked the programme immediately gives an error that “tracking position lost, please return to previous position”. Figure 5 shows that error message. That continued no matter how the settings were changed. Reinstalling everything did not help either and there was no further customer support from the developers.

Figure 5. Error message in Reconstructme screenshot [28].

After the error message appears on the screen there are two options to start a new scan or finish the scan. With first option there will be redirection to the first setup page and after clicking the finish button it starts to calculate the surface, but there is actually nothing to calculate since the scan was not performed. The *Reconstructme* software failed to deliver the scanning, it never worked.

Also to use the *VVVV* software one must learn a whole new computer language and figure out how the interface works by writing some code. 3D projection mapping is different from 2D because it is projecting 3D objects onto the real objects with a video projector, similarly to how a wrap texture would work in *3Ds max* or some other 3D modelling software. Even if the artists Kimchi and Chips [29] were very good inspiration for the project, it was actually a very hard and long process to produce the initial idea and make it good. Therefore, during the practical approach of this thesis the concentration was only on the 3D scanning. [30; 31.]

Secondly, after some research on 3D scanning was done it showed great potential and usable need for the Metropolia students and could be taken to the next step. Once *Kinect* device was found the testing stage could begin on the older audio visual technology lab machines. Unfortunately, they could not meet the requirements. There was a purchase of a new *NVIDIA* graphics card needed. It was assembled together with a new computer. Surprisingly, *Autodesk* had just released a new way of 3D scanning the objects using the thing that probably most of people have - a photo camera. Taking many images and combining them made it possible to get the captured object into the virtual 3D world. All that had to be done was to think of how can such technology be used, where could it be implemented and what kind of research need to be done to get the best results possible. It was a very interesting process to see how technology has evolved and what great new tools can be combined together to create something very powerful and interesting. Technology opens up more doors every day for the world to explore and it seems that there are no limits for human creativity and imagination.

3.2 Hardware specifications

In order to have the project up and running good hardware needed to be assembled. Obvious decision was to use the *Windows* operating system because at the beginning the *Reconstructme* software was a main programme that would have been used in this project. *Kinect* SDK, which *Reconstructme* needs to work, was only supported for *Windows*. For a real time rendering of the scanned object a powerful graphic card was needed. The best option in terms of speed, quality and price was *NVIDIA* GeForce GTX 750 Ti. For fast rendering good processing power is needed. The computer has 16GB RAM memory, Intel(R) Core(™) i5-2400 CPU @ 3.10GHZ processor. It runs a 64-bit system. The default operating system on the university campus, where the workstation was built, is *Windows* 7. For this reason, that operating system version was chosen.

For the project first generation *Kinect* was used. It has an infrared light emitter, a colour sensor, an infrared depth sensor, a tilt monitor and a microphone array. It also has a viewing angle of 43 degrees vertical by 57 degrees horizontal field of view. Vertical tilt goes from 27 degrees up or down. It takes videos 30 frames per second. The audio format is 16-kHz with 24-bit mono pulse code modulation. The colour camera has 640 by 480 resolution and depth camera 320 by 240. Maximum distance of the covering space is around 4.5 metre. Minimum distance for the object is 40 centimetres in near mode, but there is also a *Nyko* zoom and a wide angle lens to broaden the view. It can define 20 skeleton joins and tracks two full skeletons at the time, meaning two people can play simultaneously. It supports *Windows* 7 and *Windows* 8 and costs around 150 euros. [32; 33.]

When working with the *Memento* software from *Autodesk* a Canon 5D mark 3 mirror camera with a 24-70mm f/2.8L 2 USM lens was used. The pictures were waken on the Leppävaara campus with studio lighting.

3.3 Project goal

The goal of the project was to research available programmes and their capabilities and to make a low-cost, nevertheless, efficient way for 3D scanning objects or people and getting a 3D model for further usage in CAD programmes or 3D printing. As well as that, the project focused on which programme produces the best quality of scans and meshed models and how well it can be used with other software for editing or animation.

In addition, throughout the process guidelines were given that would create a simple explanation of how the software works and information which would help when choosing the right software according to specific project needs. This project has provided a working workflow that will help anyone to use 3D scanning.

4 3D scanning workstation at Metropolia UAS

4.1 Workflow

The only 3D scanner that Metropolia Leppävaara campus had was *Cubify Sense* used in the 3D printing lab. Thus, there was a decision to make a 3D scanning workstation and try other methods for making a 3D model. Although, the final scans did not came out in the quality that was expected in the beginning of the project, the technology itself gave promising results that could be edited with other CAD programmes. With the right adjustment, the models can be used well in games, movies, animation, architecture, historical preservation or industrial design. The methods used in this project are more for home use rather than expensive industrial 3D scanners. Low cost, simple to use devices and software was the main concentration during the project.

Each programme had their benefits as well as drawbacks. For example, it was hard to scan anything smaller than a bust with *Skanect* and *Sense*. Whereas *Memento* could capture smaller objects rather well. Therefore, it is recommended to use *Skanect* for human bust or full human bodies, if there is a need to capture colour as well as geometry of the body. Unfortunately, the *Sense* scanner can only save colours for printing, but not when exporting the model. So far, there was an encounter with a similar problem with *Skanect* as well, once the model had been imported to *Autodesk*, although when opening models with *Memento* that were scanned with *Skanect* the colour information was preserved. It might be possible to collect the colour map with *Autodesk* as well, after some more research is conducted about that matter; however, during this project, it was not the major aspect to have colour on the model. The main goal was to find out if the programmes could actually deliver what the makers advertise and how well did they work in practice.

While trying out *Skanect*, especially scanning half of the room or full room, it worked rather well. It did not necessarily get the most details once zoomed in, but it defiantly reconstructed the room in a well enough performance that it was recognizable. It is a good and practical way for real estate agents to show the interior of the building using virtual reality, created by 3D scanning. It can also be useful for architects, or other professionals, as long as they know how to use the gathered information correctly.

4.1.1 Skanect

First of all, *Microsoft Kinect* was tested together with a customized personal computer mentioned in section 3.2 Hardware specifications and *Skanect* software. Computing power is very fast, therefore in real life scanning there is no delay. However, while handheld *Kinect* is quite difficult to use, only with very slow movements it is possible to make a good scan of the object. Also, *Kinect* is connected to the computer with a chord and therefore all the objects that one might want to scan have to be brought to the work-station. It is best to have quite a lot of space around the object for movement, since the scan has to be made from every direction. Many times the software will tell that the camera moves too fast and it must return to the previous position. That is very troublesome to do because there is only a dim image over what the camera currently sees and once back in place there is a need to be very steady with the rest of the movements. The details that are already captured appear green on the screen. Figure 6 shows the interface of *Skanect*. On the upper left corner there is a record and stop button that can be pressed to record, pause or finish the scan, after which it is necessary to wait till the object model is completed.

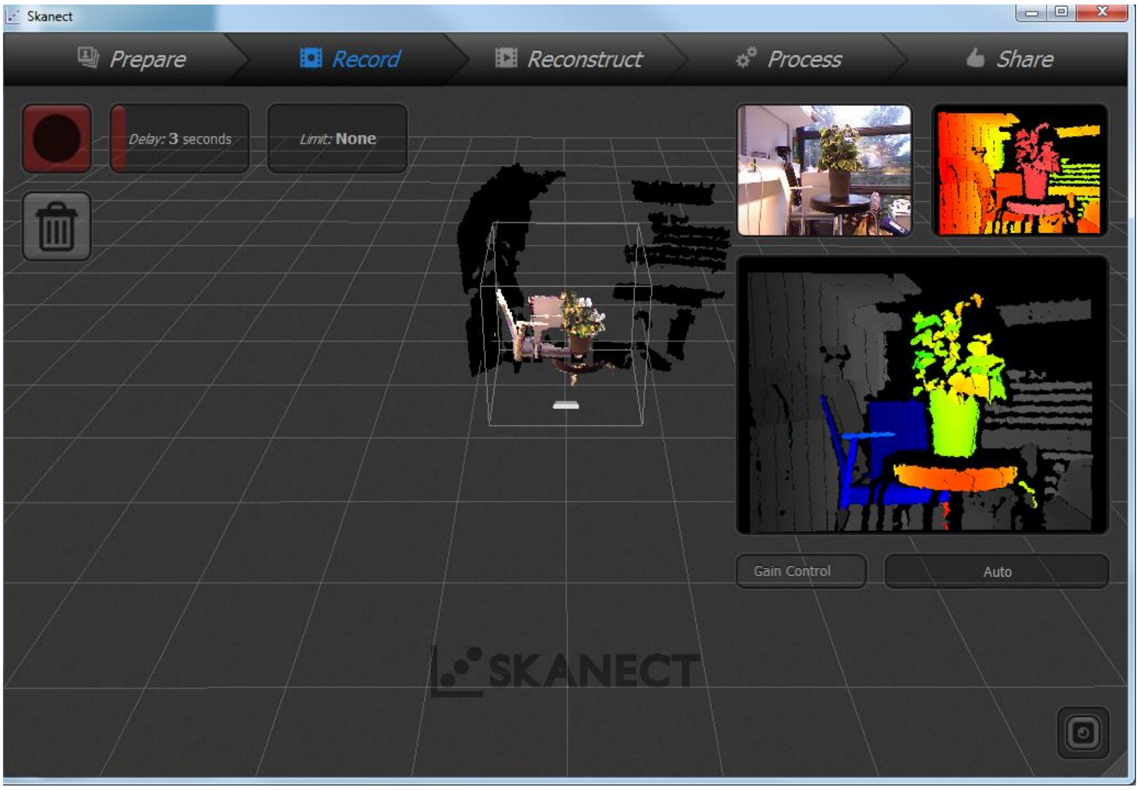

Figure 6. Skanect interface screenshot while preparing for the recording of the object [20].

Once the object is created there are several editing options that can still be applied before exporting the file. In the mesh tab there are three options — reset, watertight and external edit. If watertight is chosen a pretty nice colourized mesh of the scan will be created. In geometry the objects can be simplified in case there are too many vertices and faces, which usually is the case and might take too much computing power to process. There is a possibility to fill holes of the mesh in case some parts were missed during the scan or there was some error while making the object. There is an option to also move and crop the unwanted parts of the mesh and remove some parts of the object that are smaller than the percentage that was chosen. However, that seemed to be quite difficult to use. If the object does not have any colour by now, it can be colourized or the colours can be removed on the “Color” tab.

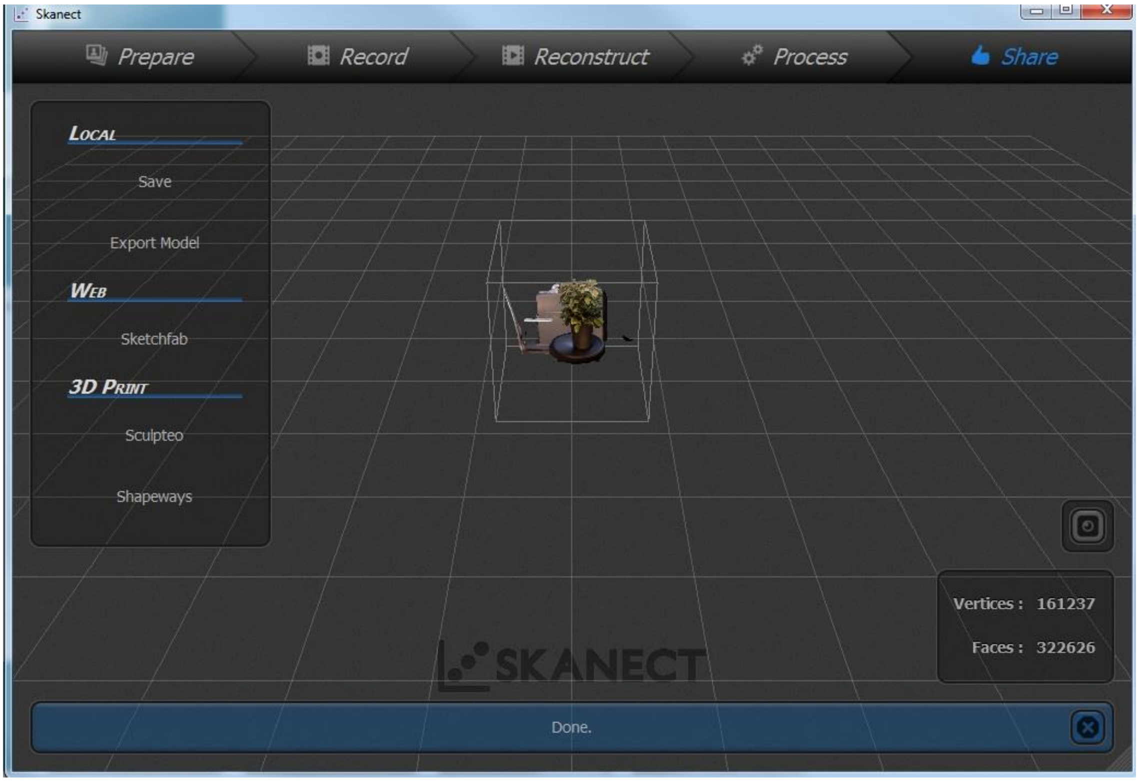

Figure 7. Sharing options and final result of the object in Skanect screenshot [20].

Once the edit is in satisfactory condition, figure 7 shows the elaborated result and sharing options for the object. It can be saved and exported in four different file types including .PLY, .OBJ, .STL and .VRML. There is also possibility to share it on *Sketchfab* or 3D print it directly with *Sculpteo* or *Shapeways*. For further object modelling such free software as *Meshlab* and *Meshmixer* from *Autodesk* can be used. As well as that, it is possible to import the files to *3Ds Max*, although editing the model might be quite difficult because it contains very many vertices and faces. It would be very hard to animate such object. Therefore it might be best to use the scans for props or scenery if the plan is to make some animation.

4.1.2 Memento

Memento was released by *Autodesk* in the beginning of 2015. It is still in beta version, but the potential of the software is impressive. Once the software is launched it gives three main menu windows that can be seen in figure 8. Those menu windows allows a 3D model to be created from photos or handheld scan (only the *Artec* device did not work with the *Microsoft Kinect* sensor) which later uploads the pictures or scans to the cloud. Hence the software is not actually using the computing power of the computer. The upload itself is very simple and fast but afterwards some time needs to pass till the objects are rendered and they also are waiting in the queue, so it takes quite a while before the results can be seen.

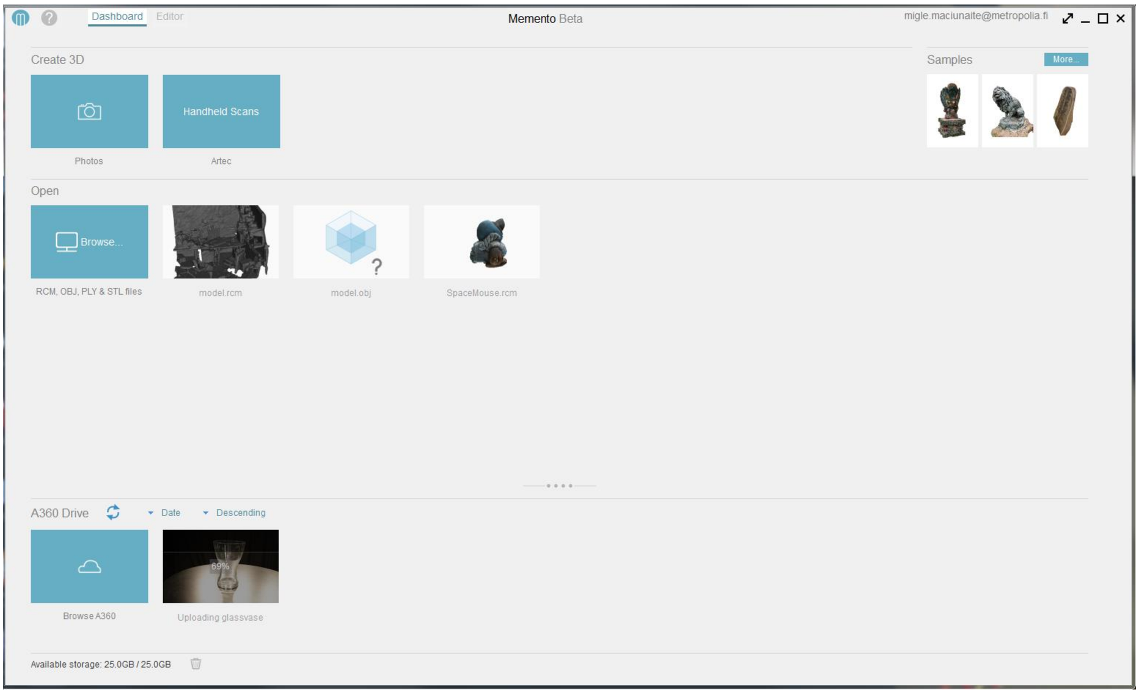

Figure 8. Memento dashboard interface screenshot [34].

There is also a possibility to open already made models that are in the RCM, OBJ, PLY or STL file systems. Once opened there is an option to edit the objects. The interface is very simple and clean, as can be seen in figure 9, with all the tools that might possibly be needed for simple and fast 3D modelling. Coordinate system can be set up, in case it is not set correctly at the beginning. Probably the most useful tool is to slice and fill or select and delete the unwanted pieces of mesh. It is very useful if scanned object is being opened, because most of the time it will have some parts of other objects in the final scan. If the scan was not perfect its holes can be filled or unwanted gaps closed and the some geometry can be smoothed out. There is also a tool that enables extruding and a few other tools to get the object to near perfection. There are a few different visualization options to have the object coloured and solid, coloured with wireframe, only wireframe or even infrared.

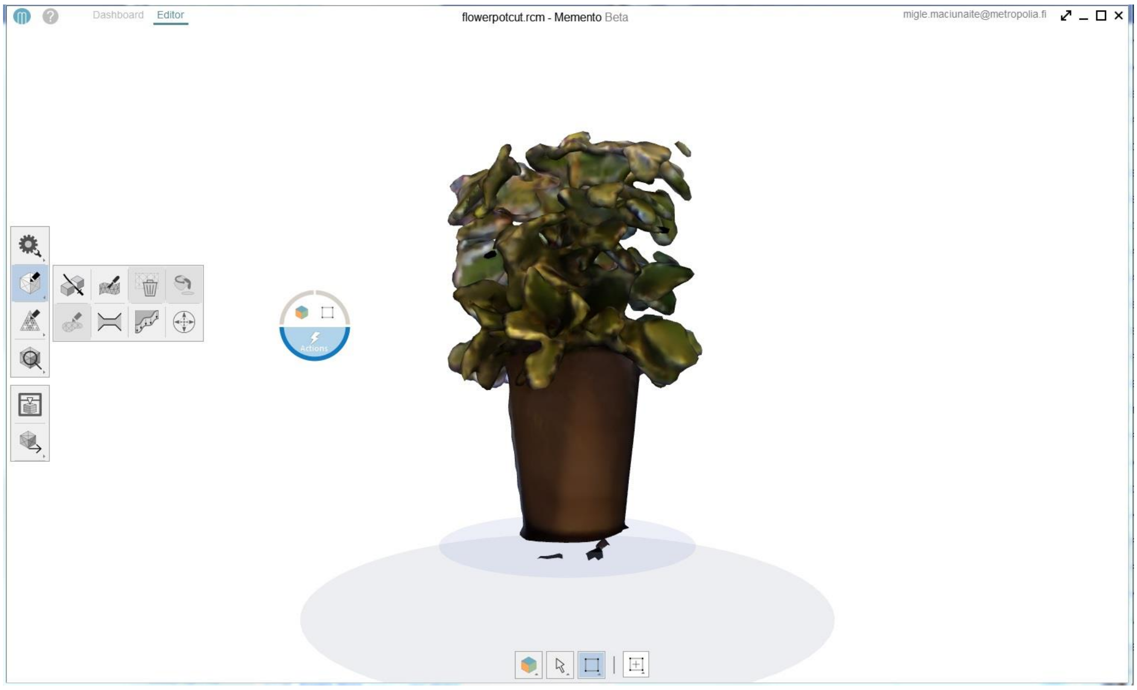

Figure 9. Editor interface of Memento screenshot [34].

Once the object is finished, it can be 3D printed it immediately or exported as a model, video or image. The video option is interesting as it has already an implemented camera. Therefore there is no need for manual animation and a turntable video of the object can be made within seconds. The video format can be chosen between few AVI and MKV files for exporting. The resolution can be 720p, 1080p or even 4K. As well as that the background colour and display mode of the object can be chosen.

There is an option for key frames and customized camera movement that can be created. This tool can be perfect if there is a need to have a scan of a room or historical artefact and if one wants to create a story with the movement. Making video with key frames with

Memento is very easy. All that needs to be done is to select the duration of the video and the interval for the key frames, then just mark the key and make the movement of the object, rotation or zoom.

For image export there is currently only the PNG option but width and height of the picture can be chosen from 1024 pixels to 8192 pixels, and also the different displays of the model.

There are a few different files the 3D models can be exported as — OBJ, FBX, STL, RCP and PLY. It is possible to select how many target faces there will be from 1 up to 28800. If that is not enough there is also a decimation percentage, an option to preserve textures or “rebake” them using a diffuse colour map, a displacement map or normal map and also an option to have no textures at all.

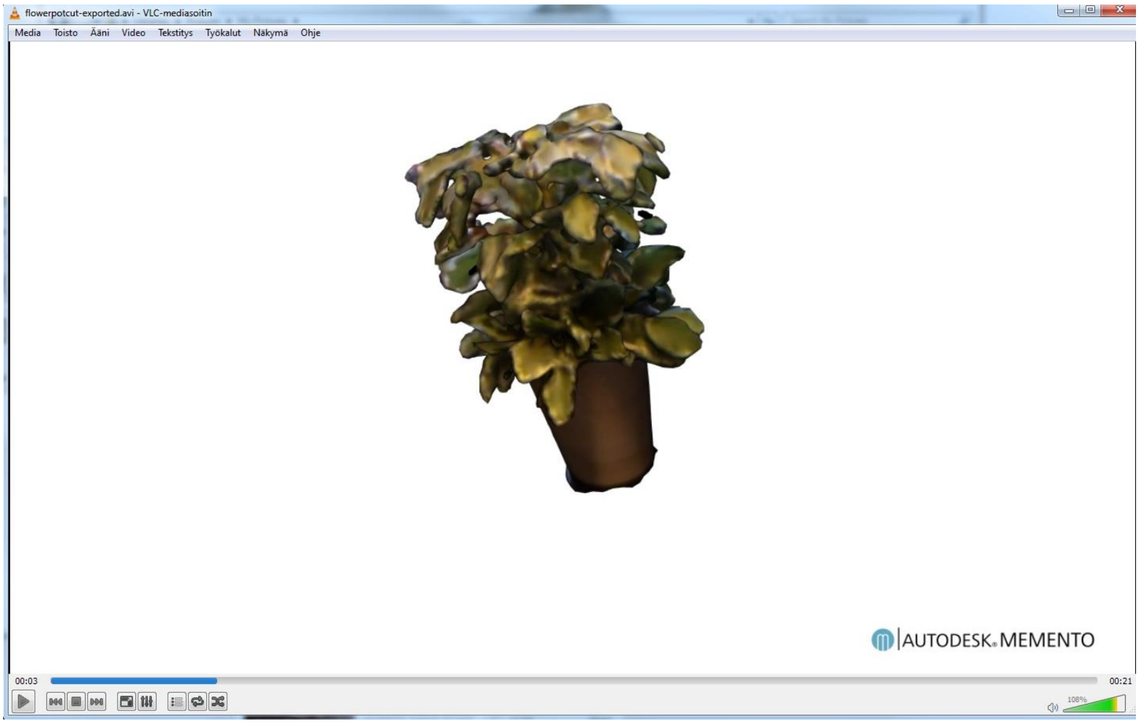

Figure 10. Flower pot video created with Memento screenshot [35].

Nevertheless, even if the software seems to be easy to use, it is actually quite hard to get good quality pictures and enough of them to produce the 3D object. Photos in a room with studio light equipment were taken and still an error was received that the model could not be created because of a few possible reasons like not enough pictures or bad quality such as blurriness, bad focus or too strong contrast. There might also be not enough overlap between the photos and, moreover, a problem with shiny and transparent objects. After the cloud rendering is done, an email is received about the process, either if there was the problem or if the model is ready. When taking the pictures it is actually hard to determine how many of them might be needed and if they are overlapping well and also if the lighting is correct and will not cause problems in the rendering for *Memento*. All of this takes quite a lot of time and it is not possible to get the models immediately. Therefore some proper planning and preparation has to be made beforehand.

The very first attempt was to make images of four different kinds of objects — a glass vase, a plastic flower pot, a yellow chair and half of the studio on the campus. The glass vase was impossible to render, it seems that *Memento* was not capable of making glass, reflective and transparent objects. It did not matter how many pictures in different ways the vase was taken. The second attempt was with the plastic flower pot, the result of which can be seen in figure 11. It looks like some strange object with part of it resembling the leaves. Texture wise it captured the leaves very well but the whole object was completely distorted and did not have good details.

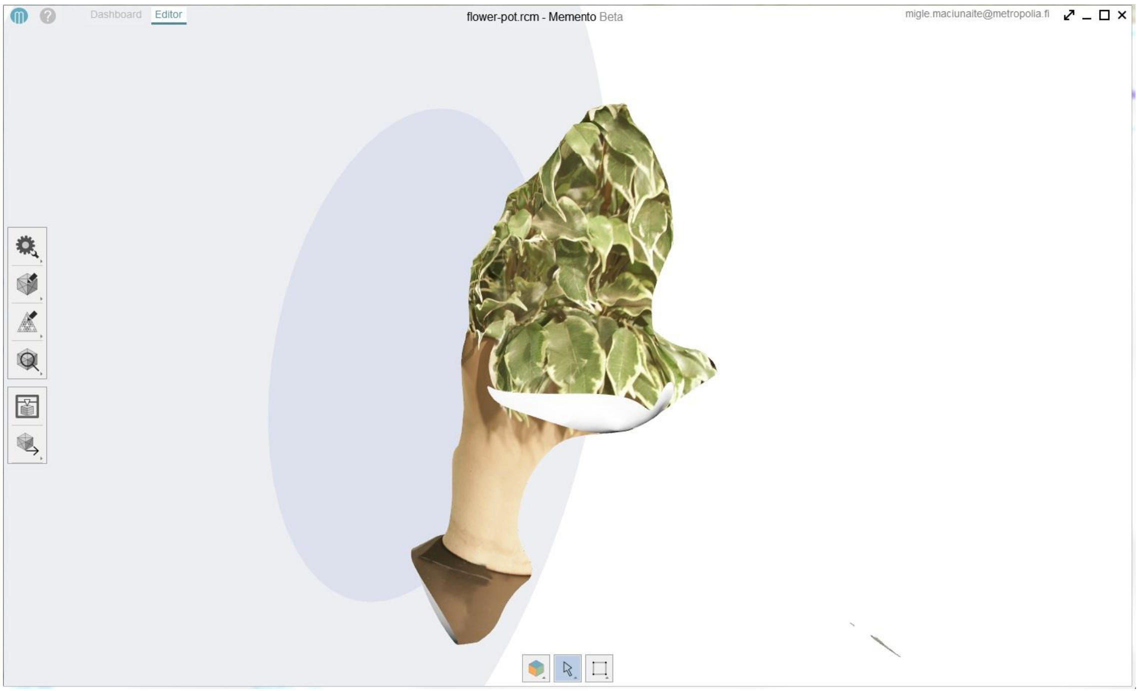

Figure 11. Flower pot images after processing with Memento screenshot [34].

The best model so far was the yellow chair from the media lab studio. Since it has bright colour, it can be lit up nicely from each direction. Figure 12 shows that the cushions on the chair had good shadows and texture details. The only problem encountered were holes in the chair, most likely due to lack of information while taking the pictures. A few more pictures might have been needed from above of the chair. However, the holes can be fixed within the *Memento* software.

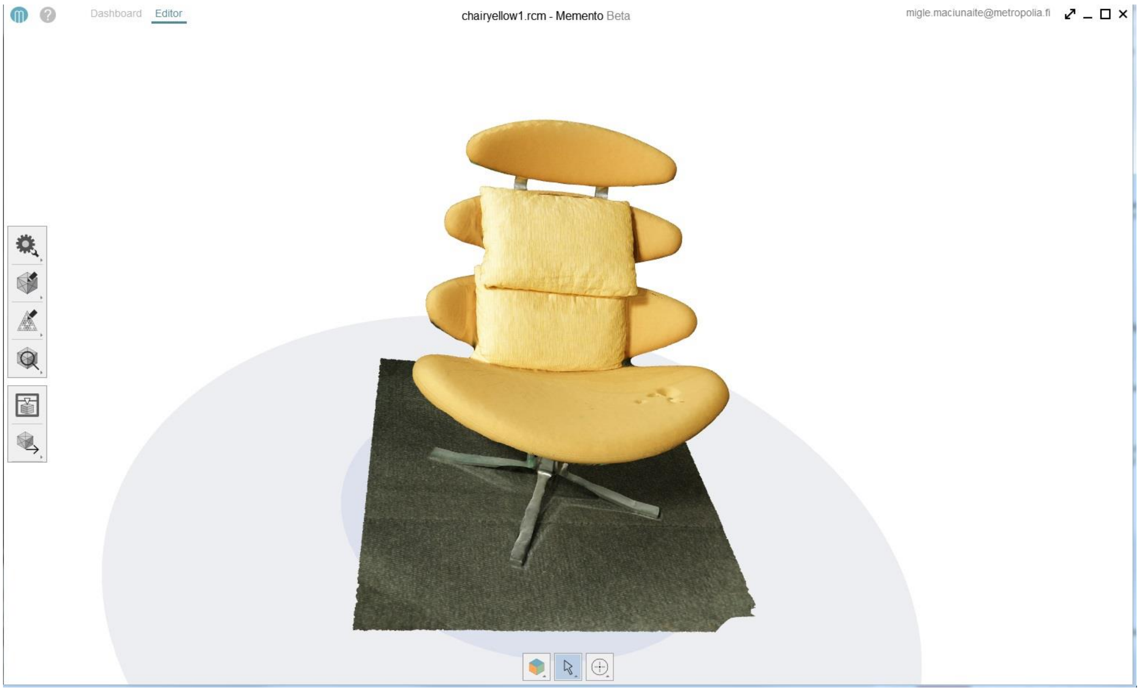

Figure 12. Yellow chair rendered with Memento [34].

The last try was with half the room of the studio on the campus. There was a need of comprising it with the option that *Skanect* has to scan half of the room, but that did not work, most likely because of the bad contrast between the walls and the floor and because the lighting was not even and because *Memento* processes too light and too dark surfaces defectively. Furthermore, it could be that there were not enough images as well, since the pictures behind the wall could not be taken and the images that were taken were insufficient.

4.1.3 Sense

From the beginning of this research it was known that Leppävaara campus of Metropolia had one scanner that worked together with the 3D printer. However, the scanner was received only in the last stage of the process and therefore there was not much time to make many scanning tests. Although, even after a few scans it was quite clear how well the software worked and how it should be used. Figure 13 shows the first window once the software is opened. There is a possibility to choose between three different sizes of the object that is about to be scanned – small, medium or large. There are examples underneath to help choose the correct size. Within each size option there are sub choices describing the object that could be scanned. The first attempt was trying to scan a human head to have a good scan to compare with other software used before.

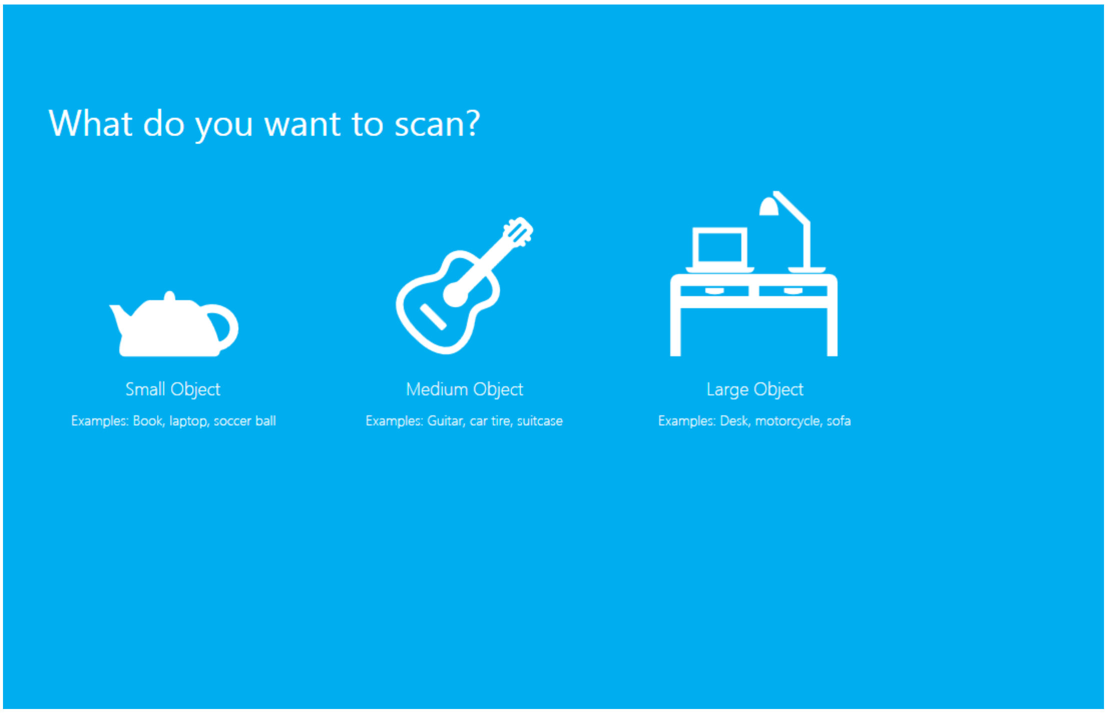

Figure 13. Sense software interface screenshot [36].

The sensor is quite sensitive, meaning it has to be stable and move slowly around the object. Otherwise the tracking is lost and it must return to the previous position to continue the scan.

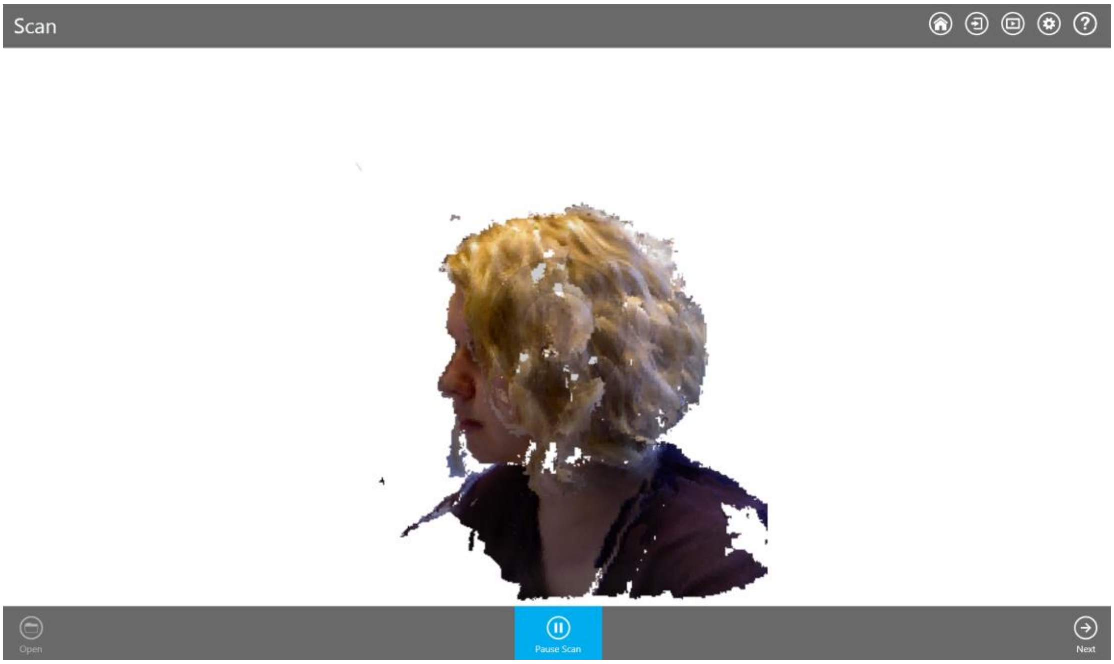

Figure 14. Sense interface during a scan of a human head screenshot [36].

After the scan is completed, the model looks good and has the colour information as well. The quality of the model during the scanning process can be seen in figure 14. It is possible to export the model in STL and PLY file formats and work with other CAD programmes or send them to a 3D printer. Figure 15 shows what happened after importing the saved files to *Autodesk 3Ds Max*. The model lost its colour information and the surface itself looked a bit different than in Sense, as it had fever details.

Figure 15. Sense scan imported to Autodesk 3Ds Max screenshot [37].

It seems that once the file was exported from Sense, it did not save any bump maps for colour information. It also had many faces and vertexes and therefore it was difficult to correct and manipulate the model. It might be easier with software like *MeshMixer*, *Meshlab* and also maybe with *Maya*.

4.2 Drawbacks

First of all, there were very many questions that needed to be answered before even starting the project. One of the first was whether the university has a powerful enough computer with a good graphic card to make the project going. As well as that, it was important to figure out where in the campus the *Kinect* device is, and what would be the best place to set up the workstation.

At the very beginning the plan was to make the scans and also try how well can the models be 3D printed, but during the summer of 2015 the campus was undergoing some constructions and the 3D printing lab was not yet set up. Therefore the plan and approach changed a little bit. On top of that, it was impossible to find the *Sense* scanner, due to the fact that everything from the printing lab was in different places and boxes and it was impossible to reach the person in charge of it.

It took quite some time to actually get the whole setting, because the computer had to be assembled together with the new graphic card and software installation had to be done at Helpdesk. Sometimes it was hard to remain patient. After the whole workstation was set up in one of the project rooms, there was another major problem. Initially *Reconstructme* software was to be used, but it just did not work no matter how the settings were changed. There was no proper customer support received from the developers and in the end the *Skanect* programme was chosen to be used instead. Student discount for the software license was acquired and everything was set to finally make some scans.

4.3 Maintenance

The workstation itself does not require a lot of maintenance. However, there are still a few important things to check regularly. All the drivers must be up to date and work well together with *Skanect*, *Memento* and *Sense Sculpt*. *Skanect* has only one year student license, which expires in June 2016. It should be updated yearly for further use. *Memento* software is still in beta version. It is not known yet if *Autodesk* will continue providing it for free or if they will start licencing the programme. As well as that, since it is only a beta version, there might be some changes coming out and therefore it is best to check once in a while for newest updates on the *Autodesk* website.

As for now, all the programmes work on the *Windows 7* operating system. They are also available for *Windows 8*, and so are the SDK drivers. In case the operating system is upgraded to *Windows 8*, the software, as well as all the drivers, have to be updated. It is unclear how the software might work with *Windows 10* for the time being, since the SDK 2.0 driver for *Kinect* now only works only with *Windows 7, 8, 8.1* and *Windows* embed standard 8. As well as that, only *Kinect* version 1 was tested. However the *Kinect 2* has better resolution on colour and depth cameras. It supports *Windows 8* only and therefore, if in use, all of the workstation should be thoroughly updated.

5 Evaluation

5.1 Final results

The end product of the research was not exactly how it was imagined in the beginning. The resolution of *Kinect* and *Sense* devices is quite low and cannot capture all of the details of the object well enough. Although, the *Memento* software seemed to be quite promising and giving good results from the pictures that were taken with *Canon 5D mark 3*. When it was uploaded to *Autodesk 3Ds Max* it actually did not look as good as in *Memento* software. First of all, figure 16 shows that when the model is received from the cloud in the *Memento*, it has too many faces. Most of the objects will have between 500,000 to 950,000 faces and it is quite a lot for *3Ds Max* to handle so much information.

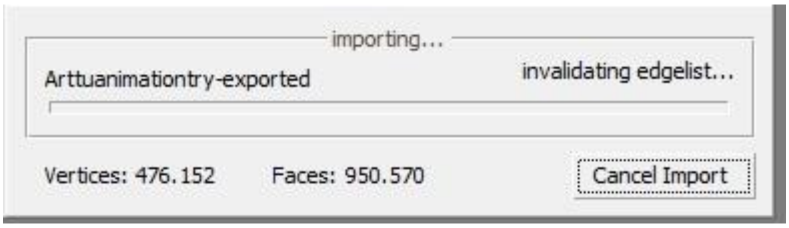

Figure 16. Vertices and faces count during the import of .OBJ file in 3Ds Max screenshot [37].

The faces count can be reduced or the decimation percentage can be lowered from 0% to 99% in *Memento* before exporting the model, which will cause the object to lose some details but will not affect the overall image. First of all, reducing the number of vertexes were proposed before opening the .OBJ file with *3Ds Max*. Figure 17 shows the importing menu, which is seen when opening the file in *Autodesk*. Different options can be chosen for geometry, normals, size and the object itself. That is also the menu for importing the materials together with the object. They are selected automatically, but in case there is no need for materials one just needs to untick them.

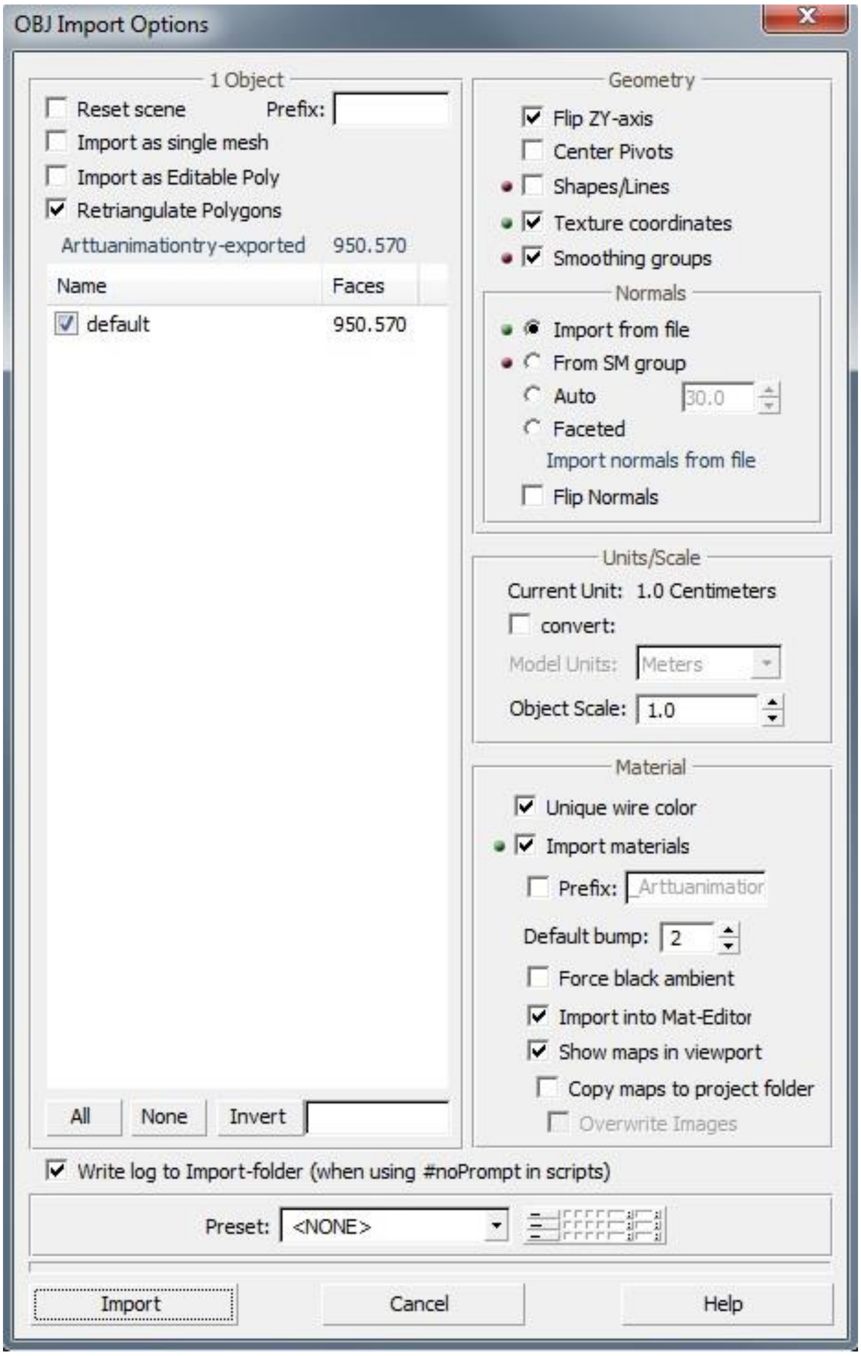

Figure 17. Import options for the .OBJ file in 3Ds Max screenshot [37].

After import the object looked not as smooth as in the *Memento* software. Therefore one more test with original number of faces was conducted. The model had a bit more detail and the surface was smoother. Although there was still something not right with the model. Figure 18 shows the image of the model, where it seems as though the textures were torn apart and did not fit correctly in the borders of the textures. Looking at the material map, made by Memento during the export of the .OBJ file, it seems that the materials look as if they were torn apart and therefore does not fit back together seamlessly on the object once it is imported to *3Ds Max*. The border lines between the materials are seen clearly, as they appear light blue throughout the object.

Figure 18. A 3D model of a human body made with Memento and imported to 3Ds Max screenshot [37].

Once more, it is actually quite difficult to capture many images of a body without movement of hands or head. Therefore, figure 18 shows that the hands are a bit deformed and that the shoes and legs have the most details because they were moving the least. The material of the head is also too bright, since there was a huge contrast between the clothes and the face and it was difficult to take pictures with optimal lighting.

One part of the research was to check if it is possible to animate the 3D scanned objects. Animate a human body seemed as a good idea, because it is simple to place a biped skeleton and make short animation of body part movement with it. When using the model with not reduced faces, the model worked fine during the rigging and making small animation movements, but after that the *3Ds* M*ax* began to crash, most likely because it could not handle so many faces and the movement for it. There was no explanation from the software why it crashed, just that it ran into an unexpected problem and the programme had to close. After the second attempt for animation, first the faces and vertices were reduced with a pro optimizer by 60% and then placed the biped skeleton once again to the body. This was more successful as now the software could actually do the calculations for the animation and the limps were moving well. However, the process is not so quick, since first the parts had to be cut separately and then the skin modifier had to be applied separately, in order to have each body part moving with the correct part of the biped.

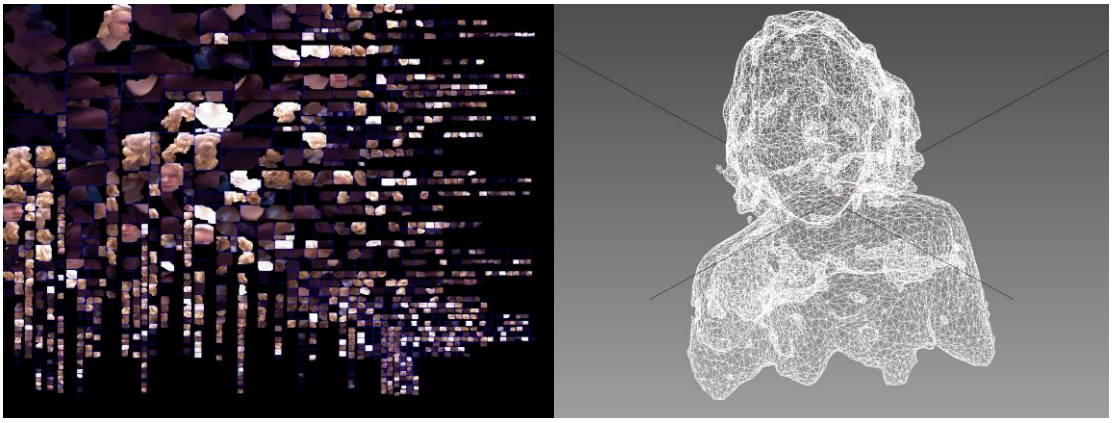

Figure 19. Material image of the object scanned with Skanect and the imported file in Autodesk screenshot [37].

The import of the model made with *Skanect* in the Autodesk programme was a similar process to models made with *Memento*. However, the right image in figure 19 shows that once the model was opened, it had no visible materials on the model and it looked transparent. It was only possible to see the object once it is clicked, and then only the vertexes of the model are showing. The left image in figure 19 shows a bit map of the object, which has all the colour information. During the import, the object came together with the bit map, but for some reason the texture was not displayed on the object in *Autodesk*. Therefore, there was no possibility for testing animation on the object when it could not be seen.

5.2 Benefits and examples

Many different fields of technology recognize the advantage of 3D scanning and are starting to use it. Some of the more interesting ones will be mentioned in this section. Starting with the most important for a human body – medicine.

There are new exciting and innovative ways to use 3D scanning in the medical field. 3D scanners together with medical CAD/CAM programmes are making custom design orthotics, prosthesis and also dental implants.

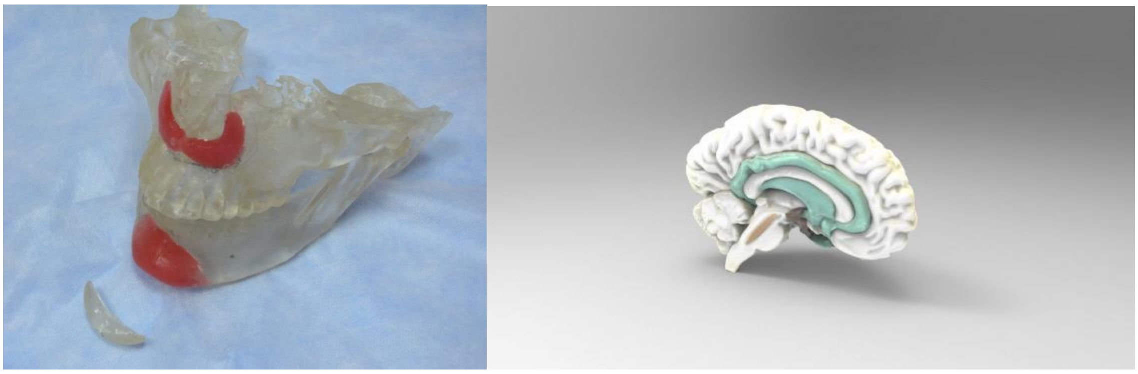

Figure 20. 3D printed models of a maxillofacial surgery on the left and a model of brains on the right. Copied from Maxillofacial surgery and 3D anatomical models for download [38; 39].

It is possible to scan a full body or its parts and organs and have them on the internet. For example, a model presented on *Threeding* website [40], can be seen in figure 20 on the right. The website has 37 other examples that are free of charge. The models can be downloaded and 3D printed by medical students, doctors or anyone who wants to learn anatomy. Doctors can now have a more detailed plan and vision for their surgeries. Parents can have a 3D ultrasound of their unborn child, which of course helps the doctors to observe the baby and investigate if the baby might have any health issues. [41.]

The exciting thing about 3D scanning and 3D printing is that it is not just about the future. It can also be used on something that has been around us for thousands of years. It is important to preserve and save the history and do not let it be destroyed. That is what archaeologists have started to do. In figure 21 on the left there is a computer model of a lost Michelangelo statue, which was scanned with a laser. The right image represents the process of 3D scanning a renaissance sculpture with the *Stereo scan 3D* device.

Figure 21. A 3D scan of a lost Michelangelo statue on the left and the 3D scanning process of a big Michelangelo sculpture on the right. Copied from engineering.com and 3ders.org [42; 43].

People can no longer be afraid of never being able to visit and see historical artefacts. Nowadays there are more historical places and art being 3D scanned for preservation than ever before, and the scanned objects can be accessed online or reproduced and shared with others. It helps not only people who are curious about seeing the pieces, but also many professionals can now examine and learn without physically touching and endangering the object. [44; 43.]

Fashion has been implementing 3D scanning and 3D printing rapidly in the past years. They give new opportunities and challenges for the fashion designers. Each body is different and it is hard to find the correct size in the mass production of street fashion. Customers want that their clothes to fit them perfectly, which can be achieved by having precise measurement of the body with 3D scanning.

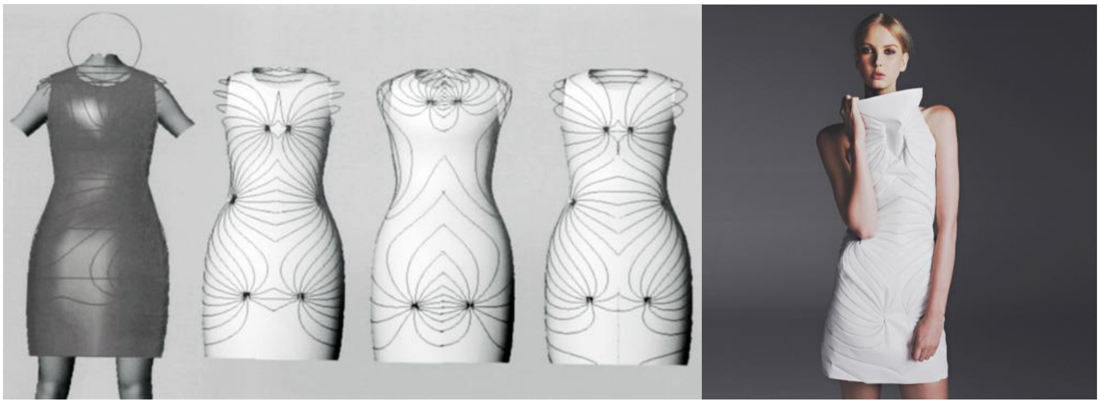

Figure 22. Custom design of a dress on a computer on the left and a custom made leather dress on the right. Copied from dezeen.com [45].

Leonie Tenthof van Noorden is an industrial designer who made custom sized dresses for her graduation project. The pictures in figure 22 represent her work. She used a body scanner to create clothes that fit perfectly to a body. The dress design can be scaled according to the size of the body, which also changes the shapes and curves of the line pattern that is projected on the dress. This is only a small glimpse of what can be achieved in fashion with technology and thinking outside of the box. [45.]

5.3 Future of 3D scanning

3D scanning technology is growing and changing the market every day. The industry is trying to improve it and make it more affordable for consumers and also solving problems for how the machines can work and interact with different materials. To capture colour and shape it is already possible, but now Carnegie Mellon University [46] is trying to find a way to get information of how the light actually interacts with the object, which is called bidirectional reflectance distribution function. This might in fact improve the technology and maybe give the possibility of scanning reflective and transparent surfaces with optical scanners. The quotation below is by Andrew Wheeler in which he explains how the new technique works. [47.]

> The technique that CMU has been developing estimates the BRDF at each surface element of an object. Each of the many surface elements of the object are isolated, making this technique unique in being able to capture light interaction with visually complex objects [47].

To simplify, this technology works in a way that the object is lit in different lighting and images are taken of the process which is called photometric stereo. The results of the research so far are very impressive. They made a model of a shiny armor helmet which reflects the light exactly as it would when rotating the object, with the shape and texture exactly as the originals.

Lumi industries are not only working on their affordable 3D printers with *Kickstarter* campaigns, but also concentrating on new ways for 3D scanning, as it becomes more and more popular. They announced in the *LumiPocket LT* video that in the future they plan to release a 3D *iPhone* scanner, which is basically an iPhone case that has a tiny rotating platform in front of the lens and lets an object to be scanned with the camera. Another thing they announced was a structured light scanner, which should work similarly to the photometric stereo technique, lighting the object with white light structured in lines or a grid. [48.]

3D scanning and 3D printing are playing a huge role in health care at the moment as well. It is becoming possible to not only print customized prosthetics, medical implants but also make living cells. The technology is not science fiction anymore and it is becoming the reality and the future that everyone might be using. [49.]

One other important use for 3D scanning is saving and archiving the historical artefacts, simply due to the fact that many of them need a very good preservation environment and to be left intact, but now it is possible to scan them without physical contact, reconstruct them in 3D and share them with the audience without being worried that they will get destroyed. [49.]

Museums, doctors and technology fanatics are not the only ones touched by the possibilities of 3D scanning and printing. The fashion industry is also starting to use it with great benefits, allowing manufacturing custom made clothing or shoes in the future much faster than with the traditional methods. [50.]

6 Conclusion

The field of 3D scanning goes from concept design all the way to distribution. Many different industries can use 3D scanning to their advantage, meaning, it can be used by manufactures, designers, engineers and developers. The simplest benefit is that it saves time and is cost efficient. As well as that, it can save the materials and ensure that the product is made correctly to begin with.

The practical part of the thesis resulted in intriguing observation. Several scans indicated that good and equal lighting with no high contrast in the object was important when the scan was performed. It is also clear that too bright, too dark and reflective objects cannot be scanned or will be scanned with a defect. Some objects that have too many details, like plants or hair, did not have the best reconstruction once they were scanned. All the programmes used recorded the colour information from the object. Unfortunately, only one software saved the colour information in a bitmap that was preserved once imported to a CAD programme. The animation was difficult to perform with the scanned objects, since the model was one big structure and had many faces and vertices which were hard to animate. It was uncomplicated to make a video of the scanned object rotating or the camera moving around it in *Memento*. However, the software had no option for animating the object itself.

The project shows that 3D scanning can be used by anyone and the devices that can perform it are already in most homes. Moreover, budget 3D scanners still have a long way to go before performing as well as industrial laser scanners.

In the end, the 3D scanning and the adjustment of the model in post processing takes a long time and is very detail oriented when it comes to having a good quality result. 3D scanning could be an easier option for people that are not particularly familiar with CAD programmes and modelling to have some sort of 3D models and objects in their product. However, for now the home use 3D scanners are not yet developed well enough, which is a shame, because there are more 3D printers available in the market gradually, but not a lot of development going on in the field of 3D scanning. This technology is not science fiction anymore, but in order for the technology to be used by anyone who might not have a degree in 3D engineering, there is still a long path in enhancing the way 3D scanning works.

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