Comparative Analysis of Photogrammetric Methods for 3D Models for Museums

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***Abstract*—The goal of this paper is to make a comparative analysis and selection of methodologies for making 3D models of historical items, buildings and cultural heritage and how to preserve information such as temporary exhibitions and archaeological findings. Two of the methodologies analyzed correspond to 3D models using Sketchup and Designing Reality. Finally, panoramic photography is discussed as a 2D alternative to 3D. Sketchup is a free-ware 3D drawing program and Designing Reality is a commercial program, which uses Structure from motion. For each program/method, the same comparative analysis matrix has been used. Prototypes are made partly or fully and evaluated from the point of view of preservation of information by a museum.**

***Index Terms*—3D Reconstruction, 3D surface models, cylindrical panoramas, Google Sketchup, Designing Reality**

I. INTRODUCTION

There are several museums and institutions around the world that have made, and are in the process of making, 3D models of museum items. According to Mr. Pletinckx [1], the making of 3D models in Cultural Heritage has different purposes: 3D for research, such as the Virtual reconstruction of Regolini-Galassi tomb; 3D for digital restoration, such as bronze disks from the Regolini-Galassi tomb, Italy; 3D to prepare physical restoration, such as Nymphaeum, Sagalassos, Turkey; 3D as documentation, such as Hal Saflieni Hypogeum, Malta; 3D as educational resource, such as Abbey of Saint-John, Biograd, Croatia; or 3D as communication tool, for visual reference and recontextualisation. The virtual reconstruction of the Regolini Galassi tomb, Italy, is a part of the European "Etruscanning 3D" project, which can be followed on the official blog [2]. With the help of 3D modeling, it has been possible to restore a part of the Nymphaeum at Sagalassos, Turkey. All the standing architecture has been conserved and damaged structures, have been repaired using matching materials [3]. Hal Saflieni Hypogeum is an enormous subterranean structure excavated c. 2500 B.C. It is the only known prehistoric underground temple in the world [4]. At the website of Europeana, a 3D pdf can be viewed for further information on this model [5].

3D models of museum items, historical buildings, archeological sites etc. can be used those to create *virtual tours*. At the Virtual Museum Transnational Network(V-MUST) website [6], some of these virtual museums can be visited. In most cases, the viewer can take a virtual tour, making it possible to visit historical places online from anywhere around the world. A virtual tour can be guided or not and can include some or all of the following [6]: written descriptions, photographs and sound-files describing an item or telling a story; maps showing the geographical location of a museum or the internal location of the museum viewer; 3D models visualized as interactive objects and/or videos that make it possible for the viewer to explore an item from multiple view points; hypothesis and historical 3D models that make it possible to tell a story about how a certain place has evolved through centuries, or to visualize an ancient cite that no longer exists.

The goal of this paper is to make a comparative analysis and selection of methodologies for making 3D models of historical items, buildings and cultural heritage and how to preserve information such as temporary exhibitions and archaeological findings. Two of the analyzed methodologies correspond to 3D models using Sketchup [7] and Designing Reality [8]. Finally, panoramic photography is discussed as a 2D alternative to 3D. Sketchup is a free-ware 3D drawing program and Designing Reality is a commercial program, which uses Structure from motion. For each program/method, functionality, the same comparative analysis matrix has been used. Prototypes are made partly or fully and evaluated from the point of view of preservation of information by a museum: the museum of *Byggðasafnið Hvoll*. Due to length, time and museum access constraints, we have not been able to combine these different methods. However, it is unlikely that the results of any linear combination of these methods would be very different than the linear combination of these results.

This paper is organized as follows. In Section II, we present the methodology used in this research, while in Section III, we show the results of our comparative analysis. Finally, we conclude this paper with Section IV.

II. METHODOLOGY

In this section, we will present the different methods used in this paper: "Structure from Motion" using Designing Reality in Section II-A, Sketchup in Section II-B and the cylindrical panorama in Section II-C.

A. Structure from Motion with Designing Reality

`Designing Reality` is a software solution creating 3D models from 2D images. The program is commercial so access to the details of the implementation is not available. However, some examples of 3D models made with the program can be viewed on the official website of Designing Reality: people,

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cityscapes, statues, landscapes, buildings. According to its founder, Ólafur Haraldsson, the method is less time consuming than normal photogrammetry and, on the official website, it is referred to as *automatic photogrammetry* [8]. Here, it will be referred to as *Structure from motion*.

Structure from motion (SFM) is the process of estimating 3D information from a sequence of 2D images. When the camera moves around an object or the object moves around the camera, information is obtained from images sensed over time. The correspondence between images and the reconstruction of 3D object needs to be found [9]. Once the 2D projection of a point in the real scene has been found, its position in 3D can be assumed somewhere along the ray connecting the camera optical centre and the corresponding spot in the image plane. Tracking its projections across multiple images and using triangulation allows the relatively accurate localisation of the point in 3D [10].

Given the sufficient number of points and lines over images, from different directions it is possible to estimate the 3D location of the structure and the camera location for each point in a 2D image. The 3D structure model differs from the true model by a projective transformation. The process of SFM aims at minimizing the distances between estimated 3D structure projections and actual image measurements [10]. The youtube video "The Structure from Motion Pipeline" [10] explains the following procedure in a very simple way:

1) Use a tripod as object support
2) Add a panoramic head that allows click-stop rotations (Manfrotto 300N).
3) Add object table on top.
4) Position object aligned with the rotation center (see Figure 1).
5) Position lights, and camera on tripod (see Figure 2).
6) Shoot object, rotate one click-stop, shoot again for 360 degrees (A rotation of 10 degrees is recommended here).
7) Shoot another round with different camera inclination if necessary.
8) Remove white background with `Photoshop` or other similar software, replace by fixed color, vignete or image.
9) Do for all images with same parameters.

For reflective objects, use an object tent with surrounding light. Put the object in the tent and install camera through the zipper opening. Then, process as recorded without tent.

As the user has uploaded the images, the procedure of the program is as follows:

- Calculates the location of the camera
- Creates a Point Cloud
- Creates a Mesh (Depth map)
- Adds texture to the Mesh
- Creates an output (video as an option)

B. Drawing of 3D models with Sketchup

`Sketchup` is a 3D modeling tool that allows the user to draw 3D models. The program is available as a free version as well a as professional and due to its simplicity, a user friendly tool-bar and the help of on-line tutorials, almost anybody can use it to develop interesting 3D models [7].

Figure 1. Position object aligned with the rotation center.

Figure 2. Position lights, and camera on tripod.

In order to investigate the possibilities of developing 3D models for the museum *Byggdasafnid Hvoll*, an introductory survey of surface classes that are easy to build, based on the book Architectural Geometry [11] and some examples of how these classes can be handled with `Sketchup` has been made. The surface classes presented are *rotational surfaces*, *translational surfaces*, *ruled surfaces*, *developables*, *helical surfaces*, *pipe surfaces* and *offsets*. Mathematical description, based on same book, is also shown. Note that some surfaces can be expressed as a surface from more than one surface class.

Rotational surfaces, sometimes called *surfaces of revolution*, are generated by rotating a plane curve γ, called the profile curve, about a straight line in the plane. If we describe γ as $(f(u), 0, g(u))$, the mathematical expression for rotational surface is $\boldsymbol{\sigma}(u, v) = (f(u)\cos(v), f(u)\sin(v)), g(u))$. Spheres, cylinders, cones and tori are well known rotational surfaces.

If we consider two curves k and l, that intersect at a single point we call the origin o, a *translational surface* can be created by translating one of the curves along the other. Thus, the surface contains a set of curves k_p that are congruent with the profile curve k. The curves are called profile curve and path curve and the same translational surface is generated when changing the roles of these two. Mathematically, each point of the translational surface can be expressed as

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$\boldsymbol{\sigma}(u,v) = \mathbf{k}(u) + \mathbf{l}(v)$. The generation of translational surfaces is straightforward and, as they carry two sets of congruent parameter curves, they are commonly used in architecture.

Surfaces that are generated by moving a straight line are called *ruled surfaces*. Cylinders, cones, one-sheet hyperboloids and hyperbolic paraboloids can all be described as ruled surfaces. They carry families of straight lines that are called *generators* or *rulings* and can be described mathematically as $\boldsymbol{\sigma}(u,v) = \boldsymbol{\alpha}(u) + v \cdot \boldsymbol{\omega}(u)$, where $\boldsymbol{\alpha}$ is called the directrix curve. The rulings go through $\boldsymbol{\alpha}$ and are parallel to $\boldsymbol{\omega}$. Ruled surfaces can also be generated by connecting corresponding points of two generating curves and this method gives a wide possibility for generating different surfaces.

Developable surfaces behave just like paper. They can be bent and twisted and unfolded into the plane without stretching or tearing. Due to this they can be easily covered with sheet metal and are therefore widely used in architecture. In addition to this, they carry a family of straight lines which simplifies their construction. Cylinders, cones and tangent surfaces of space curves are all developable ruled surfaces and have the property that a tangent plane is always tangent to the surface along an entire ruling.

Helical surface is created by applying a smooth helical motion to a spatial curve, c. One can generate the same surface either by applying the helical motion to a meridian curve or a cross section. When using the meridian curve $c = (f(v), 0, g(v)$, the mathematical expression for the helical surface is $\boldsymbol{\omega}(u,v) = (f(v)\cos u, f(v)\sin u, g(v) + a \cdot v)$.

A *pipe surface* is the envelope of spheres of equal radius r, whose centers lie on a spine curve c. As an example of two simple pipe surfaces the cylinder has a straight line as the spine curve, and the torus which has a circle as a spine curve. Obviously, non-bendable materials are not suitable for this type of surface. In practice, one uses metal tubes bent into the required form and the manufacturing of such bent tubes is challenging.

In this subsection, two methods for modeling a building are presented. First, the building is modeled from scratch, using non-digital data, that is a drawing on a paper. The interior walls are included in this model. This model could be useful for showing section planes and cuts, or to show the interiors of the house, furniture, etc. Secondly, the same building is modeled using photographs, and here, the model can be exported to Google Earth. Other methods are available, for example by importing a cad file or a drawing and use it as base-plan for the model, and photo-match, those methods are are not explained here.

1) Modeling From Scratch: Here, a three stories house is modeled by using printed plans provided by a realtor. The model contains only straight lines, and the tools that have been used for drawing are *Line*, *Rectangle* and *Push/Pull*. The door and window openings are created with a rectangle that is pushed trough the walls in order to leave an opening. Furnitures are not included. Figure 3 and Figure 4 show the house in two different modes: Shaded with Textures and X-Ray.

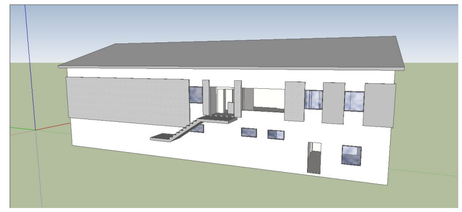

Figure 3. The house shaded with textures.

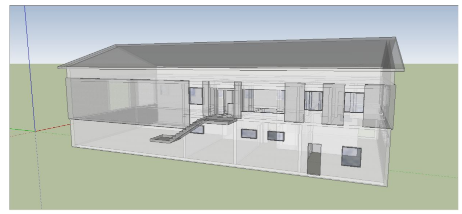

Figure 4. The house in X-ray mode. The interior walls can bee seen.

2) Modeling From Photographs: Google Earth is a useful tool when it comes to presenting 3D models and Sketchup is the most commonly used tool for Google Earth Modeling [12]. There are a few simple steps to follow, and here, the article How to Make a Google Earth Building in SketchUp is used as a guide along with the accompanied video tutorial. At the official Sketchup Help webpage, further guides in Geo-modeling can be found [13].

C. How to Create a Cylindrical Panorama

A cylindrical panorama can be created by shooting several pictures, where each pair of adjacent pictures have an overlap, and then, stitching them together. It is possible to create a cylindrical panorama using any hand-held camera, with any lens, but in order to get good quality, some extra equipment is needed: tripod, spirit level, remote shutter release, Panoramic head ("pano-head") and wide angle lens.

By using a tripod, the camera rotates around a fixed point and at the same level. It also eliminates the risk of camera shake and position change in between shots. If the photographs are not taken at a good level, problems can occur when stitching them together. It might be necessary to crop down the image and thereby reduce the vertical filed of the final result. A spirit level is useful to make sure that the tripods head is correctly leveled, this is especially needed when shooting pictures in the nature. A Remote shutter release can be useful when shooting several photos at a time and also reduces the risk of accidentally moving the tripod while shooting. A Panoramic head is an additional attachment to put on top of the tripod before the camera is attached. It makes it possible to attach the camera such that it rotates around the no-parallax-point of the camera lens. This is important in order to avoid stitching errors. There is as well the feature of click-stops, that allow you to fix the angle of each rotation of the camera and/or a built in spirit level. Using a wide angle lens has the advantage over a regular lens, that less pictures needs to be taken and it

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is possible to capture more vertically. When choosing a lens it is necessary to make sure that it is supported by the software to be used.

III. Results

In this section, we will see the results of the methods described in last section applied to a museum item (Section III-A) and to a room (Section III-B) and the comparison between different methods (Section III-C)

A. A Museum Item

In the database Sarpur [14], the following items from *Jóhannsstofa* are listed with a photo and short description: a custom made footrest, see Figure 5; and a custom made hat, see Figure 6.

Figure 5. The footrest as shown in the database Sarpur.

Figure 6. The hat as shown in the database Sarpur.

1) A Sketchup Model of the Footrest: In this section, a `Sketchup` model of a footrest has been made. The footrest is remarkable due to the extraordinary size and with `Sketchup` it is possible to emphasize this. Figure 7, shows the footrest with scale, and Figure 8 shows the same footrest next to an identical copy, scaled down to regular size, and a 3D woman uploaded from Sketchup warehouse.

2) A Designing Reality Model of the Hat: In this section, a 3D model of a museum object, in this case a hat from *Jóhannsstofa*, is created with photography and the program `Designing Reality`. Völundur Jónsson, photographer, offered his professional help and equipment, taking care of the photos and photo-editing, and Ólafur Haraldsson, the developer of `Designing Reality` created the model using his software. Figure 9 shows a snapshot of the video output of the 3D model. The video can be viewed at vimeo.com [15].

Figure 7. A scaled `Sketchup` model of the footrest.

Figure 8. A `Sketchup` model of the footrest, compared to a regularly sized footrest.

Figure 9. A Designing Reality model of the hat: Photograph, Point cloud, mesh and mesh with texture.

B. A Room

In this section, two methods have been used to partly model and visualize the room *Jóhannsstofa*. In Section III-B1, the room is modeled with `Sketchup` and in Section III-B2, some examples of cylindrical photograps have been made. Völundur Jónsson photographer, kindly offered his professional help and equipment with some of the photos in this section.

1) Modeling the room with Sketchup: In this section, the room is partially modeled with `Sketchup`. Figure 10 shows the model that was made by measuring the room and then, recreating it with `Sketchup`. The radiator was imported

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from `Sketchup` warehouse and slightly modified. In order to complete the room, texture should be added. Figure 11 shows the same room where the `Sketchup` model of the footrest from section III-A1 has been inserted.

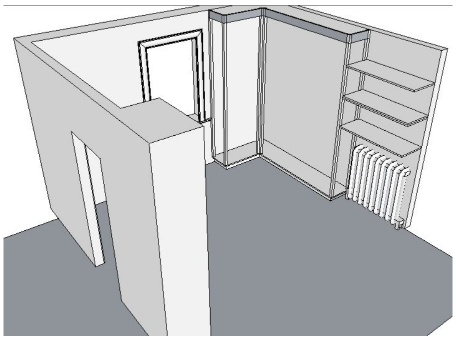

Figure 10. The room partially modeled with Sketchup.

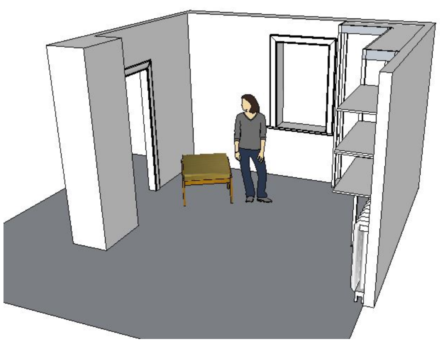

Figure 11. The room partially modeled with Sketchup, and the footrest inserted.

2) Cylindrical Photograph of the Room: In this section experiments have been made with panoramic photographs of the room. Two examples have been created using minimum equipment: only a tripod and a camera, but in each example, with different lenses. Figure 12 shows a panoramic photo of the room. The photo is created with a trial version of Easypano [16] and thus, watermarked. It is taken with a compact digital camera, Canon Ixus 220 HS, and therefore the lens-width is not sufficient for the purpose of creating a nice cylindrical photo showing the room from floor to ceiling. However, since the width of the camera is only 20.8mm, using a tripod and rotating around the center of the camera, the distance from rotation center to the no-parallax-point of the camera lens will not exceed 10.4mm. Therefore, misplacement in the vertical lines is not visible.

In order to get a photo showing a broader view in the vertical, Völundur Jónsson offered his help. Using Canon EOS 5D MKII camera and lens EF 17-40L @ 40mm, f14, a panoramic photo was created that gives the necessary view in order to visualize the museum items from floor to ceiling. Figure 13 by Völundur Jónsson, shows the panoramic picture. The picture is created with the program KOLOR Autopano GIGA 3.0 [17].

Figure 12. A panoramic photograph of the room, using a handheld camera and a tripod.

Figure 13. A panoramic photograph of the room, using wide lens and a tripod.

3) Examples of error: When taking a cylindrical photograph there are a few things to consider regarding the photographic equipment. Depending on the materials photographed, some actions might be necessary on the spot. In this case, the glass protecting the museum items should be removed before photographing in order to prevent the mirroring effect shown in Figure 14. This has not been done since the purpose was not to create a virtual tour, but to give examples. Figure 14 shows the vertical misplacement of lines that occurs if the focal point of the camera is not centered.

Figure 14. A mirror reflection is clearly seen due to the glass protecting the museum items. Vertical misplacement of lines can be seen as well.

C. Comparative analysis results

At the beginning of the project a personal interview with Íris Ólöf Sigurjónsdóttir was made in September 2012 [18] in order to detect the expectations of the museum. Another interview was made in August 2013 [19], in order to find out how the methods presented fit with those expectations. The following features are considered important to the museum:

cost (as it is a museum with tight budget), user-friendlynes (since there are no IT specialists working for the museum) and suitability for visualizing different items and accuracy. The features above are compared in Table I. `Sketchup` is a freeware, but there is a cost in hiring the staff to implement models. The accuracy is within millimeters, and depending on the modeler, is acceptable when it comes to drawing buildings. However, modeling complex or irregularly shaped items, such as a hat, is not considered to have accaptable accuracy. `Designing Reality` is not a freeware, however, there is less cost in hiring the staff. The accuracy is within millimeters, and is acceptable for complex items. Cylindrical Photography is a 2D alternative, here, not a freeware, and not much training for the staff. The accuracy should not be compared with the other programs since it is not 3D modeling. However, it often shows what needs to be shown. All three methods are considered to be user friendly.

Table I
COMPARISON OF THE METHODS.

Features	Sketchup	Designing Reality	Cylindric. Photogr.
Free	Yes	No	Yes/No
User friendly	Yes	Yes	Yes
vis. existing buildings	Yes	Yes	Yes
vis. non-exist. build.	Yes	No	No
vis. landscape	No	Yes	Yes
complex items	No	3D	2D

IV. CONCLUSIONS

The advantage of using `Sketchup` is mainly the cost, it is a freeware, but also the fact that it is a very user friendly program and compatible with many other programs, such as `Google Earth`. It has been shown that `Sketchup` can handle the surfaces that need to be dealt with in order to create 3D models of the houses. The available data at *Hvoll* is mainly old photographs and drawings and from this data, it is possible to recreate a lost building or a certain room. Furthermore, since many of the houses still exist, it is possible to measure and photograph those. In addition, if the houses have been reconstructed recently, some cad-files exist as well. It is therefore concluded that developing 3D models of historical buildings, using `Sketchup` is a possible option. The disadvantage is that, when it comes to modeling complex items, it can be inaccurate or even impossible to use Sketchup or time consuming, and therefore costly when considering the use of staff-time.

The advantage of using `Designing Reality` is that it is a simple and fast method that gives accurate results. It has been explained how to model an item, but in addition, houses and landscapes can be modeled with the help of drones, helicopters or airplanes. The disadvantage of this program is that it is not possible to make models of non-existing buildings unless the appropriate photographs exist, and the cost is high in this case. However, when compared to `Sketchup` and depending on the size of the model, the cost might be lower considering the staff-time used for each model.

The advantage of taking cylindrical photographs is that it is an easy and fast procedure, and even if not in 3D, it still gives a very clear overview of for example a room or a street-view. It can be used for making virtual tours where already existing materials such as sound-files, videos or 3D models can be included. The disadvantage is that it is usually not a freeware. However using panoramas for the purpose of creating a virtual tour could be thought of as combining it all together, rather than a independent method to compare against those previously mentioned.

The method chosen to model a historical building depends not only on available data, but also on the purpose of the model. There are a few possibilities. Museums could make use of both programs in order to create various forms of teaching material, such as pdf's, slide-shows, animations etc. Alternatively, the purpose could be simply to preserve information about a certain periodical street-view. Furthermore models can be visualized using 3D printers, 3D pdf's or video presentations (animation). Finally, the 3D models created could be used as a part of a virtual tour through the museum.

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