



know  
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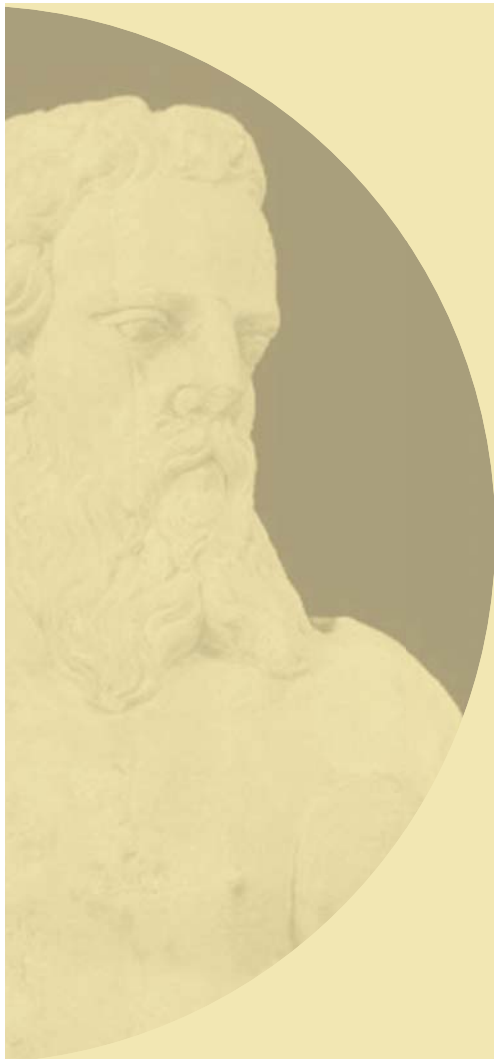
museums

Editor: Halina Gottlieb  
The Interactive Institute

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Luc Van Gool  
Maarten Vergauwen

# ***The ARC 3D Webservice***

How to turn images of an object or scene  
into 3D models for exhibitions and archives





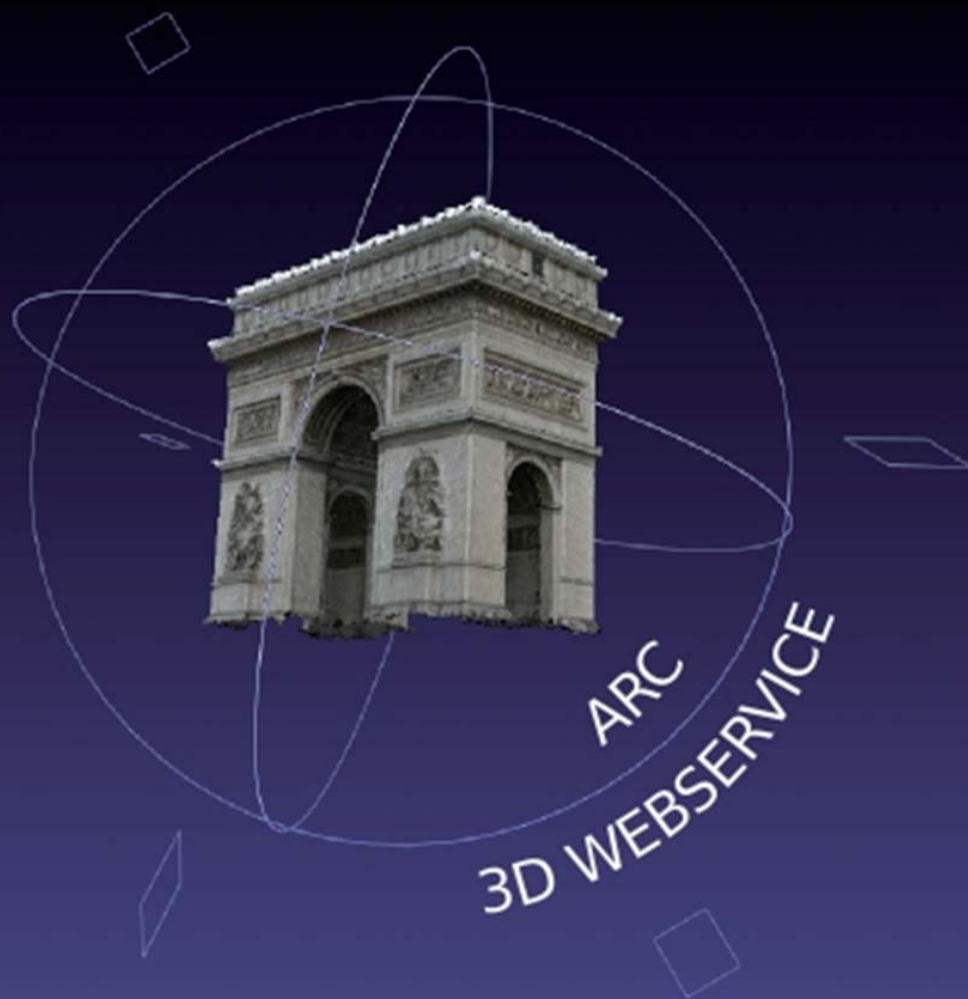
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## Summary

From the cultural heritage field comes a large demand for cheaper and more flexible ways of 3D reconstruction. Aiming to fulfil this need, the VISICS Research Group of the University of Leuven, Belgium (partners of the EPOCH network) have developed a web-based 3D reconstruction tool. This service is called the *ARC 3D Webservice*, 'ARC' standing for Automatic Reconstruction Conduit, and enables its users to transform images of scenes or objects into 3D models. The idea behind the service is very simple: You take a series of pictures of the object or scene you want to reconstruct in 3D,

upload these images to the web service and download the resulting 3D reconstruction. The service is free of charge for non-commercial use and the only equipment you need is a digital camera and a PC with access to the Internet.

The service consists of a pipeline that starts with the user uploading images of an object or scene(s) to be reconstructed in 3D. The automatic reconstruction process, running on a server connected to a cluster of computers, then determines the camera calibration and depth maps (containing

information on the distance of each pixel to the camera). The result can be downloaded from a server and visualised with a specific tool running on the user's PC.

Once you have downloaded the result, you have the choice between two different tools that can be used for visualising the result. The built-in *Model Viewer* is a simple tool that comes with the ARC 3D installer. It lets you view your result in 3D and gives you the option to export the model into several common 3D formats. The other tool that can be used is called *MeshLab* and was developed by ISTI-CNR, Italy. This tool has more advanced features and provides you with a wide range of options in editing and visualising your result.

This KNOWHOW booklet guides you step-by-step through the process of creating a 3D model with the use of ARC 3D. It also looks into future uses of 3D models by giving some tips on how museums can expand their website, archives and exhibitions by adding 3D interactive content.

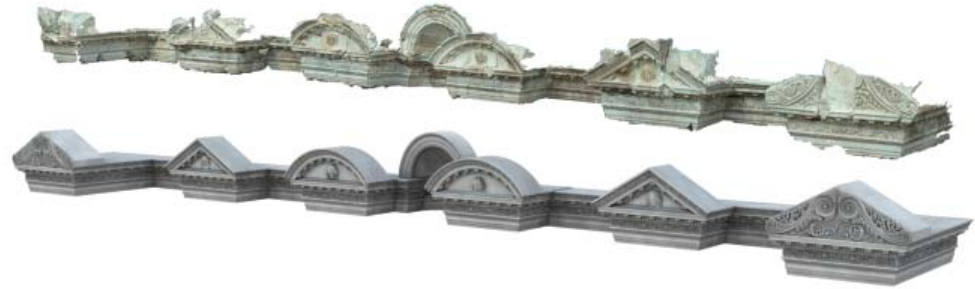
## The development of 3D reconstruction

Until the early 1990's, 3D reconstruction from images was mainly carried out with photogrammetric methods, using calibrated stereo setups, special cameras, and quite a lot of manual interaction. The increasing speed and power of computer systems, however, lead researchers in the computer vision field to develop calculation intensive methods that could deal with uncalibrated imagery (i.e. no information about the different positions or the parameter settings of the camera(s) is given). Moreover, 'dense matching techniques' and 'wide baseline matching techniques' were developed that allowed these systems to detect corresponding points in the different images automatically, thereby eliminating most of the tedious manual interaction. The K.U.Leuven VISICS

research team was one of the leading teams in this field and developed a fully automatic 3D reconstruction pipeline.

An important advantage that comes with the ability to work from uncalibrated images is that consumer-grade cameras can be used, and the images can be taken while holding the camera in one's hand. These advantages make the image capturing process easy and efficient. The possibility to use consumer-grade still or video cameras also helps to keep costs manageable. The 3D results will get better and better as the quality of such cameras improve, which is already happening at a blistering speed. Of course, not having to go through painstaking camera calibration is an important advantage in its own right.

The top image shows the archaeological remains of the roof of the Nymphaeum at Sagalassos, digitised through ARC 3D and structured light techniques, and puzzled together digitally. The bottom image shows the fully reconstructed roof.



## Background

The cultural heritage community has always had a keen interest in the creation of 3D models of objects, monuments, scenes, etc. Such models not only help in creating a more vivid picture of the past in the mind of the general public, but they are also of great value for training and research. Yet 3D modelling technology has often been expensive and time consuming to use. It is the goal of the ARC 3D Webservice to provide the community with an affordable, easy-to-use and yet effective alternative.

With cultural artefacts, the surface colour and texture are often at least as important

as the 3D shape. In contrast to several alternative 3D acquisition methods, the shape and the surface texture are not captured separately. This would lead to the need for a shape and texture alignment, which may turn out to be tricky as both are rarely captured from exactly the same viewpoints. ARC 3D uses the same images to build the 3D shape as well as extract the necessary textures, which avoids any alignment issues.

This figure shows an example result obtained with ARC 3D technology. The roof of the nymphaeum at the excavation site of

Sagalassos, Turkey ([www.sagalassos.be](http://www.sagalassos.be)) was virtually reconstructed from images.

A webservice is an attractive formula for several reasons: the limited bandwidth necessary to upload the images, the fact that the computer-intensive processing is done on the servers and the possibility to update with improved versions without disturbing the users. These were all elements that spoke in favour of a remote computing strategy. The ARC 3D Webservice has been operational since the fall of 2006 and is under constant development.

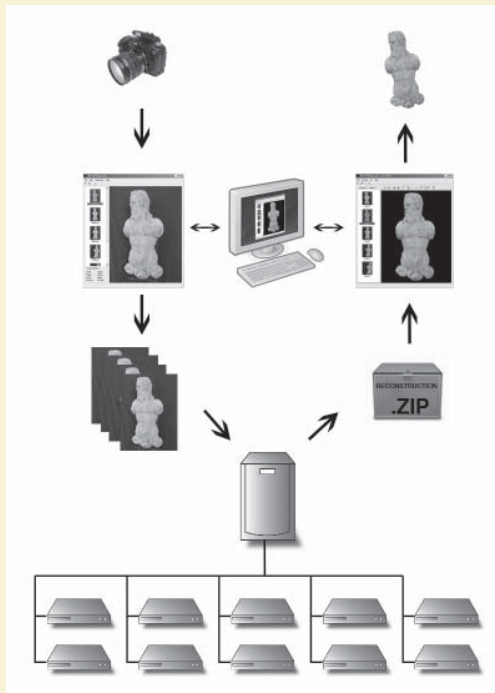
## How it works: The process of the service

The service and its process can be explained in five steps:

1. Record a sequence of images of an object
2. Upload the images to the ARC 3D server
3. The server computes the 3D reconstruction
4. Download the results from the ARC 3D website
5. Visualise the results

Equipment needed ARC 3D:

- A digital camera
- A computer
- Access to the Internet



## Prepare your recording: Problems, tips & tricks

To minimise frustration it is best to take heed of some simple guidelines, so we will explain some dos and don'ts. All of the information is retrieved from the images, so it goes without saying that the first and most important guideline is to take good care when recording them. It is better to spend two more minutes capturing the images than to have to go back and redo the job.

Secondly, objects with a lot of surface detail are much more suitable than objects with less detailed areas, such as for example homogeneous, white marble objects. Such objects should be scanned through other techniques such as structured light or laser scanning.

The third thing to remember is to avoid objects blocking the scene since it is impossible to reconstruct hidden parts. Sometimes the object is self-occluding (when parts are sticking out and thus hide other parts behind them). Try to record the pictures in such a way that self-occlusion is minimal.



Often the first thing people try is to upload their baby pictures. This will not work. Human skin is notorious for changing appearance when viewed from different angles, and it lacks textural variations. This will make it difficult for the system to identify pixels in the different images as corresponding to the same point on the surface. A blank, evenly plastered wall is a nightmare scenario for the same reason. With all points looking alike, the system cannot find the projections of the same point in the different images, and the 3D reconstruction fails miserably.

For the same reason, the appearance of the object must be consistent while recording the photographs. Glare causes problems due to conspicuous bright regions on the object's surface that move around as the camera is displaced. For the same reasons, shiny surfaces, like metals, also prove to be difficult. Transparent or translucent materials like glass are even worse, as the intensities and colours of the image pixels are determined more by what is behind the object than by the object itself.



A good sequence of a statue of Mercator on Leuven city hall

## 1. Record an object

### To obtain a good sequence:

- Choose the object to be reconstructed in 3D and make sure that the whole object fits inside the frame of the camera. Try using a wide-angle lens if you can't keep enough distance to fit the whole object in the frame. It is also important not to record the sequence too far away from the object
- the object should fill up the frame as much as possible. Do not use the 'zoom' to fill out the frame if not absolutely necessary. From close range with the image zoomed out is better than from a distance with a strong zoom.

- Centre the camera to one point of the object. Always take pictures with the same point centred in the frame of the camera while walking around the object. Always keep the same object in the frame of the camera and view the same object from different sides.

- Take very small steps while recording. For an object that is 2 metres away from the camera, take a picture every 60cm (or 30 to 40 pictures all around the object, which is an easy way in the field to know if you did a good job). In any case, you will develop a feeling for the required density of images as you experiment with the system.

- Use fixed exposure time on your camera while taking photographs.

**To avoid bad sequences:**

- It is better to record too many pictures than too few. A minimum of five or six images is required for a good reconstruction. Less than four images and the reconstruction will fail.

- The viewing angle between images should not be too large, i.e. adjacent images should not be too far apart. 10 degrees is sufficient.

- The scene to be reconstructed in 3D should be static. Independently moving objects can be discarded by the system if the static scene is dominant in the image, so it is recommended to avoid moving objects in the images. If there are independently moving objects (e.g. tourists walking around on your site), it is advisable to take more images than usual and to take images from nearby positions with larger time lapses in between, as to maximise the chance that all of the moving parts have sufficiently changed their position in order not to confuse the system.

If a person stands still next to a statue, it is impossible for the system to know that it is not part of a sculpted group and the person ends up in the 3D model. Post-processing can remedy this, but the problem can be avoided at the time when the images are captured, by making sure the person has moved in between takes.

- Do not zoom in or out during recording (as the camera parameters should optimally be constant during a set of photographs). Avoid large changes in focus as this can result in a change of camera parameters.

- Do not use a flash, as this changes the appearance of the object and creates

## Required equipment

A good camera will give you better results than a cheap camera with a subpar lens and sensor.

A 5MP camera (2500x2000) is typically good enough. More pixels mean more 3D points, but increasing the amount of pixels also leads to a longer upload and processing time. Most importantly, the camera should be equipped with a good lens. The better the lens, the more light it allows to fall onto the CCD, resulting in less distortion. Both factors lead to a better final result.

Your computer should be fairly modern and with Windows OS installed. The minimum configuration is 512 MB RAM and a 64 MB graphics card. More memory and a better graphics card make viewing the constructed model more efficient and will be necessary if you want to process your model afterwards (merging, cleaning, etc., as explained in Chapter 5 – Visualise your results). An internet connection (broadband strongly recommended) is necessary since the reconstruction of your photographs is done on the ARC 3D server at the University of Leuven.

changing shadows. Flashes also tend to create glare, which, as mentioned above, will cause problems.

- Do not use a turntable with a static camera and an object that rotates in front of the camera. Because of this very specific motion, there is not enough information in the images to allow camera calibration.

- Do not pan from the same location, as if you were recording a panorama. It is not possible to determine enough 3D information from such a sequence.

- Do not walk in a straight line towards the scene you want to reconstruct. In general, do not walk along a straight line without rotating the camera. Unfortunately, this is a typical camera motion people tend to do. Again, there is not enough 3D information embedded in such images. The result will typically be deformed, as if it were skewed. Holding the camera in your hand typically means that the camera will not perfectly follow such path, but it is wise be aware of this movement.

### **Lighting conditions and setup**

The lighting conditions when photographing are crucial to obtain a good result. When photographing objects indoors you are most likely to suffer from insufficient light when you are recording handheld images without using the flash. Many digital cameras automatically enable their flash when the light is insufficient, so remember to turn off this feature for better results.

When the camera moves during recording, the image becomes blurred if a long exposure time is used. Most cameras have a 'night mode' setting for bad lighting situations. This feature increases the camera's exposure time in order to catch more light through the lens. Do not use such features because they will most likely lead to blurry images and cause problems for the reconstruction and its quality.

To achieve a good result it might be worth setting up some lights to provide a soft, even illumination of the object. Be aware of unwanted shadows on the object, such as

your own. Using a tripod is a good option if no extra lighting can be arranged and long exposure times are needed in order to obtain good image quality. If your museum has an in-house photographer it might be a good idea to involve this person in the process. Take advantage of and learn from each other!

One could consider creating an even, dark background when shooting the object, but this is neither strictly necessary nor always advisable (see later comment on the positive effect background structures can have on the automatic camera calibration). In any case, this differs from the typical setup that a museum photographer would use. In most cases you will photograph the object all around, which means that you will need a dark background all around. Of course, this could be a partial background that you move accordingly as you take the images. If this is not possible, you could create a similar environment by shooting in the evening or at night with sufficient and appropriate lighting on the object.

In practice this means that in most cases, the object does not need to be touched or to leave the museum. By creating a dark background you will also simplify 'the masking process' used to mask out unwanted information or background in the visualisation process (see Chapter 5).

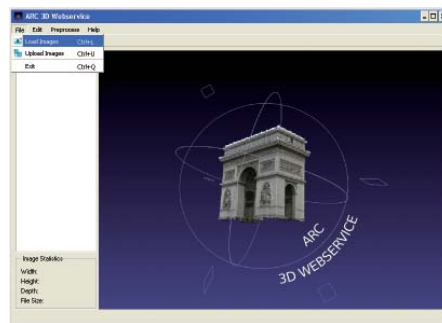
It is important to note if the recorded object does not fill the image, the calibration of the camera will not be very accurate. In these cases it is better to not hide the background, but instead keep it as it is because the calibration process will actually use these areas to improve the result.

To avoid colour changes from one picture to another (for example due to a dominant colour of a part of the object), we also recommend using a fixed white balance while shooting the photographs. Most digital cameras today have this feature.

## 2. Upload the images to the ARC 3D server

The first thing to do is to obtain an account from the website that enables you to log in and use the service. Go to [www.arc3d.be](http://www.arc3d.be) and navigate to *Request Login*.

When you fill in your name and email address, your login information will be sent to your email address. Download and install the latest version (Windows only) of the tool from the ARC 3D homepage. The service contains two programs, the *Image Uploader* and the *Model Viewer*.



### Image Uploader

Upload the images of the object you want to reconstruct in 3D using the *Image Uploader*. Thumbnails of these images are shown on the left and a large version of the selected image is shown in the main panel. Images can be removed from the list or extra images can be added, but make sure that the images are in the right order to make a continuous movement around the object.

On the bottom left, information about the image such as the number of pixels, the size on disk and the format are shown. You can subsample the images to a smaller size for faster upload and computation, but at the cost of losing some detail in the final result. You can also organise your uploads by selecting or creating 'scenes', supply a sequence label or add an academic reference, if desired. (In cases in which the ARC 3D team would use your images in a publication, they will add the academic reference. For information about the conditions, please see the ARC 3D homepage.)

When satisfied with the selected images, you upload them to the reconstruction server. We recommend uploading at least 6 images. In order to do so, you first need to authenticate yourself with your username and password. The upload is started and a progress dialog shows the speed of the upload.

Once the uploading begins, have a coffee! The process time can take from 15 minutes up to several hours, depending on the size of the upload and the traffic on the server.

### 3. Computing the 3D reconstruction

An automatic reconstruction process running on a server connected to a cluster of computers, computes the camera calibration, as well as depth maps for the images. When the server has finished processing, the user is notified by email and the results can be downloaded from the ARC 3D server.

The unique feature with ARC 3D is that it only uses images as input. The computer

vision techniques that are used to compute the results are automatic matching of images, automatic computation of camera calibration and automatic dense matching for depth map generation. These are the major steps in the pipeline and may be fragile when supplied with an inappropriate type of imagery.

The entire process is based on finding pixels corresponding to the same 3D points in the images, so-called 'matches'. All of the information is recovered from them. This means that the camera viewpoints need to be laid out in such a way that each part of the object is captured without losing the general view of the object. Only points

that are visible and recognizable in at least 2 images are useful. Note that a sufficient number of points will actually need to be visible and recognisable in at least 3 images in order for the automatic calibration process to be successful.

### 4. Download the results from the ARC 3D server

The ARC 3D service reports its result to you by email. If the reconstruction has succeeded, you are sent a URL link to where you can download a zip file containing the results. The zip file contains the original images, the calibration of the cameras, the dense depth maps and quality maps for every image. The quality map shows for



every pixel in how many images that pixel could be detected, which gives a rather good idea of the reliability and quality of the result for that point. *MeshLab* (see below) uses a colour coding of the quality maps. If for example most of your object is blue, the reconstruction will be fine, but if it tends to green or yellow the result will be poor and peppered with holes or artefacts. If the reconstruction failed, some more information is given, including tips on how to improve the result.

## 5. Visualise the results

It is now time to visualise your result and there are two tools available for this task. The ARC 3D team recommends *MeshLab*, a tool developed by CNR-ISTI in Pisa, Italy that is downloadable from <http://meshlab.sf.net/>. *MeshLab* is a powerful tool but it takes a little while to master. For a first visualisation to inspect the results you might consider using the *Model Viewer* tool that comes with the ARC installer.

### Visualise with the *Model Viewer*

Each zip bundle contains textures, camera files, depth maps and quality maps and a config file named *model.XXXX.v3d*. Unzip the file and load the data in the application *Model Viewer*. A thumbnail is shown for every image in the set. If selected, a large

version of the image is shown in the main window. Since all images have their own corresponding range-map, a model can be created for any image in the set. This 'model' is not a complete object model yet, but a 3D reconstruction for that part of the object that was visible to the selected camera.

## Creating a mask

Often images will contain other objects than the one of interest (e.g. in the background). So for a 'clean' reconstruction, it is necessary to discard this extraneous information. Typically, it is useful to remove backgrounds, floors or support structures, as they are in most cases not part of the object that one wants to reconstruct. A simple shift-click inside such a region starts a mask-growing algorithm that covers a homogeneous region. It is also possible to paint (select the pen; use the left mouse button for free motion or use the right mouse button

for dragging rectangles), erase (the same as paint, except select the eraser) or grow (by holding down *Shift-Left* button) black regions to mask out the image parts considered irrelevant.

Once satisfied with the mask, or if no mask is required, a model can be created by selecting *Create Model*. A dialog will prompt the user for the various model parameters.

Note that masking takes place at the visualisation stage. The masked objects or background could still be used for the camera calibration in the earlier stages, which is a good thing.

To create a model, begin by selecting an image. We suggest you use the image that best represents the visible parts of the object, in other words the best view of the object. These partial reconstructions or 'models' come as surface meshes.

The user can select a quality threshold, which means that the parts in the reconstruction that have a lower quality (see above) are discarded when creating the model. High thresholds yield models with higher quality, but more holes where low quality parts are absent. Lower

thresholds yield more complete models, including areas with a lower reconstruction quality.

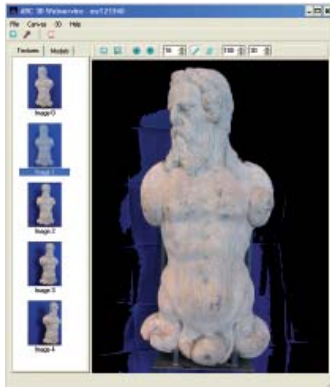
Once the reconstruction process is complete, the model is displayed in the model widget, which can be accessed by selecting the *Model* tab in the thumbnail panel. The key and mouse actions are described below:

Panning: Clicking the *middle mouse* button and dragging  
Rotating: Clicking the *left mouse* button and dragging

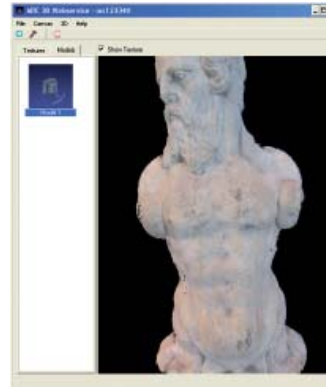
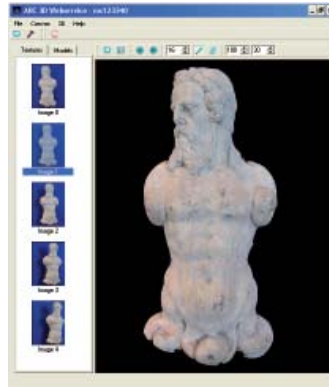
Zooming: Clicking the *right mouse* button and dragging

Picking: Clicking and releasing the *left mouse* button without dragging. This centres the view on the point that was clicked.

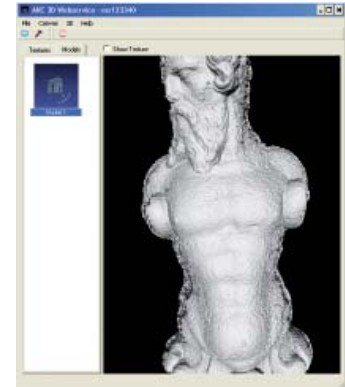
The models (i.e. camera centred, partial reconstructions) can be exported in different 3D file formats, for use with several 3D software programs. Formats that are supported are VRML2, Open Inventor, OBJ or OpenSG's native file format. OpenSG is the standard choice for the EPOCH consortium.



By holding down the *Shift* key while left clicking on the blue background in this image, the mask-growing algorithm starts to mask the background



The images show a reconstruction of the Makalös statue at the Stockholm city museum with and without texture (surface details) in the *Model Viewer* tool.



### Visualise with *MeshLab*

*MeshLab* is an open source, portable and extendible system for the processing and editing of unstructured 3D triangular



meshes. The system is aimed at the processing of the typically not-so-small unstructured models arising in 3D scanning, and provides a set of tools for editing, cleaning, healing, inspecting, rendering and converting these kind of meshes.

For more information about this tool and its features, go to the *MeshLab* homepage at <http://meshlab.sf.net> and read the documentation.

### Ideas for implementation

We will not go through any third-party web-publishing tools for 3D interactive content on web pages in this book, but there are several downloadable tools that can be used for this. For example, ISTI-CNR has created the *Visual Inspector* that can create an interactive application for large 3D models.

You could record a series of objects on a special theme like your museum's statues or other suitable objects and present these on the museum's website. Publishing such content on the website can spark visitors' curiosity about the museum even before their visit.

The webservice can also be a good way to increase accessibility of objects that may not fit in the museum's current exhibitions. To solve this problem and present it in a fine way, one could create a 3D archive that would be accessible for the public via a website. All too often, objects kept in archives never get to be seen and enjoyed by the public. The cost efficient ARC 3D Webservice could change this. So, when storing new objects, why not record those that

are suitable for 3D reconstruction and add another dimension to your museum's archive, both for staff and the interested public.

An appealing way of presenting valuable objects to audiences and putting them into a larger context is to use the **VIRTEX** tool. VIRTEX is a presentation methodology for museums that allows for a radical change in dealing with valuable pieces. VIRTEX is based upon a replica of an object that serves as the interface to explore this object. To make the replica interactive, an orientation sensor is integrated in the replica, so that the object can be visualised on a computer screen by precisely following all the orientation changes of the replica. The replica is made from a digital model of the object, made for example through ARC 3D. In this way, the user senses the shape and details of the object, sees the virtual representation of the object and triggers stories by touching parts of the replica. You can read more about this project in the VIRTEX KNOWHOW booklet included in this series.



## Benefits and notes

Many techniques exist for 3D reconstruction of existing scenes or objects. However, most of them require expensive equipment and/or trained personnel to operate the system. The ARC 3D webservice is a very cheap solution for the acquisition of realistic 3D models. The only prerequisites are a digital camera and a computer with Internet access.

As the process only requires photography, the requirements to prepare the object for digitalisation are quite few. In most indoor cases, no transport is needed to a scanning facility, although appropriate lighting may need to be added on the spot. This not only saves you time but also cuts down on the insurance and

transportation costs. If the user familiarises herself with the system and tries out a couple of image sequences to understand the limitations, she will soon find that reconstructing 3D models can be quite easy.

A tremendous advantage of the webservice is the fact that all 3D information is retrieved from the images. This means that the correct texture mapping (i.e. the colour of the object) comes for free with the reconstruction. All of the reconstructed 3D points and faces get their exact texture from the recorded images automatically, without any alignment.

As we already pointed out, a reconstruction is made from a certain viewpoint. This

means that the reconstruction will only contain those parts of the object that are visible from that viewpoint, even if you have taken photographs all around the object. The solution for this issue is to create several reconstructions from one set of all-around photographs and merge these reconstructions into one model. After merging, there can still be holes in the object (especially in creases and cavities of the object, and in object parts without surface details). There are several automatic and manual techniques to fill those holes, the latter of which does require appropriate skills and tools. Finally, the resulting object can contain too many polygons to be used in interactive applications, so simplification needs to be performed.

All of this requires appropriate skills and tools. A powerful set of tools has been developed by the ISTI-CNR group ([http://vcg.isti.cnr.it/software\\_vihap3d/download\\_cnr\\_postprocess.htm](http://vcg.isti.cnr.it/software_vihap3d/download_cnr_postprocess.htm)) and is available for the cultural heritage domain. Additionally, specialised companies can be hired to create complete and optimal 3D models.



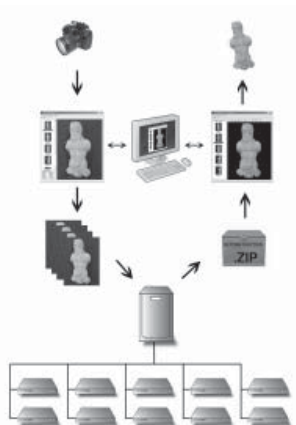
A series of still images from a 3D film of the Arc de Triomphe, Paris. The model is reconstructed from images with the use of ARC 3D and the film has been produced by VISICS.

# The ARC 3D Webservice



## TECHNOLOGY/INTERACTION

Uploading your series of images begins an automatic reconstruction process, running on a server connected to a cluster of computers. This process is based on state of the art computer vision algorithms. The result can be downloaded from an ftp server and visualised on the user's computer using a specific tool.



## IDEAS FOR IMPLEMENTATION



Enrich museum websites, archives and exhibitions by:

- Creating a 3D archive with interactive 3D models.
- Enhancing the website with interactive 3D models.
- Creating 3D content for exhibitions by displaying an interactive 3D replica of a valuable object by using the VIRTEX presentation methodology.



## REQUIRED COMPETENCIES

Basic computer skills  
(more advanced if using third-party programs)

Basic photography skills

Lighting setup (optional)

## SUMMARY

The ARC 3D Webservice enables you to transform a set of images of an object into 3D models in an easy way. You take a series of pictures of the object you want to reconstruct in 3D, upload these images to the web service and download the resulting 3D reconstruction. The service is free of charge for non-commercial use and the only equipment you need is a digital camera and a PC with access to the Internet.

## RESOURCES



Person hours: Depends on complexity of object, required level of detail, recording procedure, visualisation and implementation.

Technology, material and production costs: minimum €800

# **The ARC 3D Webservice**

## **Project team**

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*The cultural heritage community has always had a keen interest in the creation of 3D models of objects, monuments, scenes, etc. Such models not only help in creating a more vivid picture of the past in the mind of the general public, but they are also of great value for training and research within the field.*

*The ARC 3D Webservice enables its users to transform images of scenes or objects into 3D models that enhance the experience of both current and archived collections.*

The KNOWHOW booklets are an inspirational series cataloguing existing examples of a variety of projects which use ICT for the recording, display and interpretation of cultural heritage. These booklets highlight functional information covering

the design, development and implementation of ideas and their solutions, and give thoughtful suggestions for alternative applications within the cultural heritage sector. The KNOWHOW booklets aim to support people working in the area of museums, heritage sites and monuments. The information covered within the booklets benefits managers, exhibition producers/curators, pedagogues and professionals working with digital restoration, as well as those working with communication and audiences. These booklets cover projects developed by the partners of EPOCH, and are divided into the following categories: MUSEUMS, HERITAGE SITES and MONUMENTS.

[www.tii.se/knowhow](http://www.tii.se/knowhow)

