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Partage Plus

Best practice report on the wider use of 3D digital models

'Application of 3D Technology in Cultural Heritage'

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Author(s)	*Chris Vastenhoud (KMKG), Katie Smith (CT) and Zsombor Jekely (IMM)*

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Contents

Abstract

This report aims to give an overview of the current state of development, use and application of 3D technology and makes a series of recommendations for its future use within cultural heritage. 3D models in this respect are referred to as digital copies of physical objects from cultural heritage collections. These are primarily born digital but they can also be physical copies created by 3D printers or cast from moulds.

As applications of 3D technologies grow, many new innovations and uses are being introduced to the market. The first section of this report presents an introduction to the history and main processes of 3D digital model creation in the cultural heritage sector, whilst the second discusses typical applications, providing examples of presentation, preservation, education, public engagement and commercialisation. In part 3, the report looks at the future use of 3D modelling, highlighting any issues that have arisen from the research and assessing what the current expectations are of 3D. This section also contains practical information and processes on the application of 3D technology in the cultural heritage domain.

The conclusion summarises the current state of affairs, discuses approaches taken by larger institutions, looks at applications of 3D technology within cultural heritage institutions and analyses commercial applications and interactions with public.

Without question, 3D technology will continue to develop and become readily available for both professionals and end-users. The current surge in technical developments of 3D printing and increase in media coverage illustrate its popularity, and this demonstrates that cultural heritage organisations should also pay attention to this emerging technology.

The report makes the final recommendation that cultural heritage institutions should consider 3D digitisation of significant parts or their collections, as this would enable them to support documentation, aid preservation and apply new technologies more easily. For the Partage Plus project this means that the project continues to advocate 3D technology, put it into practice and follow these developments closely.

Part 1: Introduction

1 Introduction

This report is a deliverable in the Partage Plus project, which aims to digitise 75,000 Art Nouveau objects in 2D and create 2,000 3D models for display on Europeana. The Partage Plus project started in March 2012 and has duration of 24 months, consisting of 25 project partners of which 19 contribute 3D content. The aim of this report is to provide an overview of the current and wider use of 3D digital models and make recommendations for the future implementation of this technology.

As 3D technology is relatively new, knowledge of it and its applications within the museum environment amongst the partners is limited, however there is a general awareness that its simplest use is as an alternative to 2D or video visualisation where models offer possibilities for wider use. In order to increase knowledge about this technology, the project decided to maintain constant quality and avoid making large investments in hardware, instead inviting a leading supplier of 3D technology to the project. This partner, Steinbichler Optotechnics (SO) from Germany supplies materials, knowledge and manpower within the framework of the project to scan Art Nouveau collections at partner locations.

Conducting research into 3D technology and application is not the core purpose of the Partage Plus project. Other projects[1] funded by the European Commission, like CARARE and 3D-Coform (both finished) and 3DIcons address 3D in cultural heritage more specifically and in-depth, investigating technology additional requirements such as IPR and metadata. Partage Plus concentrates on turn-key solutions and so uses the results from these projects in relation to 3D technology to enlighten the processes undertaken as part of the project.

Recent years have seen an increase in the application of 3D technology in the cultural heritage sector, despite its origins lying within manufacturing and quality control. The report will look at the projects mentioned above and internet resources to investigate how 3D has created opportunities for new research and applications. It will also cover the standards, usability and viability of 3D digital models in the cultural sector and address the technology, applications and future approaches of 3D in the cultural heritage sector.

The report is divided into three sections.

1. The first section describes the background and the current use of 3D digital models in Partage Plus.
2. The second section describes a number of best practices and examples of application of 3D in the cultural heritage sector. In this section additional information about issues such as IPR and Metadata are also introduced.
3. The third section discusses possible developments and scenarios for application for the short term and further into the future.

[1] Partners in Partage Plus have links with these projects or are participating.

2 Scope

There are vast and diverse choices of application and technology in 3D. The recent surge in publicity within this area of innovation implies that this technology is only at the start of being applied on a much larger scale. 3D has its origins in science and manufacturing and as a result 3D technology is only recently being applied in the cultural heritage sector. For this reason, it is difficult to maintain the original title of the report as described in the Description of Work "Best practice report on the wider use of 3D digital models". The title contains 2 aspects that imply that application within cultural heritage is already common practice, to elaborate:

- Best practices are described by Wikipedia as "A best practice is a method or technique that has consistently shown results superior to those achieved with other means, and that is used as a benchmark."[1] As the application of 3D technology is relatively new it is difficult to talk of best practices in cultural heritage at this stage.
- Wider use implies the existence of a common, shared use. As the report will demonstrate it is difficult to define this common shared us as wider use is considered to be any application of 3D technology which makes it distinct from viewing a 2D digital image. The report will show that there are very few applications which take 3D models outside of the cultural heritage sector at the moment. This meant the scope of the report had to be redefined to the typical use in the cultural heritage sector at the moment.

The elements below further define the scope:

- Although the focus of Partage Plus is specifically on Art Nouveau culture, this report discusses experiences and best practices within the wider domain of Culture Heritage.
- The scope of this report is limited to the application of 3D scanning technology as a means to create models from objects within the cultural heritage domain and to display these in a web environment.
- The creation of 3D models within a software environment (digitally born) is excluded. However this approach cannot be neglected completely as it is sometimes used as a means to complete or add to 3D models derived from original objects. The software used to create 3D models from scratch is also used to create mash-ups, which are further discussed in this report.
- The technical aspects of printing 3D models are not discussed. At present this is most commonly found in high-end industrial applications and often remains in the area of social sharing and Web 2.0. Where possible, connections have been made to demonstrate the occasions where this has been used within the cultural heritage domain.

3 Application of 3D technology in the Partage Plus project

As mentioned in the introduction, there have been several project within the 7th framework programme which research the application of 3D in the cultural heritage domain. As Partage Plus' focus is towards 2D digitisation rather than wider research and application of 3D; the aim of the Partage Plus project in respect to 3D has two strands:

- To research and prove that 3D technology does not always need to be a lengthy and detailed process which yields a limited number of 3D digital models. Partage Plus' intention towards 3D research is to create a large body of 3D objects and generate a large corpus to explore in 3D.
- To introduce a large audience of both professionals and the general public to 3D technology and its applications, by making these models accessible through Europeana.

Since the submission of the Partage Plus proposal (May 2011), 3D technology has evolved, especially the last few months where 3D and more specifically 3D printing has become a popular topic (number 93 based on domain count[2]) on the internet. In particular the following areas have developed:

- Laser scanning, a large amount of new equipment has become available. More manufactures are coming into the marketplace, which results in stronger competition and an increase in technical ability of the equipment.
- Photogrammetry has become widely available and accessible by the introduction of a variety of low cost software packages.
- Processing, computing power and the continued development of a number of open source applications like Meshlab and the continuous development of Blender bring the processing of 3D data within reach of a larger audience.
- Representation, with the introduction of 3D information on mobile devices and 3D printing there has been an increase in the number and nature of 3D applications.

In Appendix 2 the chosen application and 3D scanning workflow in the Partage Plus project is presented in detail.

4 History of 3D digital model creation

The development of 3D technology in the computer environment originates from the USA in the 1960's. Since then, two approaches have been used, creating digitally born models or creating models which are based on a capturing the morphology of a physical object. The latter method is most often used in regard to the aspects being discussed in this report.

4.1 Digitally born

3D modelling is dependent on computer graphics and power, with the acceleration of computer power in the 1960's in USA Universities paving the way. In the 1960's William Fetter at Boeing created the first 3D representation of a human, in 1972 Frederic Parke created another model of a human face and a year later Edwin Catmull created a digitised hand, with both Parke and Catmull working on a cinema production called Futureworld in 1976. The film industry has also been a driving force for 3D, when in 1977 the science fiction film Star Wars was released, it became one of the first films where 3D models played an important role and George Lucas would remain at the fore front of new cinema technology.

Today's technology used to create a 3D digital model with a computer is referred to as "digitally born". Digitally born in some sense is the opposite of the type of 3D modelling most commonly used in cultural heritage, where often the morphology and texture of a real object is captured and brought turned into a digital object. Born digital objects can currently be found in all aspects of creation; but specifically within games, cinema, video and as a first step into the production of a physical, real object, such as CAD (Computer Aided Design).

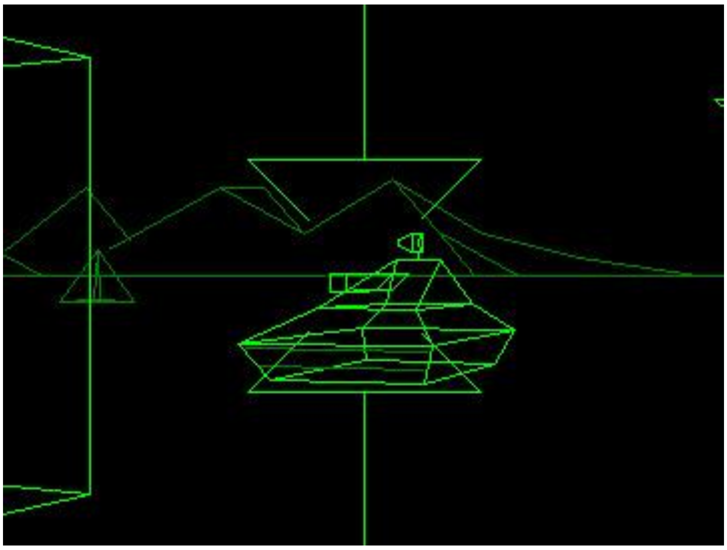


Figure 1: A wire frame image[3]

4.2 Capture morphology from physical objects

The origins of 3D capture are more recent. Although photogrammetry has been known since the 19th century, digital photography and today's applications running on desktop computers are more recent developments and allow 3D technology to be accessed by a much larger audience of professionals and amateurs/enthusiasts. Professionals often apply this technology to control the results of the production process, whereas amateurs and enthusiasts often experiment with all facets 3D technology. It is therefore easily understood that aspects of 3D and especially 3D printing have many links with Web 2.0 and sharing of resources initiatives.

Laser scanning is another technique used as a means to derive information about the dimensions and details of an object. It is a more recent innovation than digitally born techniques although it was initially developed in the 1960's, only later applied to cultural heritage at Stanford University where research groups scanned Michelangelo's statues in 1999 using laser scanner technology based on triangulation. Since then, many different variations of capturing technology (see 5.1.2) and processing have been developed and put to use.

Today, both techniques of 3D scanning are used, however capture and scanning is most commonly used in the cultural heritage sector as it enables organisations to gain a true replica of an object, rather than creating something entirely new and 'born digital'.

Part 2: Current Practice

This section discusses the current practice of 3D modelling in cultural heritage. The chapters contain information on how 3D models are created, what the most common preconditions are that need to be considered and presents an overview of examples and applications considered good practice.

5 Core processes in creation and use of 3D models based on the morphology of objects, structures or landscapes

As there are many different technologies used to create 3D models of physical objects, an introduction to the main categories of this technology is useful. The introduction contains additional, but equally important processes that ensure long term accessibility and procedures for dealing with IPR and digital preservation. In order to produce and display a 3D model derived from an existing physical object, a sequence of three steps must be followed: Capture, Processing and Presentation:

- Capture - Deriving information from an object’s shape by means of a light based technology;
- Processing - The adaptation of this information to the specific needs;
- Presentation - The selection and application of the suitable format and technology for presentation of the information.

The sequence of these processes is usually one directional and cannot be reversed. Therefore it is advisable to safeguard and digitally store all the information generated in each step of the process.

This section presents a non-exhaustive overview of the equipment and applications used to create 3D digital models using this process.

5.1 3D model Creation

As discussed, 3D digital models can be created in 2 ways:

1. Construction of a digital model using software on a computer.
2. Capture of morphological information using specific equipment and processing in computer environment.

The construction approach, also called procedural modelling involves a process of preparing geometric data for computer graphics. The capture approach involves equipment which is able to record the shape and possibly the texture of an object. Post processing software is then used to process the data for the purposes the 3D model is created for, which can be varied, see section 7, Applications.

5.1.1 Construction

The creation of 3D models from scratch, or so called digitally born objects, is achieved by combining basic shapes such as boxes, spheres and cones. Software uses data to create virtual 3D environments, such as in computer games, and this technology can be used to create a model of a 3D object. There is a possibility that the models generated as part of the Partage Plus project (using the capturing technology), will be incorporated into these types of construction software when used for further applications, although further discussion of this falls outside of the remit of this report.

3D models can also be created using proprietary and open source software packages. The table below demonstrates a number of the current programmes available, without any bias, categorising them into commercial, open source and free software:

Proprietary (commercial)	Open source	Free
3Ds Max (Autodesk	**Blender** (Blender Foundation)	**MeshLab**
AC3D (Inivis)	**CloudCompare**	
LightWave 3D (NewTek)		
SketchUp Pro (Trimble)		
ZBrush (Pixologic)		

A more detailed overview of the software available can be found at:

- http://en.wikipedia.org/wiki/3D_computer_graphics_software.

Although it is possible to implement these programmes 'in-house', using this kind of software can require skills and training. A program often used within the cultural heritage domain is open source software called Blender. Blender has combated this issue by offering workshops, providing user groups online and additional resources for users.

5.1.2 Capture technology

To collect data from a 3D object, capturing technology is most often used in the cultural heritage domain. This method uses optical technology to gather information about the shape and texture of objects. There are many different types technologies, which will be discussed in this section which range from built in scanning devices or scanners to digital cameras.

5.1.2.1 Laser scanning

Technology

Laser scanning is a technique where a laser beam scans the surface of an object. The beam is pointed in a specific direction and the distance of the scanner to the point where the beam touches the object is calculated.

There are several specific types of laser scanning, depending on the purpose, such as using mirrors to deflect the laser beam. Laser scanning enables the scanner to vary the intensity, colour, number of beams and light patterns (e.g. fine lines or wider lines, see Figure 5). An advantage of laser scanning is that it can give accurate results for measuring, although the resulting data does not contain information on the colour, surface or texture of an object. This information can be added afterwards by manually warping digital images round the 3D model.

Applications

The range in application of laser scanning varies from small objects to large structures, heritage sites or buildings. Each type of application uses a specific type of scanner and technology.

Laser scanning is most commonly applied on large scale objects for the control and checking of dimensions and deformations. In particular industries such as the automobile industry and car tyre manufacturers, who favour this method due to its accuracy. Terrestrial laser scanners form a specific sub category of laser scanners and are used predominantly in archaeology, geography and biology. These scanners are able to scan large sites and surfaces, generating a digital replica of the site. The typical output of this type of scanner is a point-cloud which can be developed into 3D models using specific software. The images below illustrate The Discovery Programme, a state funded Irish Institution whom adopted this approach, scanning some of the historic and prehistoric sites in Ireland.

Figure 3: Typical terrestrial laser scanner

Figure 2: Preparations for scanning Pounaborn Ireland. © The Discovery Programme

Figure 4: A result: Glendalough, © The Discovery Programme

5.1.2.2 Structured light scanning

Technology

Another method of capture is using structured light technology. This is where a line or a pattern of light is projected on a three dimensional object. The line or pattern is consequently distorted and these deformations can be recorded by a camera. A computer then uses this data to recalculate and reconstruct the shape of the surface of the object.

This type of scanning is used in the Partage Project, where both the Artec 3D and SO’s Comet use the structured light technique.

Applications

As structured light projects a pattern on the object and calculates the shape from the distortion of the beam, this type of capture method is limited to the studio environment. In this environment it can be used on a variety of shapes and materials, provided they are not, transparent or reflective for example.

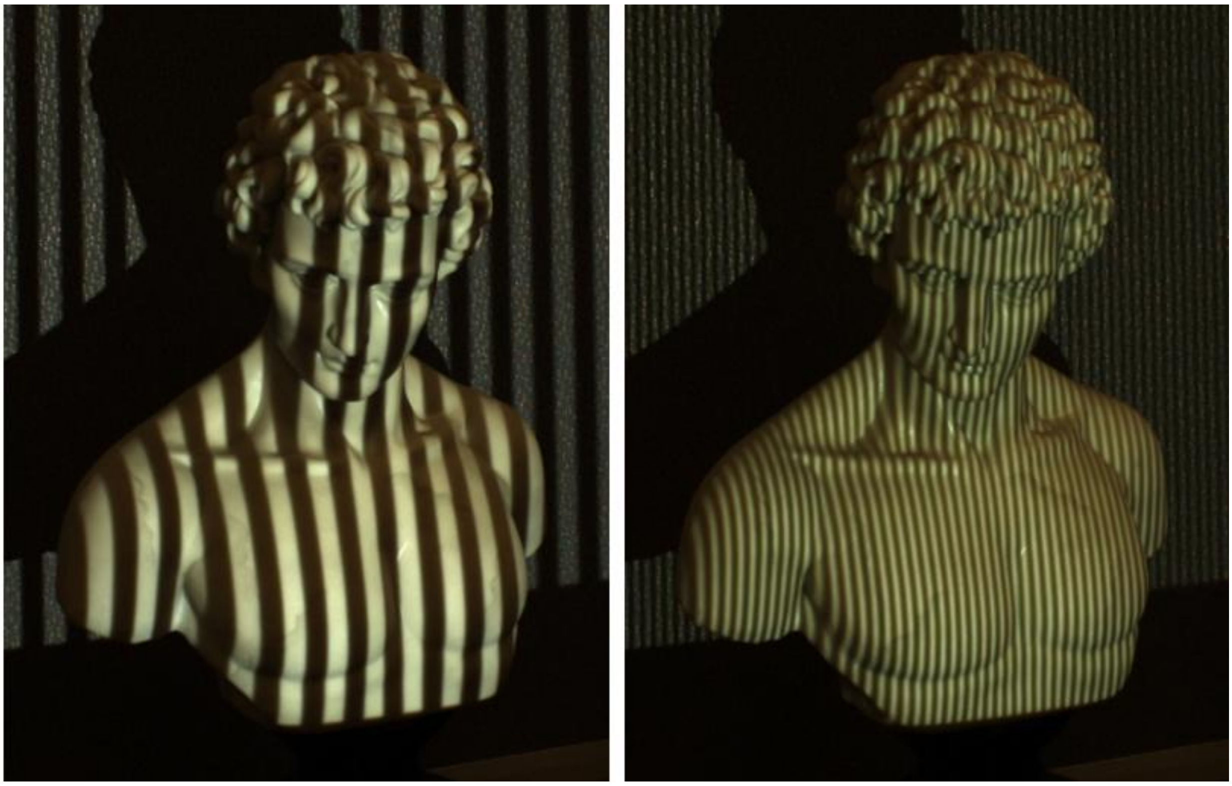


Figure 5: Structured light. © Brown University.

5.1.2.3 CT scanning

Technology

Computed tomography (CT) scanning is often found in medical applications. This technique combines x-ray images into a single object. The key feature of this type of scanning is that it produces a 3D model of the outside and inside of an object. As the equipment to produce such images is often only found in the medical environment, the hardware can be costly. Despite this, there are many examples of cultural heritage institutions using hospital equipment out of hours to scan their objects.

Application in cultural heritage

This method is often used for any object of which it is necessary to know its inner construction. An example of this is The Musical Instruments Museum in Brussels, who used a hospital CT scanner to scan musical instruments and generate information about the construction of the instruments. A common use of this scanner in cultural heritage is in scanning mummies.

5.1.2.4 µCT scanning

Technology

This method, also called Industrial CT scanning, uses the same technology as CT scanning but in a higher resolution (microns). Applications are mainly industrial and the equipment used is often smaller than CT machines used in medical institutions, this technology can be even more costly than regular CT scanning.

Applications

The best results are achieved when scanning small objects such as insects or seeds (see image below):

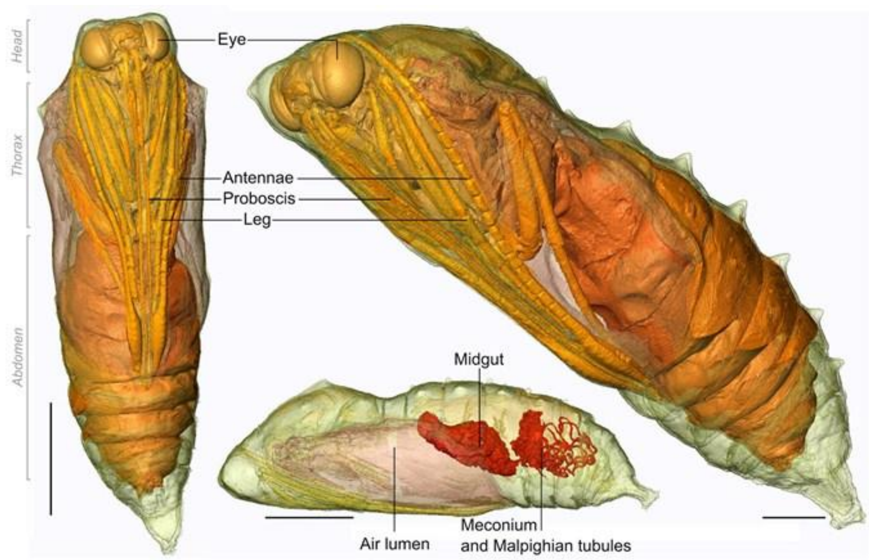


Figure 6: V. cardui chrysalis at day 16 of development, showing many aspects of adult butterfly anatomy. © Journal of the Royal Society Interface.

5.1.2.5 Photogrammetry

Technology

Photogrammetry requires an image recorder (e.g. digital camera), a computer and software to process the data. Photogrammetry is relatively cheap because often cameras and computers are readily available. The advantages of Photogrammetry are:

- The texture is captured as well;
- Currently little to none specific knowledge of 3D modelling is required. Online solutions like 123D and Arc3D are available that enables the user to upload pictures which are processed on the provider's network. The result can then be downloaded by the user.

The only useful requirement when using this technique is a good understanding of photography, lighting and background, as well as a little understanding of an image manipulation software like Photoshop. Research from Partage Plus enables the following recommendations to be made for organisations who wish to start experimenting with 3D model creation:

5.1.2.5.1 *Photomodeler Scanner*

Photomodeler has been used for simple geometry extraction of 3D models and works well, although it can be a complicated piece of software and the advanced aspects e.g. the scanner were not explored in this project. Despite its name, the scanner function is not a piece of "external hardware"; it is part of the software that scans from existing photos. The scanning then generates a point cloud which creates a visualisation from a very high number of polygons, which can be an issue although but both Photomodeler and 3Dsom feature tools to help with polygon reduction.

5.1.2.5.2 *3Dsom*

To use 3Dsom, a (small) object is placed on a mat and a series photos of photos are taken of the object to build up a 360 degree image of the object, the software then builds a model from the photos. This project found that it is advisable to have a studio setup when using this method to ensure correct light placement and white background, as this can affect photo quality. An issue with this technique is that if there are reflective surfaces in the photos it can cause problems. A specific version of the software (3.2) allows the user to model large objects without a mat by placing "pins" on the photos and matching them up to generate camera positions.

5.1.2.5.3 *Agisoft Photoscan*

Agisoft Photoscan is a recent development from Russia. The program is easy to understand and has useful tutorials and forums which can be found online. Agisoft Photoscan provides useful feedback in the way the photographs are used to build the 3D models and offers several functions to include or discard individual images.

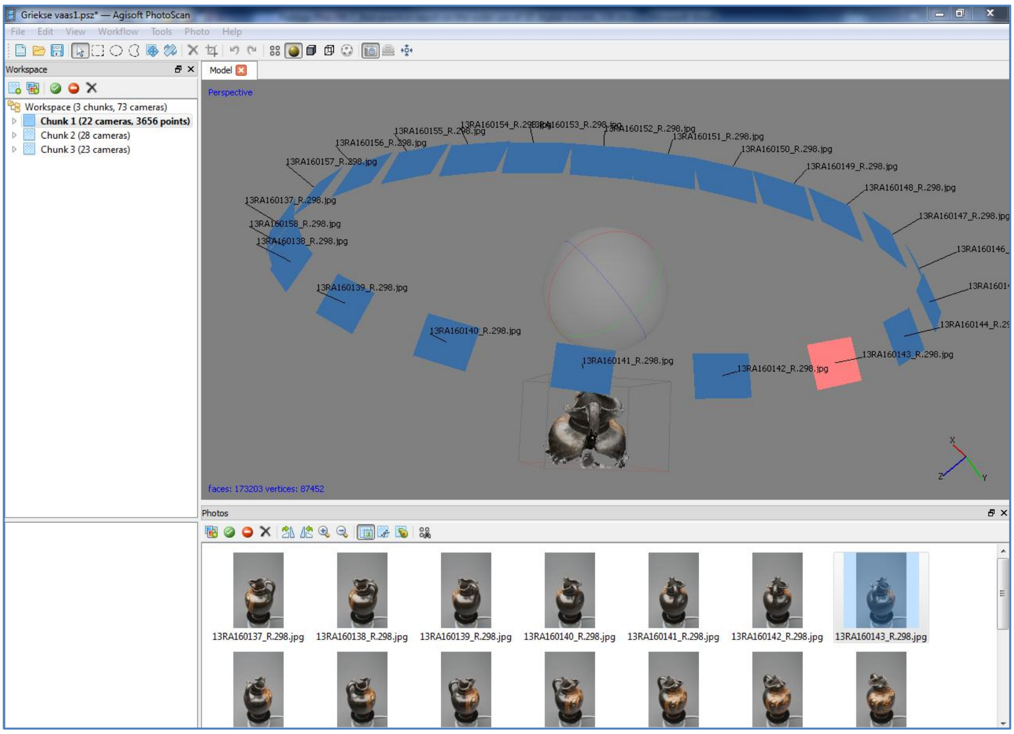


Figure 7: Agisoft Photoscan

5.1.2.5.4 *Arc3D*

Arc3D[4] is a web service and development form KU Leuven, partners in the EPOCH project and subsequently the 3D Co-form project. The user prepares a series of photographs which are uploaded to the KU Leuven servers and then processed. The user receives a message when the 3D object has been created, and can then download the results. The service is currently operated by the VISICS group at KU Leuven and is a non-commercial initiative, available free of charge.

5.1.2.5.5 *123D by Autodesk*

123D[5] is an online service for creating 3D digital objects similar to Arc3D. The user can upload a number of pictures which are then processed on Autodesk's servers, making the result available to the user. It is interesting that Autodesk positions 123D as one of a series of applications, of which each addresses a specific aspect of 3D technology such as printing or creating mash-ups (remixes) of several models. An advantage of 123D is the strong links to 3D printing, through its sponsorship with i-materialise[6] (a Belgian 3D printing services provider) and offering a direct link to the service for free, non commercial use.

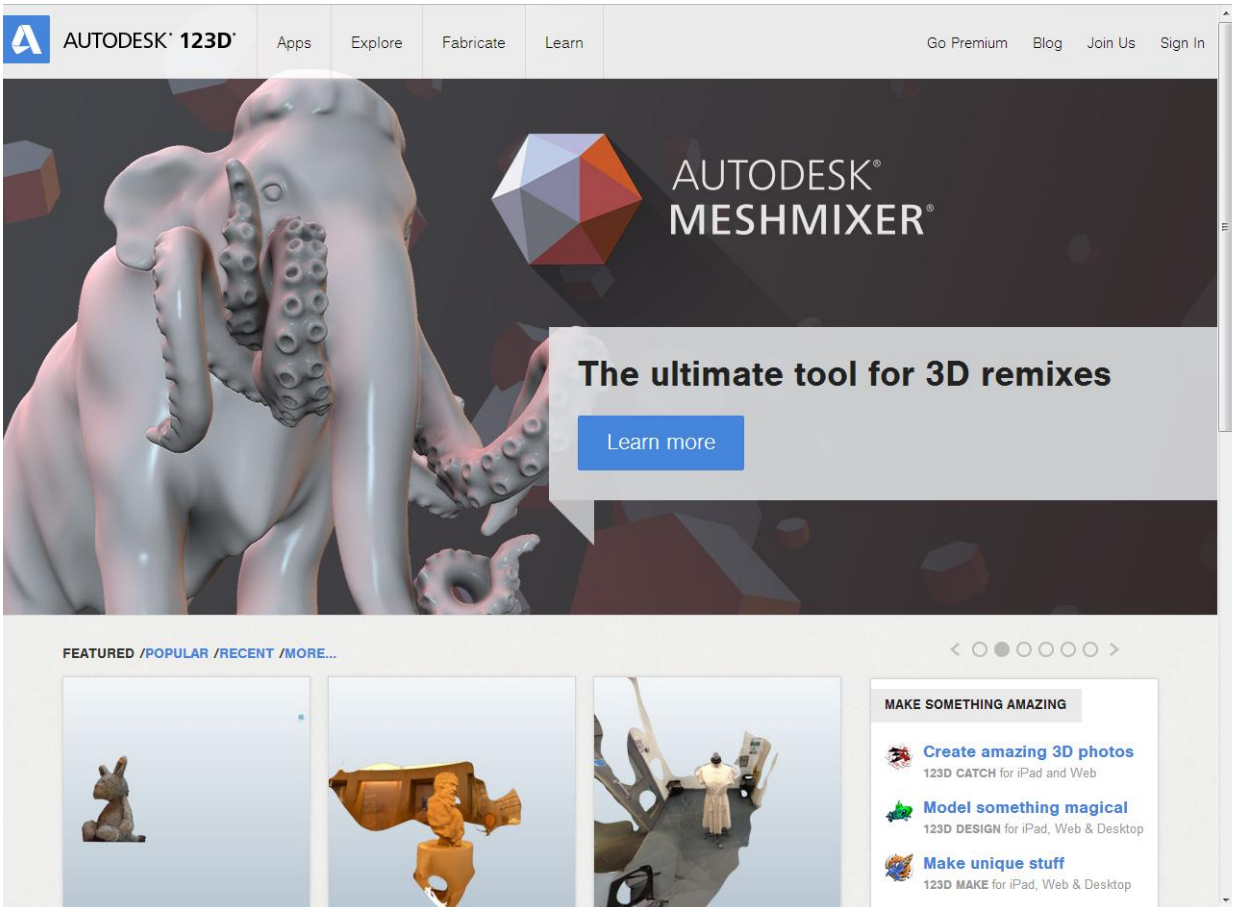


Figure 8: The Autodesk 123D web page, focussing on applications. Note the elephants' tusks.

5.1.2.5.6 *Kinect*

Kinect uses sensing technology and can be used to create a digital image of an object. It originates from a motion sensing input device developed by Microsoft for the Xbox 360 video game console and Windows PC's, enabling users to control and interact with the Xbox 360 without the need to touch a game controller, using gestures and spoken commands.

The technology used by Kinect has been adopted by a number of companies who use the sensor in combination with software, as a scanning device. As the resolution is about 1 mm, this application works well with larger objects.

5.1.3 Model quality

As with all the techniques described, the aspect of quality is an important end result. In this part several aspects that influence quality are discussed.

5.1.3.1 Incompleteness of scans

3D scanning is an optical process; this means the scanning equipment needs to “see” every part of the surface of an object in order to generate a complete scan. Sometimes it is impossible to cover the complete surface of the object and there are several reasons why this can occur:

- One surface blocking another surface;
- Object has cavities or folds;
- Sections of the surface are difficult or impossible to scan with regards to their optical characteristics, such as:
    - Highly reflective materials like polished metals;
    - Transparent components such as glass or gems;
    - Surfaces which do not reflect the emitted light probe.

5.1.3.2 Inaccuracies in 3D models

Although 3D technology claims to be highly accurate, it is not always the situation. Data gained from image capture is presumably as accurate as the equipment can currently deliver, however when generating models, there may be some misinterpretations which may lead to an inaccurate representation on the object.

5.1.3.2.1 *Scanning Resolutions*

Laser scanners work with either resolutions or a number of reference points, whereas a digital camera works solely on resolutions. Resolution is one of the elements that define the accuracy of a recording and when reproducing objects in cultural heritage, scanning resolutions should be significantly less than 1mm. However this is different when scanning buildings or sites, in which a lower resolution is usually acceptable. Despite this, a resolution should be decided upon by assessing the purpose of the scanning in combination with the budget.

5.1.3.2.2 *Deformation in post processing*

In post processing recorded data, the software will sometimes make assumptions which may be incorrect about the source object, as the image below illustrates. This can take some time to correct, although it is possible to resolve these issues during the post processing process.

Figure 9: Deformation of bottom of object by Photoscan

5.1.3.3 Colour

Systems or methods for controlling the accuracy of colour such as those used in the 2D printing industry have not yet been developed in the 3D scanning environment. As previously discussed, in laser scanning often the colour texture of a model is added in a separate step. Sometimes this is a manual process, linking specific points on a photograph to specific points on the 3D model, known as ‘warping’, or sometimes the scanner automatically records and aligns the colour information. The accuracy of the colour of a 3D model depends on the quality levels defined, the material and technology available and the skills of the personnel.

5.2 Processing

Processing the acquired data is the second step in producing a digital 3D model. The acquired data point cloud or mesh needs to be processed in order to create a model which fits the purposes of the scan. For example, in industrial applications where the control of the dimensions is more important than colour, colour is often of no significance. In the cultural heritage sector however, colour is often of more importance. The previous section has outlined the growing number of applications that are currently on the market for scanning and producing 3D scanned data, however it is still important to discuss software which is specifically tailored just to process this information and create a 3D model.

5.2.1 File formats

In this section some of the most commonly used file formats for object data are discussed. The large number of options is typical of the current technological climate, with many different formats and standards. An additional development that is currently on the horizon is the introduction of HTML5, which will open up possibilities for online display of 3D objects, as they can be integrated in a webpage.

The distinction between proprietary and non proprietary (private companies and open, free to use standards) is often unclear, as often formats evolve from proprietary to non-proprietary. This section has chosen to select the formats most commonly used and discuss them.

5.2.1.1 Obj

The Wavefront .obj file format is a standard 3D object file format created for use with Wavefront's Advanced Visualizer and available for purchase from Viewpoint DataLabs, as well as other 3D model companies. Object files are text based files supporting both polygonal and free-form geometry (curves and surfaces). The Java 3D .obj file loader supports a subset of the file format, but it is enough to load almost all commonly available Object files. Free-form geometry is not supported by this file type.

The Partage Plus project uses this file type for long term preservation.

5.2.1.2 PLY

PLY was developed by Stanford graphics lab and is also known as the Stanford Triangle Format, in addition to Obj format, PLY allows grouping by adding keyword functions, like property and elements. As cultural heritage 3D capture is a self-contained process, there is no advantage to use this format.

5.2.1.3 3D PDF

3D PDF is currently one of the most used formats for distribution of 3D models via the internet. The origin of 3D in PDF format was its use in technical documentation and manuals, which often contain diagrams that would offer more information and insight if they could be viewed from different angles. The 3D PDF functionality also offers the possibility to access and control views on the object through hyperlinks. 3D PDF has several advantages which make it a good candidate for a 3D platform today:

- The file size remains relatively small, which allows for quicker download/access time;
- The models can be accessed with Acrobat reader, software commonly installed on end-user systems;
- The 3D object comes in a container (the PDF document) which offers functionality for manipulation of the object on screen and interaction with text.

Although 3D PDF has many advantages, particularly its accessibility, one big issue is that at present it is difficult to print the object from within 3D PDF. In 2010 Adobe moved their 3D activities into a separate company called Tetra4D, it is still unclear about the future developments of this technology under the new company.

The Partage Plus project uses this file format to display the 3D models online.

5.2.1.4 U3D

U3D (Universal 3D) is probably the most widely known standard for 3D computer graphics. Developed by a consortium amongst which Intel, Boeing and Adobe feature, it has been standardised by ECMA International in 2005 under Standard ECMA-363[7]. Like all formats discussed here, it is a compressed format, mainly intended for the promotion of 3D, manufacturing, construction and industrial plant design. The focus is on data exchange and the format is closely linked to 3D PDF, some versions of Adobe Acrobat support U3D as a format to prepare 3D PDF documents.

5.2.1.5 E57

Although much has been made of the lack of a non-proprietary file format for 3D data, recent developments propose a solution with the E57 format. If one wants to losslessly convert from one proprietary file format to another, E57 can be used as the intermediate file format. E57 is not designed to be a working format, nor was it designed to be an archival format. The file format is specified by the ASTM, an international standards organization, and it is documented in the ASTM E2807 standard. The E57 format was developed by the Data Interoperability sub-committee of the ASTM E57 Committee on 3D Imaging Systems. It is not clear yet if E57 will be widely adopted by industry.

5.2.1.6 STEP

Step is a file format used in the manufacturing industry. It describes product data for manufacturing and therefore is not taken in to account in this overview.

5.2.1.7 HTML5

HTML5 will probably have a major influence on opening up access to 3D cultural heritage, as it will incorporate functionality for displaying 3D in web browsers and mobile platforms. Before HTML5 has been was very difficult to display 3D directly on a website unless there was considerable programming capacity available. This is the main reason why Partage Plus chose to use Adobe 3D PDF's.

5.2.1.8 File Conversion

Without leading standards yet, there are many different file formats in 3D. As a result, file conversion may be required in order generate files in the appropriate format. The possibilities for conversion from one file format to another are limited or not offered by most software solutions. Therefore it is worthwhile considering the process of file format conversion into account during the early stages of planning when producing 3D models.

If file conversion is needed, there a couple of tools available:

- Babel3D[8], an online conversion utility on subscription basis;
- PDF3D[9] (not from Adobe) offers a range of solutions when converting from one file format to 3D PDF (Adobe products are rather limited in the number of input formats for 3D PDF creation).

5.3 Output

There are many ways for displaying 3D models within the digital environment. However all of them must provide a way that enables the user to manipulate and move the 3D model on the screen, allowing them to look at the model from different angles, zooming and panning.

5.3.1 Projection/display

Display on screen is currently and will continue to be the most used method to access digital information, whether alphanumeric or graphical. 3D technology requires specific functionality in the display systems, and this is discussed below:

5.3.1.1 Desktop and notebook computers

In most cases 3D models are processed and generated using 2D screens of a typical desktop computer or workstation. Since the processing requires ample computing power and storage space using specific viewers, the 3D experience can be enhanced by using video cards which are able to produce a 3D image on a 2D screen. The user needs specific glasses to see the image in 3D.

5.3.1.2 Mobile devices

Mobile is evidently changing the way we live, talk and communicate. In 2010, Steve Jobs announced that the industry is moving towards 'post-pc' era and projects findings also point to this conclusion.[10]

Today mobile devices often lack the computing power for processing the large amount of data that comes with 3D models. If devices can display a reduced version of 3D files, mobile devices can open the possibilities to include 3D models in museum applications such as guided tours or educational programs. Moore's law[11] governs here as well as everywhere in IT.

5.3.1.3 Immersive systems, caves, glasses and helmets

These systems are often used in more complex research and simulation areas such as augmented reality. There are however a number of initiatives which brought these kind of systems to culture heritage institutions. In most cases, this implementation was done in caves where the public are able to interact with the 3D models on display. Such systems are used at the Foundation of the Hellenic World, Athens, Greece and The Allard Pierson Museum, Amsterdam.

5.3.2 "Hardcopy"

The combined use of 3D scanning and 3D printing technologies allows the replication of real objects without the use of traditional plaster casting techniques. Using a traditional plaster casting technique requires covering the original object with the material the mould is made from and can be considered dangerous for the conservation of the object. Through using 3D printers and scanning, cultural heritage organisations are now able to print copies of the object to create a 3D replica without damaging their collections.

Recent years have seen a surge in the number of 3D printers being introduced inside and outside of the sector. Printers vary in varieties and technology, with the price range starting at about € 1500, for entry level printers designed for the enthusiasts market. It is interesting to note that quite often 3D printing is associated with the more social part of the internet, with for example 3D HUBS, a website where printer owners can offer their printing capacity to those who have an object to print. See 7.2.4.3 for more on 3D printing.

6 Preconditions

6.1 Metadata

As with all digital assets and especially in cultural heritage, metadata is required about a digital object to enable access, in particular with relation to identification and classification. The past years have seen a surge in the integration of metadata, with Europeana as the catalyst. Within the ICOM environment, under direction of Partage Plus partner UNIMAR, LIDO has been developed as a method to describe objects. Within the European Commission project environment, many consortiums have contributed to the possibilities of bringing metadata together and exploring them in multiple languages.

The CARARE project produced specific metadata standards for 3D, of which the CARARE metadata schema[12] contains specific entries for the documentation of 3D models. Although the project has now ended, the work of the project is continued within the 3D-Icons project, where the CARARE standard is further developed in to the CARARE 2.0 Metadata standard.

6.2 Intellectual property

A feature of 3D models is that they can be reproduced quite easily provided they are delivered in a format which allows for reproduction, something that is not always desirable within the cultural heritage domain. Adobe 3D PDF offers a solution, providing strong protection of the model or parts of it. Here the original application from Adobe provides means for an interactive document with a solid protection of the information contained in the file.

With applications and technology continually developing, 3D models are likely to gain wider use on the Internet, which also increases the possibilities for misuse. 3D technology, having some of its roots in reverse engineering, opens up the possibility for those who want to create copies using 3D printers, or on a larger scale, to use the information contained in the 3D digital models for producing moulds out of which a larger number of copies can be produced. Current technology allows for the shape of an object to be reproduced far more easily than the texture; as a result, this means that although replicas could be made, they would still be tangibly different from the original. However this is still an important issue to recognise as it can be expected that in the near future the challenges of applying texture to an object will be overcome. As the number of websites offering 3D models grows, so will the amount of content they offer. The research conducted has also found that most of these sites also offer mechanisms allowing the provider of the model to select a certain level of IPR which is conveyed to the user through its metadata.

Thingiverse[13], one of the websites offering 3D models, proposes Creative Commons as a means to share and protect 3D models. The use of the internet to offer and exchange 3D models is a new market, where new business models are being developed and little knowledge of the benefits of this are currently known, however this is being explored in cultural heritage, for example at the Art Institute in Chicago who have put a small number of their models online at Thingiverse.

It appears that many museums, who offer their 3D models online, do so under a creative commons non-commercial license. It is up to the provider of the model to protect the data from being misused or abused and these museums only act as an intermediary.

The 3D PDF format, supplied by Adobe and used by the Partage Plus project and Europeana to display 3D models online, is very difficult to use as source for any output other than on a screen. As a result, the limited resolution and PDF's inherent protection mechanisms make it hard to employ 3D PDF for other application than display online. It is also worth noting that as a 3D object visualisation is a new work, the creator of this is the owner as they made the work.

6.3 Preservation of digital information

Digital preservation involves many activities which are necessary to enable continuous access to digital content. These activities include "collection, description, migration, and redundant storage."[14] A 3D digital model can be regarded as a snapshot of the morphologic characteristics of an object at a certain time and this information can be useful for present and for future information. It is therefore paramount that digital information gained from 3D scanning is preserved.

In the short term, information gained about an object at that moment in time has value with respect to the time and effort put in the creation of the model (selection, preparation, scanning, post processing) and the state of an object at that point in time, which is a considerable investment. In the long to very long term, the models can be regarded as a digital copy of the shape of the object and be used for preservation (see 7.2.1). Considerable effort should be made to ensure that digital information is accessible and useable in the future. It is important to maintain a stringent back-up policy and also safeguard proprietary file formats and applications, as they often depend on one another. It is also important to ensure that files produced 20 years ago are still accessible via today's versions of the software. A short introduction on Digital preservation can be found on Wikipedia and further discussion of suitable file formats can be found in section 5.2.1.5.

6.4 Ethical aspects

Authenticity is an important issue within cultural heritage, if a copy is used instead of an original object, then it is widely accepted that the public should be made aware. However, there are examples where this is not the case, for example, is a 19th century plaster cast of a Greek statue not an original itself? There are museums, such as The Museo Hendrik Christian Andersen in Rome, that only display the work of this kind. This therefore demonstrates that the public can be accepting of the use of replicas, providing they are properly used and or explained to them.

An example where replicas have been used instead of an original object is the exhibition of 3D printed Van Gogh paintings in the Van Gogh Museum, produced using the Relievo system. This so called Relievo[15] system is based on a process called Reliefography. The system, a combination of 3D scanning and high resolution printing and is developed by Fujifilm Belgium. In this instance, Relievo produced high quality 3D prints of the original Van Gogh paintings. The museum argues that the "Size, colour, brightness and texture are reproduced as accurately as possible to create a full-scale premium 3D replica of a Van Gogh painting. The final result has been approved by the curator of the museum." The Van Gogh Museum sees some interesting new possibilities, "The museum intends to generate extra revenues and to find new target groups with this new generation of reproductions", "In addition to selling the product, it is also meant for educational purposes. For instance, segments of a Relievo are used in the *Van Gogh at work* exhibition." It is interesting that the museum chose to use segments in the exhibition, immediately informing the audience that the object in question is a replica.

Figure 10: Relievo Print of the Sunflowers by Van Gogh: Van Gogh Museum, Amsterdam

Figure 11: Relievo Backside Detail of 'Sunflowers', Van Gogh Museum, Amsterdam

From this research, this report concludes that, it can be argued that it is likely that the public will accept replica, providing:

- They are properly informed about the use of a replica;
- Possible deviations on the replica are explained.

7 Applications

7.1 2D still images

2D digitisation is currently the most common approach to museum digitisation. Many projects and initiatives use this approach when documenting the world's cultural heritage. Europeana, the European portal for cultural heritage predominantly displays objects depicted in 2D, and it can be argued that 2D digital images can perform many of the functions of a 3D digital model. However, often the additional third dimension means that 3D models perform this function better. A main barrier for the use of 3D technology is that it is still relatively new, whereas 2D digital technology has matured over the past 25 years. 3D has also evolved from developments in 2D technology; relying on computing visualisations on screen. Through innovations in 2D technology it is now possible to develop applications based on photogrammetry like Photoscan, and therefore it is vital to acknowledge this relationship between the two formats.

7.2 Cultural heritage disciplines

The section below highlights some examples of 3D technology applications within the cultural heritage sector. The examples of applications are presented according to their respective disciplines, although in reality, projects often cross over a mixture of disciplines (e.g. Sgrafitto, see 7.3.2).

7.2.1 Conservation and preservation

Three-dimensional information of an object, combined with accuracy which can be as accurate as µmeters (for example 0.018mm for Steinbichler COMET L3D 8M) makes a 3D model useful for several activities within conservation and preservation. A particularly beneficial use is to monitor objects over a period of time to check for any degradation or damage and to highlight any conservation issues.

7.2.1.1 The theft and restoration of Rodin's thinker

An example of how 3D technology has been applied in this area is in the reconstruction of a cast of the Thinker by Rodin. This statue was stolen from the gardens of the Singer Museum Laren, the Netherlands in 2007 and severely damaged by the thieves. In an attempt to sell the sculpture for scrap metal, thieves tried to dismantle the object using a grinder. The police, upon finding the sculpture, returned it to the museum and a process of research began to restore the object. They found another plaster model of the sculpture in the Musée Rodin, Paris and this model was then scanned in 3D. The damaged parts of the statue were re-cast using moulds created on basis of the 3D models and any damage done by bending and hammering could be repaired based on the information obtained from the scans.

Figure 12. Rodin's 'The Thinker' after the mutilation 17 January 2007, C-print, 2007, Singer Laren

Figure 13: Rodin's 'The Thinker' after the restoration, Auguste Rodin, De Denker, ontwerp 1881, Singer Laren Beeld © Singer Laren/Kees Hageman Gert Jan Kocken (1971)

7.2.1.2 The resurrection La Madonna di Pietranico

Another example is from Italy, when an earthquake destroyed the iconic Italian statue La Madonna di Pietranico, in 2009. Conservators harnessed the power of technology to scan fragments from the statue and piece together a virtual reconstruction from the jigsaw puzzle of remains. Using this knowledge they could then undertake the difficult task of rebuilding the statue of the Madonna and repairing its surface. The 3D scans helped to analyse traces of the original layers of colour, while 3D models provided shape and form for the creation of new internal supports. Working together, conservators and technologists achieved a remarkable restoration.[16]

7.2.2 Scientific research

Researchers often want large quantities of data, or in the case of cultural heritage, access to many objects or large collections. Although there is no substitute for the real object, 3D models may be able to provide some of this information and allow objects to be studied remotely, enabling researchers to approach their subject from other angles.

7.2.2.1 Dispersed collections.

Over time, some collections have been dispersed amongst several cultural heritage institutions. When research requires access to collections, the creation of digital copies may help to facilitate access, prevent damage and reduce cost as the original objects will not have to be moved. Providing that the correct method of digitising is chosen, it is possible for organisations to provide access to this detailed information in 3D online.

7.2.2.1.1 *Glypcol*

An example of this is the Glypcol project, where collections from several institutes were scanned locally and combined in an online database. At KMKG clay tablets were scanned by what is called the Leuven mini-dome. This is a transportable tabletop dome with a centrally fitted camera and in a wire frame functions as a unique light sources for a series of image recordings of an object. The recording is automatic and controlled by a computer. The different light directions each create an individual shadow pattern on the object, which is recorded and processed by a computer. The result produces a 2D image of the object, which, by using a specific interface can be lit from different angles by the user. It is a combination of several of these images that results in a 3D model. This technology enables researchers at the museum and in other parts of the world to study the collection digitally. This technology helps Assyriologist to read and interpret cuneiform tablets and seals on clay tablet much more efficiently then studying the original object.

7.2.2.2 Interpretation

3D technology, through its ability to be very accurate in three dimensions, can enable a better understanding of construction and provenance. An example of this was carried out at the Musée du Louvre in Paris, where they used 3D technology to compare three glazed ceramic vases. Experts at the department of Islamic Antiquities knew that one, the Rifaat vase, was produced in Granada, Spain, during the 14th or 15th century and they aimed to show that the two other vases came from the same mould as the Rifaat vase. By aligning the 3D models of the middle portion of the vases, experts were able to test how far their shapes and sizes matched. Through demonstrating the level of similarity, the researchers scientifically measured and proved that the three vases came from the same mould and therefore, the same workshop.[17]

7.2.2.3 Internal assembly and construction

At The Musical Instruments Museum in Brussels, a number of musical instruments were scanned in CT scanners in order to visualise their interior. The information generated helped to understand the construction of these instruments. There are countless examples of mummies being scanned in analyse them internally.

7.2.3 Education

Education is an important use of 3D within the museum disciplines, offering new ways of bringing the public in contact with objects. Applications for 3D interactives seem unlimited, as 3D objects can:

- Be deconstructed and placed into a digital environment;
- Integrated into games with educational components;
- Illustrate digital reconstructions of objects or sites.

A physical copy of an artefact which can be handled is possibly the simplest way to engage the public, enabling visitors to get hands on experience of an object. As 3D opens up the possibility for museums to offer more tangible experiences, it naturally lends itself to helping to engage visually impaired visitors. This next section discusses institutions that are researching the educational aspects of 3D technology:

7.2.3.1 Allard Pierson Museum

The Allard Pierson Museum[18], the archaeological museum of the Amsterdam University focuses specifically on new interactions with the museum visitor. The museum cooperates closely with the media studies department of the University to develop new concepts for engagement. 3D digital content forms an important resource for this research.

7.2.3.2 The Museum of Pure Form

The Museum of Pure Form[19] is a research project funded by the EC and has been specifically developed as a virtual museum of digital art, exploring new paradigms of interaction with digitally reproduced cultural heritage objects. The museum applies innovative technologies that the visitors can use to interact with 3D art forms, such as stereovision, to recreate feel and touch with virtual works of art.

7.2.4 Creative engagement using 3D

Most of the possible uses of 3D have only been exploited superficially. At present, capturing technology, storage and output/display still offer many challenges and new functions and technology have seen little development. However at present in the USA, there is serious interest in large scale capture (Smithsonian Institute) and working with the results.

7.2.4.1 "Please feel the museum"

In "Please feel the museum"[20] Neely and Langer argue that the use of 3D technology can enhance the visitor experience: "Restrictions on allowing visitors to take photographs in galleries are on the decline. Whether the new acceptance of photography is due to an "If you can't beat them, join them" approach or a recognition that photo sharing is key to word-of-mouth marketing, visitors are more free than ever to take photos in galleries where the museum owns full rights to the works. At the Rijksmuseum in Amsterdam, as well as other museums, visitors are actively encouraged to document their visit by taking photographs—even of the museum's most famous artwork, Rembrandt's *The Night Watch*. Because 3D models of objects are usually formed by stitching together photographs using photogrammetry, this overall shift in gallery policy enables visitors to examine the object more deeply through the process of creating a 3D model. This also means that "Introducing the opportunity to create a full 360-degree scan, which can then produce a 3D print, allows a visitor to go deeper into the experience of the object. The time that it takes to construct the virtual model means closely scrutinizing; making mistakes and fixing them; and finally producing a finished model that can be modified, printed, shared, modified again, mashed up with other models, printed again, and so on—in an infinite process of sharing and changing, all of which can be traced and mapped."

Such approaches require substantial investment and support from the organisation in terms of technical facilities. Incidentally, the Rijksmuseum as mentioned in the quote above, have recently adopted a new policy towards the use of images of their collections more generally. As many institutions still try to protect their digital images by reducing the resolution when displayed online, the Rijksmuseum makes high resolution images available for free for non commercial use. The museum policy is that the online visitor should be able to do more than just watch, and so it offers the possibility to download high resolution images.

7.2.4.2 Thingiverse

Thingiverse[21] is a website where 3D models can be uploaded to and downloaded by the community. The Art Institute of Chicago has put a number of models online through this platform. The model is in STL format, which makes it printable, although there is no colour information attached. The models on the Thingiverse site reference the information about this artwork on the website of the Chicago Institute and challenge the public to engage with the models. The models can also combined into new models and mash ups.

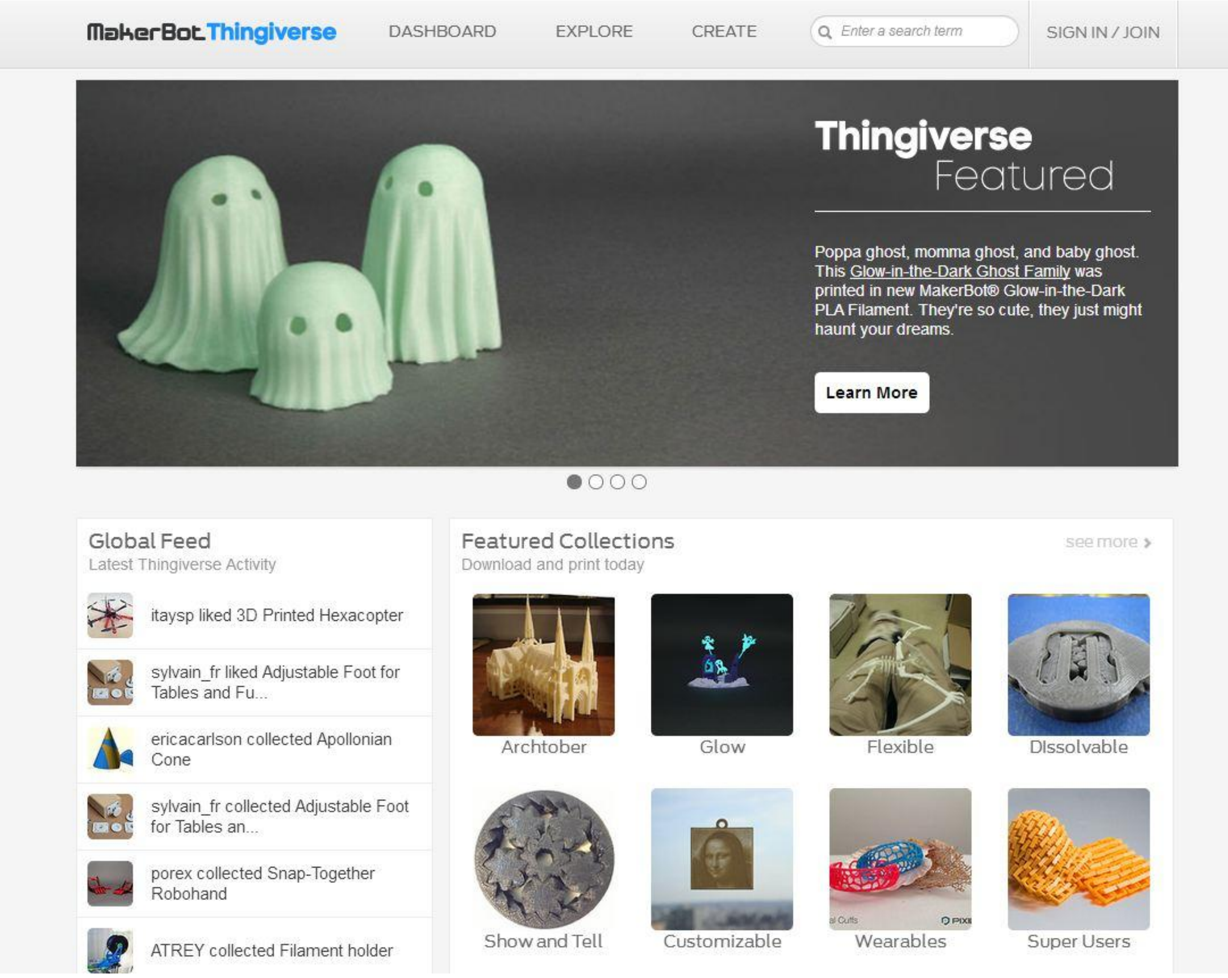
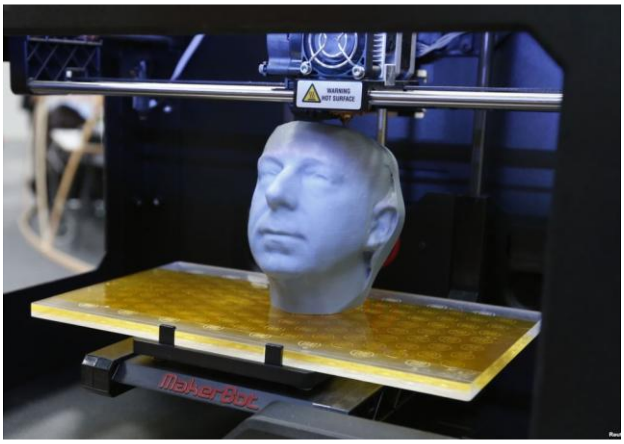


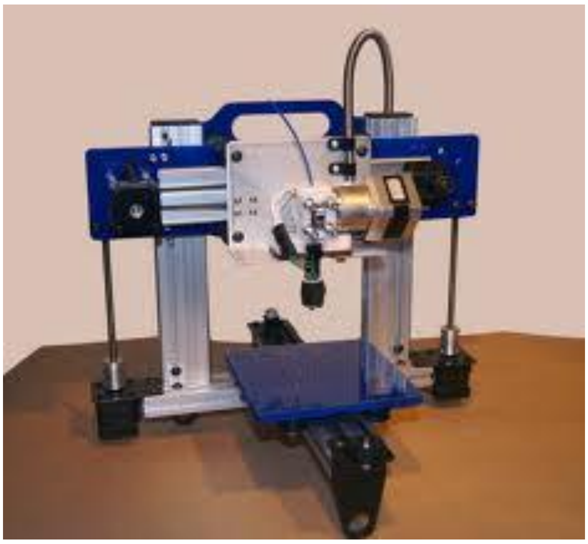
Figure 14: Thingiverse website, note that all images are 2D representations.

7.2.4.3 3D printing

In the past year there has been an explosion in the hype surrounding three-dimensional printing. There are many articles published on the impact on the economy and how 3D printing will reform the industry, such as how 3D printed parts can be perfect replacements for some parts of the human body.

Few museums have taken up 3D printing to date, either for collection or visitor/commercial related activities. Due to logistics it is likely that it may be some time before the visitor can select an object from the museum's collections and take a 3D printed copy home at the end of the visit. Despite this, 3D printing technology is developing rapidly, although most 3D printer's still use thermo plastics as a means to create the prints, other materials (mainly metals) are starting to come into the arena as well.





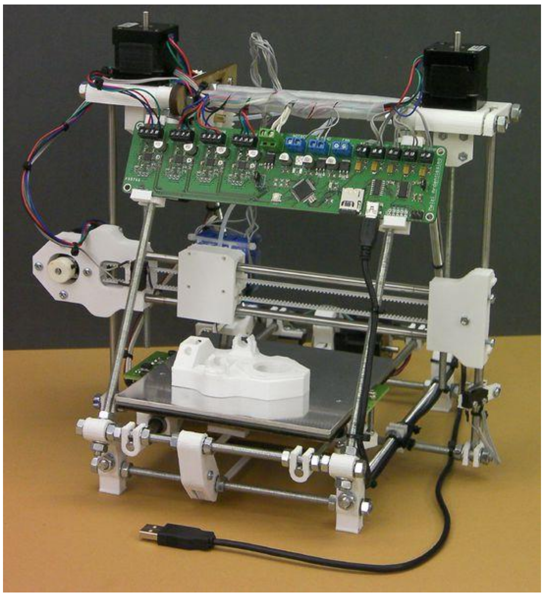


Figure 15: Examples of 3D printers

3D printing at present is not intended for or able to be mass produced. It is currently best suited for creating unique or end products, for example when objects are combined into new objects, or where scans of a person are combined with objects. In the manufacturing industry 3D printing plays an important role in the production of moulds from which copies in other materials can be produced. This can also be applied in the cultural heritage sector. The printers and applications presented above are all in the small, social networked area of 3D technology. There are also commercial suppliers of 3D printing services who are able to produce exact replicas of originals. Fujifilm have developed a technology named Relievo, which is a combination of high resolution 3D and colour printing, with which they made entire copies of some of the paintings by Van Gogh, see for more information 6.4.

7.2.5 Presentation

Although cultural heritage professionals adhere to the originality and provenance of objects, sometimes choices have to be made of if and how to put a representation or copy of an object on display. There are various reasons why replication and display might be a preferred method to displaying the original. One such reason may be that the original is not available, too valuable or very fragile, in which case the creation of a copy using 3D technology might be the best solution if the story is better told with than without an object at all. Laser scanning is a non-intrusive, non-contact process, where the object only needs to be displayed once under the supervision of the institution's staff. As a result, reproduction through a 3D printer becomes cheaper, more easily available and scalable.

7.2.5.1 The Kafazani boat

An example of such an application comes from Cyprus, where the Kazafani model boat, a unique grave artefact, was found in a tomb in 1963. Crafted from pottery in the 12th century BC, it is now on display at the Cyprus Archaeological Museum in Nicosia but it is too fragile to be moved.

Figure 16: Original (centre) and 2 copies of the Kazafani boat. 3D-Coform

3D-COFORM partners at the Cyprus Institute have been experimenting with 3D technology to see if an accurate replica of the boat could be made, which would then reach a wider audience. The boat was scanned using the Next Engine scanner, and subsequently a model created with Meshlab software. This created a digital 3D copy that was as accurate as possible in every detail. Rapid prototyping technology then produced an exact replica of the artefact. Size, shape, colours, and surface markings, evidence of past damage and previous episodes of restoration were all recorded and recreated through 3D scanning.

Figure 17: The Kazafani boat in the 3D-Cofrom exhibition. Source: 3D-Coform.

The 3D scanning process has enabled conservators to analyse the boat in greater detail without risking any damage to the original. The experiment has also shown how simple and cost effective this method of creating replicas can be, with obvious benefits for curators, education and merchandise.

There are other reasons why working with a replica would be preferred:

- It is possible to re-scale the original dimensions and create a model;
- Tangibility, it allows the possibility to touch an object.

7.2.5.2 The virtual Hampson Museum

A pioneer in the area of not only 3D scanning models but also in creating a complete virtual environment is the virtual Hampson Museum[22], Wisconsin, US. In Artefact Studies, Artefact Data and information technology, a point in time review by Rob Sands of the University College Dublin (2009:50) said, "The Virtual Hampson Museum Project is a good example of the way in which 3D data is being used both within a museum environment and potentially within a research environment." Approximately 450 artefacts have been 3D scanned as part of this project by the Center for Advanced Spatial Technologies (CAST). Access to the digital version of the collection is via an interface that is deliberately designed to look like objects in display cases. Objects can be selected by type, location, keyword or by browsing the virtual shelves. The objects are a very specific collection and the types identified are small groups of 'things' (e.g. bowls, jars, effigies, lithics) and in this sense it exemplifies a well-bounded 'problem' for which this approach provides a practical solution. Having said this, the project usefully demonstrates potential as it is not just a passive web example. All of the items on digital display can be downloaded in a number of formats including the latest 3D iteration of PDF. 3D PDF allows for the object to be explored, measured and for cross sections to be made.

Figure 18: The website of the virtual Hampson Museum mimics a museum display.

7.2.6 Commercial applications of 3D models from cultural heritage

The expectations for commercialisation of 3D technology for cultural heritage are high. (The same assumption was made at the time of writing of the proposal for the Partage Plus project). In reality these expectations are not yet fulfilled and the original purpose of this report, to present best practices on the wider use of 3D models had to be amended, because there were not any. This probably is a consequence of the relative young age of the technology, which has, as we described, not yet realised its full potential. This results in unfamiliarity and lack of knowledge within cultural heritage institutions both on a technical level (skills and knowledge) and on an application level. Despite this, this next section discusses a number of assumptions that can be made.

7.2.6.1 *Reproductions of 3D models in commercial setting*

Creating 3Dmodels can reduce the cost for production of replicas or souvenirs and widen the product range, reasons for this include:

1. The mould can be produced at lower cost;
2. There are possibilities to create moulds in a non-invasive manner, this widens the model range;
3. Scanned models for scientific purposes can be commercialised without extra cost;
4. As a result of 1, 2 and 3, it is possible to present a larger variety of objects on offer.

Unfortunately this process is more complex than simply scanning and printing the objects for commercial use. In order to be able to make reproduction of 3D models on demand profitable a museum needs an infrastructure to provide for this. This infrastructure consists of:

1. Large potential target users, as without a solid customer base and demand, the investments will not be returned;
2. Personnel capable of operating the 3D printing facility. The technology is still difficult to operate, examples of mistakes can be found online;
3. Digitise specific 3D models which:
   a. Are seen as iconic by the visitors, the objects should be aesthetic and/or representative for the event or the institution;
   b. Are economical to produce in 3D - not complex and small in size;
   c. Have been 3D scanned and processed for 3D printings. This can have been executed by qualified museum personnel or external companies with equipment and experience.
4. Marketing, based on a sound, long term marketing plan or policy. The investments in personnel costs and equipment are considerable and cannot be recouped on short notice.

At present, printing on the spot and taking away a product immediately is currently impossible due to limitations of speed in printing and complexity of the process. Museums contemplating such services should consider a model where the prints are sent to the customer after their visit, spreading the workload. It would also be an option to cooperate with networks of 3D printers, such as 3D Hubs as assuring quality in the latter setup is difficult.

Most of the challenges mentioned above are temporary and relate to the output of the 3D modelling, rather than image capture. It is certain that these practical problems will be overcome within the next few years and having a number of models ready for production would be beneficial to an organisation. Starting with the capture of 3D technology at present, the following should be considered:

1. Is the scanning technology now more matured than the output and/or printing?
2. As output technology will improve it is not a waste of money to start the creation of 3D models, both from scientific and commercial perspective. When output technology has improved, the presence of a stock of 3D models could prove valuable.

The Fitzwilliam Museum which is part of the University of Cambridge has successfully commercialised their collection using 3D, reproducing objects from their collection to sell in the museum shop. The object has been scanned in 3D, printed and then moulded traditionally to create facsimile replicas of priceless objects. The concept is realised with external partners for scanning and production of the models. Another interesting use case of commercialisation of 3D was conducted by the Discovery Programme in Ireland. While scanning the medieval town walls of a city in the UK, a 3D scan of the town gate was used to produce a mould for making chocolates. This is an interesting development, as the developers did not choose to create complex or ingenious products, but instead very simple products at affordable prices.

Incidentally, KMKG, partner in Partage Plus, still maintains one of the three predecessors of 3D model reproduction for cultural heritage, a plaster cast workshop[23]. The Plaster-cast Workshop was established in the nineteenth century during the reign of King Leopold II and houses a collection of more than 4000 casts of art dating from prehistoric times to the eighteenth century. In reproducing those works of art, the workshop's specialised craftsmen employ traditional techniques in both the casting and patination. By offering casts at reasonable prices, the workshop helps to promote the museums collection, offering smaller and larger replicas for the public to purchase. The museum also uses this unique facility as an attraction to visitors, opening up the workshop to visitors for free and offering guided tours on request which are organised by the Educational and Cultural Service of the Cinquantenaire Museum. In the future, it would be interesting to research how these traditional techniques and the contemporary digital techniques can complement each other.

7.2.7 TV & Film

As well as printed or cast models, there are high expectations for revenue generation from 3D cultural heritage models in the film and TV industry. 3D modelling is regularly used in historical dramas, and to some extent in most film & TV, in particular architectural 3D. There are some interesting examples displaying the use of 3D in the TV series, Boardwalk Empire[24]. However, in the current climate these examples demonstrate that there is little application within this sector for museum objects.

7.2.8 Games and other interactives

The big caveat with games and other interactive is that they require very low polycounts (the numbers of polygons). Consequently, it is usually cheaper to physically model an object and wrap it with photos than to decimate or retopologise scan data. However there are some cases when modelling particularly organic or detailed objects where using scan data is better. The primary advantage of using 3D is that most rendering applications can output the animation with an alpha channel or can create a model separate from its environment. As an example, it is very easy to drop a 3D model into Augmented Reality applications such as ViewAR[25]. This however is an application most commonly found in the educational environment in relation to exhibitions.

7.2.9 Use on websites

As the size of a 3D model is considerably large, often specific viewers are needed to display and manipulate them. Outside the cultural heritage sector (where the display of a 3D model is often done internally), there are few applications for displaying 3D models, for example, in tourism.

7.3 Best practices or good examples of 3D in cultural heritage

As mentioned earlier, best practices with regard to 3D technology in cultural heritage do not currently exist, particularly when assessing at the commercial viability and application of 3D models in this sector. However, despite this, this next section highlights three initiatives that have tried to address these issues and offer a more integrated and general approach to applications and best practices of 3D technology in cultural heritage.

7.3.1 English Heritage report

English Heritage in 2011 published the second, revised edition of their report on 3D laser scanning, "3D Laser Scanning for Heritage[26]". This report gives an overview of scanning techniques mainly used in scanning sites and monuments. A number of UK institutions gave evidence of their work, experiences and the equipment used.

7.3.2 Sgrafitto in 3D

The Sgrafitto in 3D project, or "Sgraffito in 3D. Late Medieval pottery seen through the eyes of Joachim Rotteveel" was a collaboration between the Boijmans van Beuningen Museum in Rotterdam, and media technologist Joachim Rotteveel, with support of several other Dutch institutions between 2008-2009. The project analysed medieval Sgraffito pottery (which used a technique of applying different layers of tinted plaster on buildings or objects and drawing in the still wet plaster) and aimed to make the collection available to a wider audience. The techniques employed in the exhibition were more varied then in the usual museum exhibition, with particular regard to the fact that this was five years ago as a direct result of implementing 3D technology. The exhibition contained elements that set an example of the integrated approach, applying 3D technology both as an addition to the user experience and in scientific research of the collection. For the general public, a number of concepts were developed with the aim to enhance the experience, these were:

- Creating an online database containing 3D models of the objects in the exhibition;
- A protagonist- antagonist approach where a 3D scanned and printed copy acted as the antagonist of the protagonist, the original. Visitors were allowed to touch the replicas and feel the shape, whilst the original was safe behind glass;
- In the Augmented Reality section virtual objects (scans of the originals) were projected into the real world, with the possibility for users populate a table with virtual objects;
- Creation of a 3D pop-up book, where a traditional book acted as an interface to display digital images, play medieval music and project texts;
- A reconstruction lab where the visitor could manipulate 3D printed fragments of pottery and receive information about their history and the objects they belong to.

As such, the elements in this exhibition are a catalogue and showcase of the application of 3D technology in exhibitions more generally. For more information on these approaches see the Sgrafitto in 3D website[27].

These image below illustrates how the innovative ways employed by this project are part of a workflow which enabled the curators both to generate the 3D information for research purposes and for public engagement:

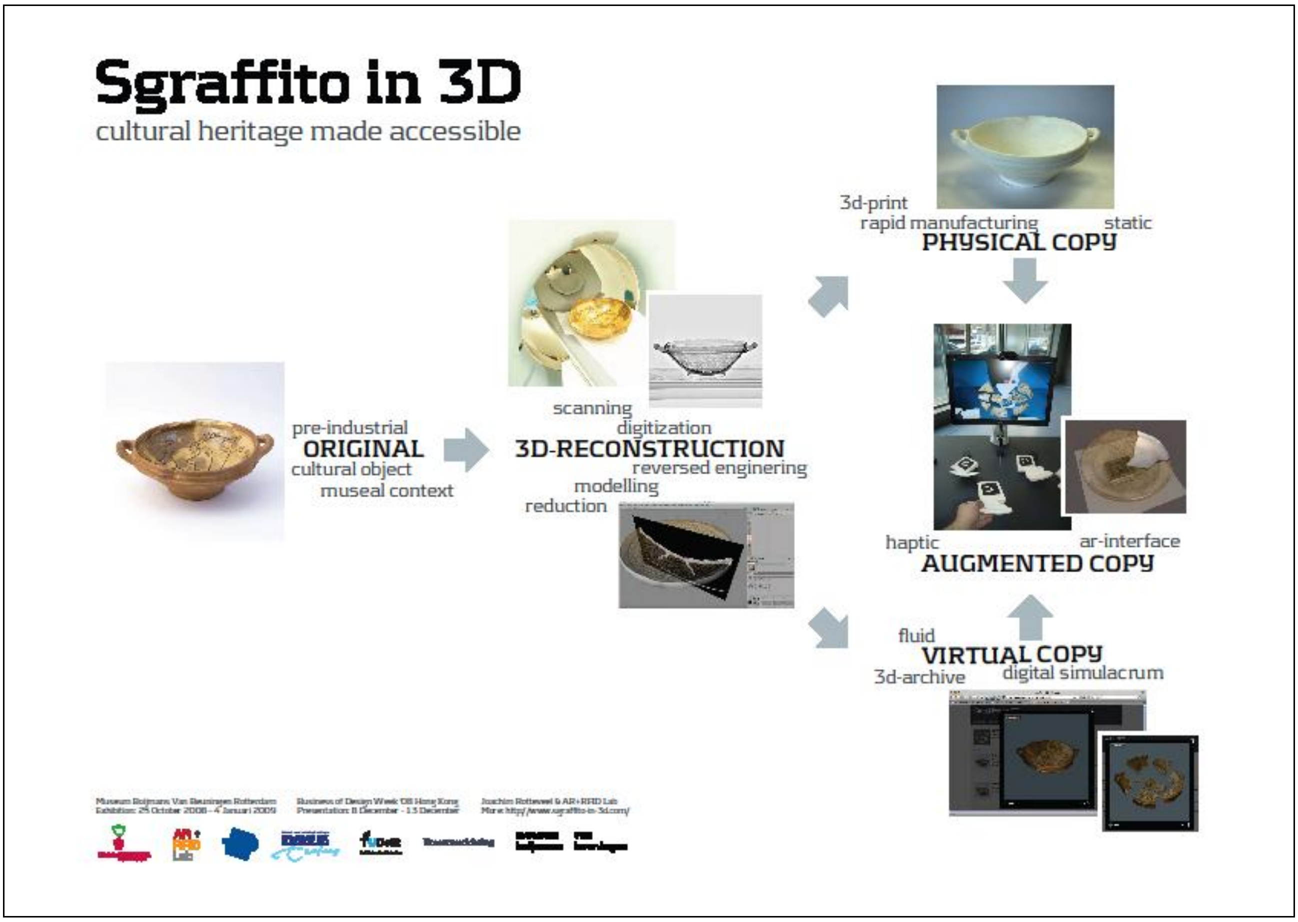


Figure 19: The Sgrafitto 3D workflow, from original to physical copy to virtual copy. © Joachim Rotteveel

7.3.3 Smithsonian Institution

The Smithsonian Institution, Washington DC is the first cultural heritage organisation to institutionalise 3D scanning and employ personnel full time on the 3D digitisation of part of its collection. A concise article[28] on the backgrounds and application of 3D scanning at the institution recently appeared on the National Geographic website. The Smithsonian Institution has chosen to apply 3D technology in almost every possible aspect of its work, such as:

- Facial reconstruction, they produced a scan and facial reconstruction of a skull which allowed the Institution to create a portrait of one of its former employees;
- Scanning statues in order to visually enhance the inscriptions. These inscriptions were difficult to decipher using traditional techniques; by 3D scanning and enhancing the cavities, the inscriptions became readable. This is similar to the application in the Glypcol project (7.2.2.1.1).
- Emergency preservation of information on archaeological or geological sites. 3D scanning is much quicker process than the traditional ways of mapping these types of sites, see also 3D Icons (12.3.5) and Laser Scanning (5.1.2.1).
- Production of a cradle which was designed specifically to support a work of art.

- Scanning of dinosaur skeletons before they are dismantled. This gave scientists the possibility to study 3D models of the skeleton and provides information for when the skeleton is reassembled.

7.3.4 The Cenobium project

The Cenobium project is a cooperation between several institutions in Italy. The project applies and combines new technologies for display in 2D and 3D of building details and components such as the capitals of three Italian monasteries. The technology applied enables the user to zoom in on details in 2D at a very high resolution. To a lesser extent this is also possible for 3D models. Both technologies are based on the concept that only data for the section being visualised on the screen is needed for display and not the entire model. The project applies the IIPImage image server[29] for streamed web based viewing, which is open source software.

Part 3: Future Use

8 Expectations

Niccolucci and Geser argued that “If we consider digital technologies helpful or even necessary to achieve today’s standards in museum operations and that a museum which does not put this technology to use is anachronistic museums should start (or continue) to make their collections digitally available” [30]. It is clear that ICT and the internet have fundamentally changed and will continue to change the way museums work. It is fair to say that as a result of this, the following three developments have happened:

1. Alpha numeric ICT created the possibility to manage museum processes more efficiently, in particular with regards to integrated collection inventories and management systems;
2. Digitisation currently carried out enables museums to digitally visualise the objects in their collections in 2D images and link them to their databases, use them for engagement such as exhibitions and education;
3. The internet has enabled museums to put their collections online; to share them, mesh them and open up the museum repositories.

A significant fourth evolution is the introduction of 3D technology. For the first time, museums are now able to use 3D technology to recreate their collections in three dimensions, giving the viewer a far more accurate and tangible experience than what can be obtained from a 2D image.

3D technology brings museums back to the age of plaster cast replicas, whilst propelling them into the future by enabling them to exist in a completely virtual environment. This is something that a small but significant number of museums are now recognising, with the Smithsonian Institution leading the way, and demonstrating the benefits that can be obtained from embracing this technology.

Although there are further developments required before all museums have the capacity to start digitising their entire collection in 3D, there are many tangible benefits that can be harnessed by museums if they choose to digitise in this way. In particular, producing a new way to research their collections, opening them up to a wider audience and investigating the potential for commercial re-use are all hugely beneficial to these organisations. It is expected that in the coming years, this technology will become more affordable and available, and there will be an increase in the number of institutions adopting this technology.

9 Short term technical challenges

As mentioned in the previous section, it is likely that in the future many more cultural heritage organisations will adopt this approach, however many issues need to be resolved and technology improved. Despite the rise in popularity of 3D, (which may give the impression that this technology is now fully matured) there are still significant challenges that must be resolved before this is the case and 3D technology will be applied widely in the cultural heritage sector:

9.1.1 Capturing colour

In almost every application, colour plays an important role for cultural heritage institutions and this still needs to be improved with regards to 3D applications. At present, most scanners can effectively capture an objects shape, however the texture is less effectively done. Capturing equipment often combines 2 devices to obtain this information, incorporating a digital camera to capture the surface or in other cases after capturing the shape of the object, the object is then photographed with a DSLR and the images are aligned manually with the shape information in specific software.

Apart from the technical ability to capture colour, the quality of the information about the colour captured also needs development. Wherein 2D printing there is control and transparency in every phase by using colour profiles, a similar approach for 3D printing does not exist, and is likely not to emerge in the near future. If 3D modelling is to increase in use it is important that these workflows are simplified into one process for capturing shape and colour effectively.

9.1.2 Reproducing colour

Reproduction of colour on a 3D model is a challenge as there are very few output devices (printers) that are able to reproduce the true colour of an object. Developments have been made within this area, such as the products produced by MCortechnologies[31] of Ireland, who produce a model using paper as a printing material which can be coloured in any colour. However, as the control over colour is still very limited during the input process, it cannot be expected to produce accurate results in the output.

Figure 20: Orange printed on Mcortechnologies IRIS

9.1.3 Display

The presentation of a 3D model on a screen is still somewhat of a challenge. 3D models are large in terms of file size, and this demands larger bandwidth and processing power which is a technical challenge that the sector has to overcome. File types such as 3D PDF’s offer a solution to this issue.

9.1.3.1 Within the exhibition environment

Displaying 3D within an exhibition environment can still be considered a challenge and may be costly. Monitors are only able to give a 2D representation of a 3D object, although there are solutions to overcome this, but these also have limitations:

- 3D monitors are expensive and only offer a good view from specific locations such as directly in front of the monitor;
- 3D glasses (green and red lenses) require special presentation of an object and glasses require distribution (and collection afterwards).
- Immersive systems, such as caves only have capacity for a small number of people at a time.

This results in 3D often being considered and presented as a gadget. It will be a challenge to integrate the use of 3D display technology into day to day museum practice.

9.1.3.2 Internet

The display of 3D models on the internet is still a big challenge, as not only bandwidth, but most web browsers are currently incapable of displaying 3D models autonomously and users are often required to download viewers or plug-ins. As there are no standards, end user may end up with many different plug-ins for different cultural heritage applications and therefore, standardisation in some extent seems necessary. Several initiatives and projects are currently working on solutions for this issue and we can expect that the release of HTML5 will help to resolve this in the near future.

9.1.3.3 Display on portable devices

The limitations for displaying 3D models over the internet are even more difficult on mobile devices. These devices do not possess the processing power of notebook or desktop computers and usually depend on wireless communication systems for transportation of the data.

9.2 Is there a need for a standard?

Research demonstrates that there is a need to implement standards for 3D modelling in cultural heritage. Although 3D modelling is used across a wide range of materials and objects, creating a standard would enable future developments, a wider use of this technology and confidence in its use. Although this is outside the remit of this report, the research gathered demonstrates that there is a need for standardising this practice, as without standards, there is no reference point for good and bad practice. Development of this standard is an issue that should be investigated further in the future as 3D technologies develop.

10 Conclusion

This report has described the current practices and the future use of 3D modelling in the cultural heritage sector, discussing the applications and expectations of this technology. By doing this, the report hopes to give practical information that is useful when starting 3D projects. The report can confidently conclude that the application of 3D technologies in the cultural heritage sector has developed significantly over the past few years and will continue to do so in the near future.

During the research for the report, it has become clear that there are no set standards or best practice at present with regards to 3D digital modelling. Although the subjects and applications in the cultural heritage environment are diverse, it is clear there is need for definition of the requirements on the underlying technologies in terms of accuracy, performance, and usability.

With regards to the capture/input part of this process, 3D technology can be considered relatively sophisticated, although colour management is still an issue. The issue with colourisation mainly hinges on the display and output part of this technology, which is still in rapid development in both display and printing, although at present there are no developments that appear to resolve this issue.

There is little doubt that 3D technology will play an important role in the future of the cultural heritage sector. This technology enables a variety of applications and approaches to increase access to the original objects as much as possible. The information captured from the digital model will remain useful for a long period of time and is particularly useful for preservation purposes. However this report has demonstrated that there is still research to be done into the commercial application of these models.

At this stage in the development of 3D technology, cultural heritage institutions could and should consider 3D scanning parts of their collections, in order to be prepared when the full potential of 3D technology becomes realised.

11 Considerations before conducting a 3D project

There are a number of considerations that an organisation should consider before it commences 3D digitisation and these have been investigated in this report. In terms of best practice, it is impossible to devise a general recommendation or approach for 3D digitisation in the cultural heritage environment at present. Projects vary greatly in their objectives, and range from the unique and fairly small to the vast, large budget projects (Smithsonian Institute). In line with the conclusion above, if a cultural heritage institution is considering applying 3D it is important to consider their motivation, budget options and technology:

11.1.1 Motivation:

As with all initiatives and proposals, motivations and goals are key to the conception and execution of initiatives regarding 3D. Therefore, organisations should ask themselves the following questions:

- What are the reasons for applying 3D technology?
- How many objects are to be captured?
- What technology would be able to accomplish the goals?

11.1.2 Technology

The same approach should be taken when choosing the appropriate technology, organisations should ask themselves the following questions:

- What will be the main use of the 3D model information?
- Are exact dimensions important?
- Is accurate colour and texture important?
- Will they be printing in 3D?
- What are the dimensions of the object/subject?

11.1.3 Budget

Budget must also be addressed as 3D is fairly costly, both as an initial investment and within personnel costs, therefore organisations should be aware that in the current climate the following costs are likely to be incurred:

Capturing equipment

- Digital Camera: include lenses and studio equipment (flash, tents), price range from €2000;
- 3D scanner, price range from €2000 – €100,000.

Processing equipment:

- Workstation: Generating 3D models is a very computer intensive process. A workstation needs a top video card, lots of storage space, processing power and memory, price range from €1500;
- Software: Whatever capturing equipment you apply, additional software for processing or finalising the 3D model is necessary. Price range from: free (open source).

Storage space:

- 3D models and their processing data need large amounts of storage space. For objects, calculate 1 GB per object. As a lot of effort and money is spent creating a 3D model, it is wise to include proper procedures for digital preservation including time and materials required for maintaining backups.

Personnel costs:

- A 3D project requires extensive staff resources as well staff becoming acquainted with the new processes and techniques used to conduct this work. This requires organisations to build in workflows to manage this and then execute the work.

11.1.4 Preconditions

Finally, it is important for organisations to ask themselves the following preconditions:

- Are the IPR arrangements covered?
- What metadata is recorded - where, how and when (is this done during the recording process)?
- What digital preservation arrangements have been made?

12 Contact research

This report was originally intended to be a best practice report on the wider use of 3D, which included research into other sectors. To produce this report, contact has been sought with a number of projects and organisations. The results and reflections of these contacts are presented in this section.

12.1 Special Effects industry (includes games, education,)

During the research for this report, a number of Art schools, Cinema institutes and producers of 3D interactive games were contacted via telephone and email. This was to enquire about their familiarity with and to gain ideas about the concept of incorporating 3D models produced by the cultural heritage sector in their production. The concept of reuse was easily understood by the organisations, and this produced a list of individuals who know more about the subject. Although the concept was well-understood, it has not been possible to identify any application to date.

12.2 Travel and Tourism organisations

Research has shown that there seem fewer applications of 3D than expected at the time of the submission of the proposal for Partage Plus. However, organisations promoting tourism regard digital 3D models as another tool that they are able to use within their online presence. The same opinion is also held in some communication departments of cultural heritage institutions. A main issue when implementing this is that displaying 3D digital models online requires extra programming and ICT facilities which are in contrast to the easily editable content management systems these organisations often use.

Digital 3D models do not currently seem to have much appeal outside of the cultural heritage sector. As mentioned earlier, this is mainly due to a lack of digital infrastructure and the complexity to incorporate 3D digital models in web presentations. However, as technology develops, this will change and it is worthwhile for cultural heritage organisations to seriously consider digitising their collections in 3D.

12.3 Projects

The report mentions a number of projects which have focussed on 3D applications within different areas of the cultural heritage sector. The projects have been funded by different sources which are illustrated in the projects description. This section provides a more detailed overview of the aims and objectives of these projects.

12.3.1 3D-Coform

The 3D-COFORM[32] project (EC, 2007 – 2013) aimed to establish 3D documentation as an affordable, practical and effective mechanism for long term documentation of tangible cultural heritage by addressing both the state of the art in 3D digitisation and the practical aspects of deployment in the sector.

12.3.2 VMust

V-must[33], Virtual Museums Transnational Network (EC, 2011 – 2015) is a Network of Excellence that aims to provide the heritage sector with tools and support to develop Virtual Museums. The aims of V-Must also convey the aims of this report as it reiterates the requirement of digital content when developing a virtual museum. The tools developed in V-must can help partners in Partage Plus to repurpose their content and the project website links to over 40 virtual museums. As an associated member in the V-must project Partage Plus work package leaders KMKG participate in events organised by this project.

12.3.3 ViHAP3D

An older project is ViHAP3D[34] (EC, 2001 – 2004), which was aimed at preserving, presenting, accessing, and promoting cultural heritage by means of interactive, high-quality 3D graphics.
The project can be seen as an early adapter of 3D technology in cultural heritage.

12.3.4 CARARE

The CARARE[35] (EC, 2001 – 2004) consortium, existing of heritage agencies and organisations, archaeological museums and research institutions and specialist digital archives established a service that made digital content for Europe's archaeological monuments and historic sites interoperable with Europeana. It also brings 3D and Virtual Reality content to Europeana.

12.3.5 3D Icons

3D Icons[36] project (EC, 2012 – 2015) predominantly researches technical solutions for scanning and documenting large structures such as buildings and landscapes. 3D Icons builds on the results of previous EU projects such as CARARE for aggregation services and guidelines on the publication of 3D to Europeana, and 3D-COFORM for 3D creation, management and visualisation tools. The project started in 2012 and runs for 3 years.

Amongst the subjects scanned by the project are more than 50 sites such as:

- Arc de Triomphe, Paris, France;
- Centre Pompidou, Paris, France;
- Paleochristian & Byzantine Monuments of Thessaloniki, Greece;
- Hill of Tara – Royal Site, Ireland;
- Historic Centre of, Italy;
- Historic centre of Naples, Italy;
- Historic Centre of Rome, Italy;
- Pompeii, Italy.

It is clear that the type of equipment used for scanning these sites and working methods differ from equipment used to scan objects in a museum environment.

Besides these sites, partners will create 3D models of archaeological objects, often related to the sites or to other Unesco World Heritage sites or candidates.

As the project often scans sites or locations of which the copyrights are held by the cultural institution that owns the site, the project develops valuable knowledge how to deal with these complex IPR issues. This knowledge will be reflected in an IPR management scheme, which will also include a pilot for business models for production and publication.

12.3.6 CASPAR

CASPAR[37] (EC, 2006 – 2009), Cultural, Artistic and Scientific knowledge for Preservation, Access and Retrieval was an integrated project co-financed by the European Commission within the Sixth Framework Programme (Priority IST-2005-2.5.10, "Access to and preservation of cultural and scientific resources" which looks at the preservation of digital data,.

12.3.7 Agora 3D

Agora 3D (Belgium, 2012 – 2014) started 2012 and runs for 24 months in Belgium. Several Belgium institutions cooperated to create an overview of the 3D scanning technologies applied today and compare the results. One of the goals of AGORA is to establish a set of protocols to identify which technique to use for each type of application, taking in consideration:

- Size;
- Material;
- Need for internal structure or not;
- Need for texture or not;
- Money;
- Time.

The project maintains a website[38] where the result of different scanning methods are displayed and compared.

Appendix 1

12.4 Terminology

With the introduction of 3D technology a whole new vocabulary has been introduced. It would go beyond this report to cover this exhaustively, however the definitions below aim to help demonstrate a correct understanding of the subject.

12.4.1 3D

3D can be described as any object in a digital environment which can be represented along an X, W and Z axle (Cartesian space). This representation is mathematical; the object is not an object as such but is represented by a very large collection of points or triangles (polygons).

12.4.2 3D Models

Any representation of an object in digital space is called a 3D model. If you took a look at the raw information that comprises a basic 3D model, it would simply (or not so simply) be a collection of data points that mark thousands or millions of different coordinates in Cartesian space.

12.4.3 Polygon

A polygon is a closed 2D shape formed by straight edges. The edges meet at points called vertices. There is exactly the same number of vertex points as edges. The simplest polygon is a triangle. A polygon mesh is a collection of polygons that defines the shape of an object in 3D computer graphics and solid modelling. The more polygons a 3D model consists of, the higher the resolution. Depending on the complexity of an object, tens of thousands to hundreds of thousands of polygons define the shape.

12.4.4 3D printing

3D printing is a process of making a three-dimensional solid object of virtually any shape from a digital model. 3D printing is achieved using an additive process, where successive layers of material are laid down in different shapes. The used materials are usually polymers or plastics but also printers using metal powders to create metal objects become available.

12.4.5 3D scanner

A 3D scanner is a device that analyses a real-world object or environment to collect data on its shape and possibly its appearance (i.e. colour). The collected data can then be used to construct digital, three dimensional models.

Many different technologies can be used to build these 3D scanning devices; each technology comes with its own limitations, advantages and costs. Many limitations in the kind of objects that can be digitized are still present, for example, optical technologies encounter many difficulties with shiny, mirroring or transparent objects.[39]

12.4.6 Photogrammetry

Photogrammetry has been defined by the American Society for Photogrammetry and Remote Sensing (ASPRS) as the art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena.[40]

12.4.7 Stereo photogrammetry

A more sophisticated technique, called stereo photogrammetry, involves estimating the three-dimensional coordinates of points on an object. These are determined by measurements made in two or more photographic images taken from different positions (see stereoscopy). Common points are identified on each image. A line of sight (or ray) can be constructed from the camera location to the point on the object. It is the intersection of these rays (triangulation) that determines the three-dimensional location of the point.

Appendix 2

Grant Agreement 297384

Partage Plus

Report on 3D Digitisation at KMKG

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Author(s)	*Chris Vastenhoud (KMKG)* *Thomas Nasswetter (SO)* *Sebastiaan Kuiper (SO)*

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This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

Contents

1 Introduction

This deliverable describes the preparations, the proceedings and the results of the 3D scanning operation which took place at the Royal Museums of Art and History (KMKG) between June 18th and 29th 2012. It contains guidelines for all project partners regarding studio lay out, materials and practicalities for the scanning operation.

3D model creation is a significant part of the digitisation efforts in Partage Plus. The project aims to capture in 3 dimensions 2.000 Art Nouveau objects. These high resolution objects will enable the partners to employ new technologies for presentation and preservation.

There is little experience in this field. Although 3D scanning techniques are becomingmore widely known, there is less experience in scanning the materials which were often used in the making of Art Nouveau objects and even less in mass producing 3D digital object collections. Therefore, the 3D scanning session at KMKG had a two objectives:

1) Gain experience and insight into the possibilities, techniques and best practices for scanning part of the Art Nouveau collections at partners locations within a short time-frame
2) Produce a number of 3D digital objects

This report focuses on part 1), and produces an overview of recommendations and experiences.

The scanning was executed by partners Steinbichler Optotechnik (SO) at partners KMKG's location. Post processing is done at SO by SO. SO will visit all partners who are supplying content at their own locations over the duration of the project, each visit will have a duration of approximately 2 weeks.

2 Scanning equipment

For capturing objects shapes in 3D, specific equipment is used. There are many different technical approaches towards the creation of 3D digital objects. The different technologies, like photogrammetry, laser scanning and MicroCT are applied according to the needs, budget and nature of the objects to be scanned. For Partage Plus, structured light scanning is used (see Figure 1).

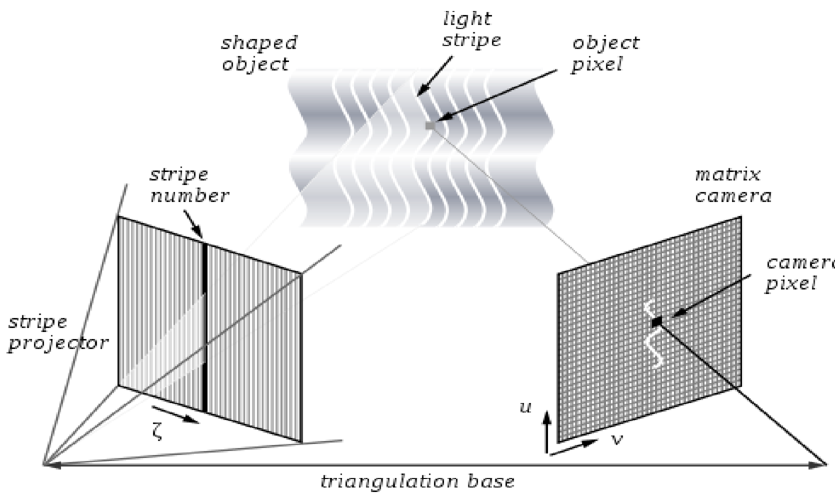


Figure 21. The principle of structured light capture. Wikipedia

2.1 3D Structured light, general technology:

The scanning method used for this operation is so called structured light. A scanning device projects a light pattern (often squares) on the surface of the object to be scanned. The resulting pattern is recorded by the device and processed by computer. The deformations in the light pattern can be recalculated to the shape of the object. This creates a set of data which contain the morphological information in a wireframe, consisting of hundreds of thousands of linked triangles (polygons).

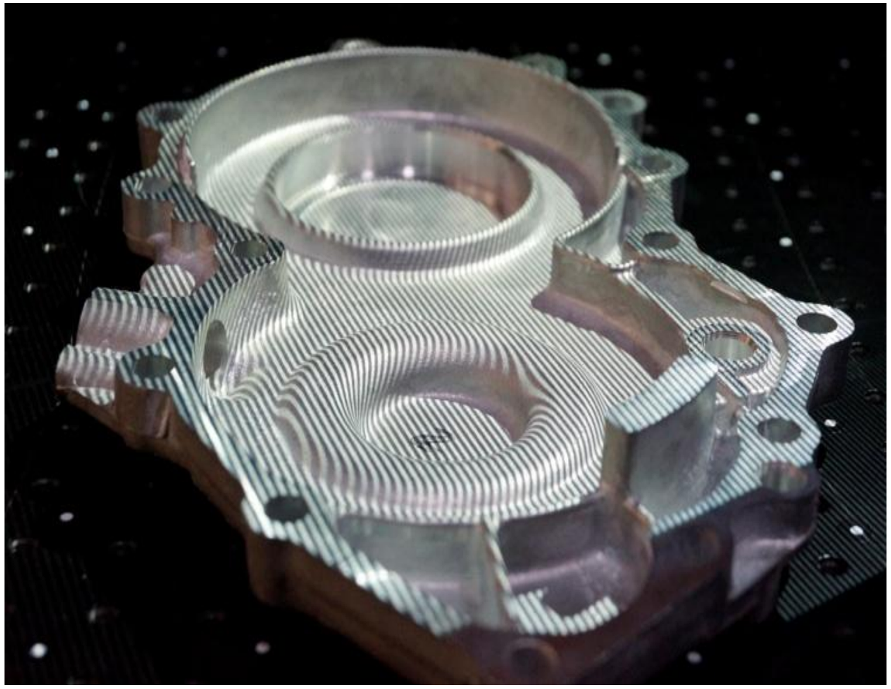


Figure 22: Structured light on machine part

Texture Information

For capturing the texture information (surface, colours) there a two methods: the more general method of making still images using a digital camera. These images are warped around the wire frame manually during post processing. A quicker method is applied by the Artec 3D scanner, which takes still colour pictures during the scanning operation. This method avoids the need to warp the still images on the wireframes afterwards.

2.2 Steinbichler COMET L3D

The Steinbichler's COMET L3D 5M is a high resolution structured light 3D-scanner. The scanner is available in resolutions of 1, 2, 5 and 8 megapixel. Depending on the size of the object to be scanned and the desired lateral resolution, an appropriate lens setup has to be selected in order to get the best scanning result possible with respect to resolution and accuracy.

Figure 3. Steinbichler Comet L3D 5M

The COMET L3D uses a 2-step process, where the morphological information and the texture are acquired in separate actions. Morphological information is acquired using a structured light scanner; texture is acquired by digital photography. During post processing, the texture information will be warped over the 3-dimensional object data manually. For the texture capture a Nikon DSLR camera with a standard autofocus lens was used.

In operation, the scanner is linked to a computer that stores the data and controls an automatic turntable. Once set up, scanning from one angle is a
fully automated process. If more angles are needed to cover all areas of the objects, the scanner needs to be repositioned manually.

2.3 Technical aspects and settings regarding the scanning of cultural heritage objects

This scanner is used for high resolution, high quality scans. Objects can have relatively small details and complicated morphologies. Depending on the setup, the resolution can be adjusted down to 18µm. Objects have to be pre-selected. They must have texture which is allows scanning (non transparant, not reflecting ect.) but can have relatively complex morphologies like sharp edges or small details. This scanner gives the advantage of very high accurate and dense 3D surface data. The texture is captured by digital photography and in a later process is mapped in a manually onto the 3D surface model. This scanner will be used to produce high quality, high resolution scans which require a high amount of data storage space.

2.3.1 Specifications

Hardware specifications of the COMET L3D scanner can be found in the following table.

Camera Resolution	1M, 2M, 5M, 8M
Measurement Volume in mm³	45 x 38 x 30 74 x 62 x 40 120 x 100 x 60 260 x 215 x 140 480 x 400 x 250 750 x 630 x 500
3D Point Distance in µm	Up to 18
Fastest Measuring Time	Down to 1 sec
PC	desktop PC or notebook
Sensor Positioning	tripod or sensor stand with manual rotation and tilt axis
Automatic Object Positioning	rotation table (COMETrotary, COMETdual rotary)
Available Software	STEINBICHLER COMETplus
Digital Photocamera	Nikon D700
Resolution	12 Megapixel

Table 1

The original output of the COMET L3D scanner for the 3D model is a stl-file format. The output of the digital camera is set to jpg-file format. The combination of these two formats is done in software, which after mapping outputs obj-file formats. This format contains 3D dimensional data in combination with colour texture information.

2.4 Artec 3D

The Artec 3D scanner (Figure 4) is a single pass scanner, both morphology and texture are recorded at the same moment. The combination of capture of different aspects in one pass allows for very fast capturing of data.

The resolution of up to 0.5 mm is more than sufficient to reproduce objects adequately. However for conservation purposes or research on materials, higher resolutions would be needed.

In operation, the scanner is linked by USB cables to a computer that stores the raw data.

Figure 4. Artec 3D scanner

2.5 Technical aspects and settings regarding the scanning of cultural heritage objects

For this scanner it is necessary, that objects are pre-selected which have surfaces that can be scanned and relatively smooth morphologies, as the resolution is limited to 0.5mm. This scanner has the advantage of very fast scanning and also maps the texture automatically onto the 3D surface model. This scanner will be used to produce the majority of the 3D models to be done within this project.

2.5.1 Specifications

Hardware specifications of the Artec Scanner can be found in the following table.

Ability to capture texture	Yes
3D resolution, up to	0.5 mm
3D point accuracy, up to	0.1 mm
3D accuracy over distance, up to	0.15% over 100 cm
Texture resolution	1.3 mp
Colors	24 bpp
Light source	flash bulb (no laser)
Working distance	0.4 – 1 m
Linear field of view, HxW @ closest range	214 x 148 mm
Linear field of view, HxW @ furthest range	536 x 371 mm
Angular field of view, HxW	30 x 21°
Video frame rate, up to	15 fps
Exposure time	0.0002 s
Data acquisition speed, up to	288,000 points/s
Dimensions, HxDxW	180 x 187 x 260 mm
Weight	1.6 kg / 3.5 lb
Power consumption	12V, 40W
Interface	2x USB2.0
Calibration	no special equipment required

Table 2

The output of the Artec scanning process is an obj-file format. This format contains 3D dimensional data in combination with colour texture information. An example of a 3D scan is shown in figure 5.

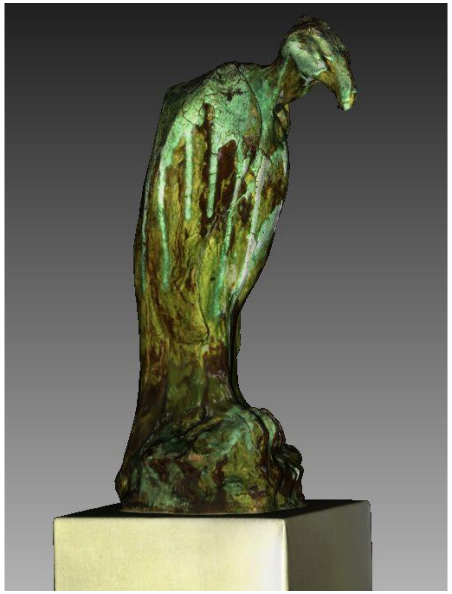


Figure 5. 3D Image of a scan

2.6 Computers and software

Both scanners operate via a cable link to a computer. The scanners produce large amounts of data which are analysed in real time and stored in the computers HDU's. In the case of the Comet scanner, the computer also controls the movement of an automatic turntable.
Both scanners use proprietary software. This software processed the scanned data in real-time and gave the operators constant feedback about the quality of the scanning and the areas covered of the specific object. The scanning operation was directed by the software, Ensuring that if the scanner did not return sufficient or coherent data (due to reflections, materials, sub resolution) the software would detect this and would not continue the scanning process

The scanning used high an 8 core desktop machine was used, as demand for bandwidth and processing power increased.

3 Material and morphological aspects of objects

As stated in the introduction, 3D scanning in large quantities is relatively new. Therefore it is recommended to start with a selection objects which are expected to be relatively easy to scan at the start of the process. Once the operation is well underway the attention can be directed to more difficult objects (in terms of scanning). The table in appendix 2 gives an indication of what can be expected based on previous experiences.

During the operation the limits of what can be scanned properly have been sought. Below an overview of objects of aspects that did not come out correctly:

- Small objects like jewellery. Especially when they contain gems or stones;
- Combs;
- Fine metalwork, file grain;
- Objects larger than a chair;
- Cracks in porcelain or earthenware;
- Transparent glass;
- Shiny metal;
- Thin rims of plates and vases;
- Any textile or fabric which is partly maze or transparent;
- Flexible textile, moving textile.

4 Planning

As presented in the kick of meeting earlier this year, extensive preparation of the collection to be scanned is crucial for an efficient scanning operation. Issues to be considered are the

- selection of objects
- availability and preparation of the objects to be scanned,
- a location where the scanning can take place and
- having personnel available which is authorised to handle the objects.
- For further information refer to the appendix 1.

Figure 6: A jewel consisting of fine shiny metal and transparent stone: impossible to scan

4.1 Selection of objects

As the scanning operation was intended to gain knowledge of the limits of the equipment used, a large variety of objects were scanned. Amongst these were objects of which were expected to be impossible to scan with the scanning equipment available. Amongst these were fine jewellery, transparent glass objects, shiny metals etc. All of these were scanned, but often the scanning had to be aborted as the scanners did not retrieve sufficient data to continue the scanning process.

5 Personnel

The scanning at KMKG involved 11 persons in the preparations and the execution of the scanning operations.

5.1 KMKG

As the collections of Art Nouveau objects are partly subdivided by material three curators were involved in preparation and selection of objects.
Three museum-technicians worked permanently on the preparation of the studio and object handling. They were supported by the KMKG project coordinator.
At KMKG, as in many other cultural heritage institutions, object handling is restricted to qualified personnel such as museum technicians. This implied that at least one museum technician had to be present during all sessions of the scanning. In the case of KMKG, where the Art Nouveau collections are dispersed over several departments, this meant that in some circumstances several assistants were present during the scanning.

5.2 SO

As this was the first scanning session in the project, SO delegated two specialist technicians to perform the initial tests and consequently scan the collections. They were supported by one technician and project management based at SO offices.

6 Preparations

The preparations for the scanning were made a few days before the SO team arrived at KMKG. As a result, only the studio space could be prepared. The studio was housed in a large exhibition space, which became temporarily available due to a change of exhibitions (see Figure 7). Each partner must prepare the following things to ensure the scanning visit is as productive as possible:

1) Prepare a collection of objects to be scanned;
2) Prepare a studio;
3) Prepare sufficient digital storage space for the storage of the 3D digital information (+ 1 GB per object).

6.1 Studio set up

The studio was set up in a temporarily unused exhibition room with no natural light. This gave the team sufficient space to keep the objects waiting for scanning out of the way and give distance between the computers used for storing the raw data and the locations where the objects were actually scanned.

A horizon-less background was set up for the 2D still photography and several tables for objects and equipment were also set up in the room.

The studio was guarded by internal KMKG security and could be locked during breaks and overnight. This was useful as it meant scanning equipment could remain in the studio and did not need to be packed, unpacked and calibrated every day.

Figure 7: Temporary studio exhibition space

7 Support materials for scanning

For the scanning to work efficiently, stable support and visual access to all sides and parts of the objects is necessary.

Object support

The most important item was a turntable stool (see Figure 8) which could be turned manually. This gave the scanning technicians complete control over the area of the object being scanned. As the results of the scans are displayed in real time (informing the technicians on progress and quality of the scan) this allowed for immediate corrections to be made when necessary.

As light travels (almost) linear and objects need to be scanned from all sides in order to create a complete 3D view, specific equipment and a number of supports was brought together. These supports helped to raise objects in order to scan them from a lower angle looking up, or to position an object upside down.

Scanner optical guides

The scanners sometimes need some visual aids to maintain their orientation and focus. These aids can consist of all kinds of materials and shapes, like post-it's, small stickers which are temporarily attached to the object (see Figure 9), or laths which were set in the background.

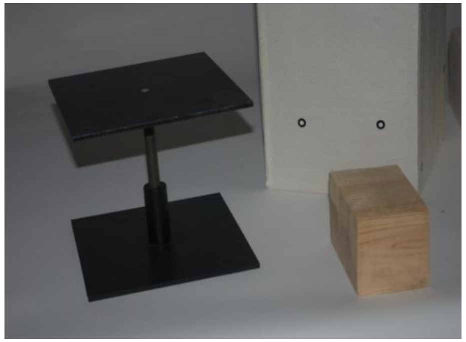


Figure 8: Object supports with above the very useful stool-

Figure 9: Visual guides for the scanners

8 Lighting

As the studio did not have any natural light, this allowed complete control over the lighting conditions. The studio had different arrays of fluorescent tube lights which were used according to the needs during processing intervals. Both scanners had their own light sources build in so that no extra light sources of specific illumination were needed.

Figure 10: Simple round wall

9 Proceedings

This chapter describes the development of the scanning session as it progressed in time and the team gained experience in techniques and logistics.

9.1 Initial tests

Initially, both scanners, the SO Comet L3D and the Artec 3D were operated simultaneously. There were technical problems for the Artec at the start, as the capture rate was too low. These problems were resolved overnight.
In order to gain insight into the quality of the scanning, the data acquired from the first scanning activities were post processed immediately after the scanning had taken place. Although this took time, it allowed for adjustments to the settings of the scanners on the spot.

After scanning a few test objects, it became evident that the Comet L3D setup, although probably yielding higher quality results, was too slow to achieve the target of scanning 100 objects in 10 working days.

9.2 Production workflow

After the second half of the first week, two aspects regarding the scanners turned out to be important factors:

- Speed: working with the Artec 3D was much faster than the Comet L3D;
- Movability:

The Artec 3D scanner generated sufficient quality in a short space of time and was far more manoeuvrable than the fixed Comet L3D 5M. The Artec because of this, allowed for more complex objects to be scanned like chairs.

Figure 11: Working with the Artec 3D and the turntable

Post-processing
Post-processing took a lot of time. In order to make efficient use of the time post-processing at KMKG was abandoned completely and SO would post process at their location.

Towards the end of the second week, with a good supply chain of objects installed, one technician would be able to scan 20- 30 (simple to scan) objects per day.

10 Results

154 objects were scanned during the session at KMKG. This includes tests of which some have been discarded. The results of the post processing may reduce this number further.

11 Publicity

In the project plan it is stated that these scanning sessions will also be used by the project partners as an opportunity to generate publicity for the project and its results. As the focus of both partners SO and KMKG in this first session was on gaining experience, it was decided that a dissemination opportunity at KMKG will be organised towards the end of the project, the 4th Quarter of 2013. This will also allow the project to display a far larger number of 3D Digital objects than can be done at this stage.

12 Conclusions

Scanning at KMKG was the first session in the scanning schedule of Partage Plus. All partners providing content and having 3D objects available for scanning will be visited.
It is expected that over the next 18 months, technology will improve and knowledge, experience and insight will be gained. Nevertheless, after 2 weeks of scanning, we can draw the following conclusions:

- The resolution of the scanners used is very adequate to generate 3D representations of the objects in colour.
- The resolutions used by these scanners seem too low to analyse fine deformations like cracks
- The speed of Artec 3D scanner enables the scanning of the number of objects proposed by the project within the proposed time frame.
- Preparation is crucial for scanning to be an effective and efficient process.
- Scanning in 3D for publicity is a much quicker operation than scanning in higher resolution for research or analyses purposes.
- The efficiency of single pass scanners is higher than half of the time for separate morphology and texture capture.

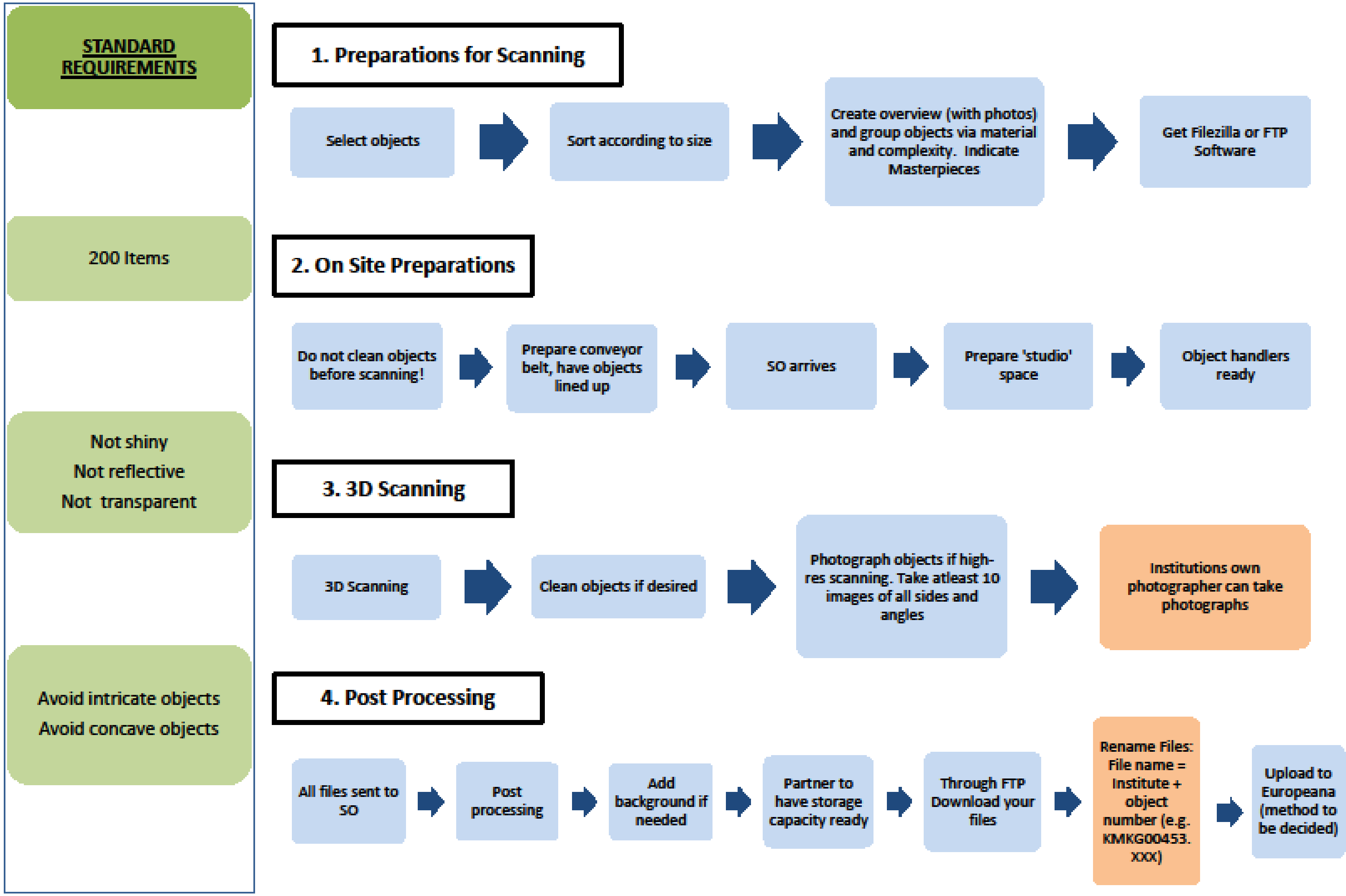
12.1 Additional scanning

The focus of the scanning is to create a portfolio of 3D digital objects. During the scanning at KMKG we found that by using the Artec 3D it was able to create the number of scans indicated in the Description of Work within the allotted timescale. We also found that the Artec 3D encouters limitation in resolutions below 1 mm. As a result, in these so called Medium-resolution-scans sometimes cracks and sharp rims could not be visualised. It also became apparent that it is not possible to use the same technology for all types of objects (varying sizes and materials) and the same application, for example conservation analyses ore reproduction.

In order to investigate wider uses, the project proposes to extend the number of 3D models created by creating additional scans in higher resolutions of selected objects. This work will be carried out within the frameworks of time and money.
Thus the project will create a portfolio of 2,000 3D digital objects using the Artec 3D scanner and in addition will create an additional body of 3D high quality objects. In order to realise this, at each visit SO will bring a high-resolution scanner which uses a two-step process using structured light and digital photography. The scanner will capture high resolution data of the shape of the object in monotone and SO technicians will warp digital stills afterwards using computer technology on to the frame. It is expected that these digital objects will have sufficient resolution for conservation and reproduction.

The high-resolution scanning will take place after the end of each scanning visit. The objects will be selected between the staff at the partner institution and the SO Technicians. These new scans form an extra set of high-resolution 3D digital objects and raise the number of scanned objects to above 2,000. Scanning and process time will be dependent on the size and complexity of the objects; it is not possible to indicate a total number of high-resolution scans in this stage.

Appendix 1: Workflow for 3D Digitisation:



Appendix 2: Material and morphological aspects of objects

Easy to scan	Property	Difficult/complex to scan
Dull Not Reflective Non transparent Flat Finely woven	**Surface**	Shiny Reflective Completely transparant Accidented Coarse
Simple shape Convex Box or round(compact)	**Shape**	Complex shape Concave Arms and legs (complex) Holes
rigid One type of material	**Material**	Flexibel Mnay different materials
Small (pot or vase)	**Seize**	Very small Large (chair) though not impossible

Appendix 3: proposed registration list

Below is a proposed list for the registration of the objects captured using 3D scanning technology. WP1 needs an overview of objects scanned. As the aim of the project is to research the possibilities for mass-production some extra information is needed to calculate capacity (start and finish time, Scanner type an morphological complexity of the object.

Object #	Description	Start date:time	finish date:time	Still numbers ## - ##	Scanner type	Complexity
				-		
				-		
				-		
				-		
				-		
				-		
				-		
				-		
				-		
				-		
				-		
				-		
				-		
				-		
				-		

End Notes

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