

Cultural heritage 3D reconstruction from historical materials

Dagmāra Krūmiņa

Department of Geomatics, The Faculty of Building and Civil Engineering

Riga Technical University, Riga, Latvia

ABSTRACT

This thesis describes the use of different types of documented materials from various archives and websites to reconstruct and create 3D models of cultural heritage sites. This work focuses more on damaged cultural heritage objects and on the lost heritage.

The first part of the thesis reviews documentation methods that are divided into two categories, image-based techniques and those obtained by other techniques, such as, tape measurements, traditional tachymetrical surveying or laser scanning.

The second part looks at historical materials available in various archives about historical objects in Latvia. Description of the type of data, and the possibilities of digitization is given.

In the third and fourth part of the thesis, the three-dimensional reconstruction methods of cultural heritage sites from the historical materials were created, described and put in praxis in several case studies. During the study, data on 4 historical objects in Latvia have been obtained in field studies.

Keywords: 3D, reconstruction from historical materials, documentation techniques, archive materials

1. INTRODUCTION

The current dramatic episodes of destruction of many cultural heritage objects have emphasized the problem of safeguarding the already threatened heritage and reconstructing all the objects that were lost by the armed conflicts of the past or simply human negligence. We must appreciate our cultural heritage, because they hold universal value to all humanity and have a legacy for generations to come.

Nowadays there are many new technologies and instruments available, Laser scanners or professional digital cameras, allow us to collect dimensional data. With proper knowledge, they can be easily transformed to 3D models. But what about the data that already has been collected, and what about the data that contains information about lost or partially destroyed cultural heritage sites? It is important to find the best solutions to reconstruct cultural heritage 3D models from historical materials using already collected information in the archives.

The historical materials, that are stored in various archives or web sites offers a possibility to recover the destroyed building and monument geometry and to reconstruct a 3D



model to document, study, restore and maintain their memory. The reconstruction process of a historical cultural heritage sites contains a set of challenges that are dealt with in this Master Theses.

The current recording and archiving activities of cultural heritage can be divided in two main categories:

1. Preventive actions aimed at digitizing still existing, specific sites or monuments, depending on their degree of risk,
2. The reconstruction of lost heritage through existing data collected.

This work focuses more on the second category of lost heritage but also on damaged cultural heritage objects.

The study explores 3D reconstruction methods using authors previously collected data from various resources. Task is to try different methods, describe the existing ones and analyse their results. It is explained which methods are more applicable in different situations. For example, if the materials are from different resources or one resource, if a wide range of images are available or only a few pictures, if the material is obtained with one documentation technique or several different techniques.

2. CATEGORIZATION OF CULTURAL HERITAGE DOCUMENTATION TECHNIQUES

Good documentation of a site allows for a better understanding of its value—historical, scientific, aesthetic, social, and economic. Recognition of a site's value and significance is often the first step toward its conservation. [1]

When we think about cultural heritage documentation first it is necessary to consider that documentation has been made at different times with different technologies and tools. There is a wide variety of documentation techniques, therefore it is easier to understand them when you sort them into categories and groups.

Every object is different from other, each of them has their own unique characteristics. The objects are documented in different time periods and they have been in different physical conditions. In the Table 1.1 categorization is based on two parameters – image-based, non-image - based.

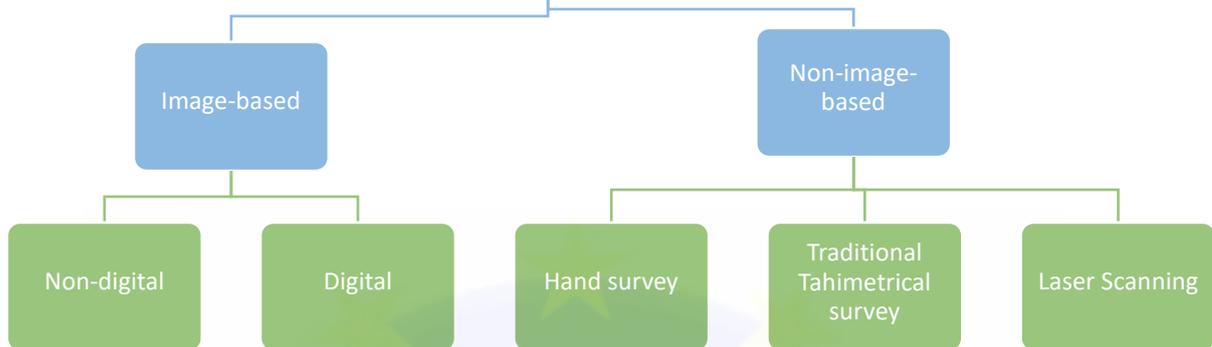


Table 1. 1 Documentation techniques [author]

3. ARCHIVE DOCUMENTATION

This phase in cultural heritage reconstruction process is the most time consuming and can be very expensive. Finding sources and the right materials, that can be used for recreation is complicated, long process. In Latvia there are several options where to look for sources of information:

- The regional state archives. In Latvia there are the territorial units of the Latvian National Archives, which deal with the accumulation, recording, preservation and use of documents to be included in the National Documentary Heritage in the territories of local governments,
- National cultural heritage inspection. They provide information on state-protected cultural monuments, such as, photos and different types of documentation materials,
- The National Audio-visual Archives is a functional unit of the National Archives, which ensures the accumulation, recording, preservation and use of audio-visual, photo, sound and electronic documents to be included in the national documentary heritage,
- Historical images can be found in library archives - from a nationwide library to a local village library,
- Materials of cultural heritage objects can also be found also in documentary collections of cooperatives or private citizens,
- Wide variety of materials are available on Internet resources

A large part of the state archives is not encouraging. They do not issue the material for further processing or require a large fee for the documentation. As well as private collectors do not want to supply the original materials but will share with the scanned or re-photographed



material itself. However, to achieve the highest possible result, the information should be as clean and understandable as possible without any additional distortion or outside interference.

3.1. Photographic Products

The performance of image (photography or orthophotography) as survey products is determined by the image resolution and the quality of the captured image (coverage, attitude, exposure, and sharpness, extent of shadow and incident illumination) as well as the reproduction standard used. [2]

The materials of this type of documentation archive are useful at times when a cultural-historical building has been lost from the earth's surface, collapsed, rebuilt, partially demolished or simply changed over time. Using historic photographs, it is possible to restore the building partially or completely. The accuracy of the 3D model depends directly on the quality of the pictures and their quantity.

It is a great challenge to work with non-digital archive documentation. Often there is no information available about camera parameters, position, under what conditions under what the photo was taken, spectral and tonal sensitivity, resolution and so on. In this case there are many unknown parameters that should be taken into consideration in further post - processing.

3.2. Plans and maps

3.2.1. Historical plans and maps

The availability of historical plans of the destroyed buildings is varying very much. A lot of detailed plans which are showing the whole building are available. However they are very inhomogeneous in level of detail and in scale. In some cases unknown historical measuring units are applied. [3] In a general sense, old maps are referred to all cartographic records such as historical cadastral maps, city plans, and topographic map series. [4] Cartographic records already exist for many centuries. European nations and parts of their former colonies have been repeatedly mapped. Digital libraries and also National Mapping Agency increasingly makes large map collection available online. Largest historical source of maps online portal in Europe is “OldMapOnline”, which provides access to many digital maps. The only problem is that these maps are not georeferenced and for further use in research, the date of the map survey as well as the exact location of the map content have to be known. In Latvian georeferenced historical maps are available at “kartes.gisnet.lv” and “vesture.dodies.lv”.

3.2.2. Architectural plans

Architectural plans contain information about architectural design – interior, exterior, object geometry, semantics.



Usually the architectural plans exist in the following two formats:

- Vector (hand drawn, or prepared using CAD software),
- Raster (scan of hand drawn floor prints). [5]

And raster format can be:

- Digital,
- Non-digital (drawn on paper).

When considering constructing a 3D model from architectural plans or use them as reference in further modelling process, it is important to understand the difference between all available architectural plans in the cultural heritage documentation archives. [6]

3.3. Digitization process

In the case of fragile carrier like photographic plates, negatives or old paper plans digitisation can ensure long-term preservation of archive documentation. Digitization can be done with a high-resolution office scanner for photographic plates in the best case with a professional slide and negative scanner. Digitizing process can vary considerably depending on the method which is later used to create a 3D model. When exporting a file, it is important to find the appropriate file format considering the further processing program and method.

4. 3D RECONSTRUCTION FROM HISTORICAL MATERIALS

4.1. Image – based reconstruction

Considering this purpose, an initial investigation into the material provided by the chosen library - National Heritage Inspection, State Archive of Audio-visual Documents, internet resources and private archive, shows several challenges to the process of automatic reconstruction such as:

- Images are sometimes labelled incorrectly, or the labels are missing,
- Some images are not yet digitized with a high enough quality needed for the algorithms used in digital reconstruction,
- Keyword searches do not show images of buildings exclusively,
- Images have different illuminations or image errors,
- Images contain no colour information,
- Images are not taken by the same photographer with the same camera at the same time,
- All the available images of a building of interest often show the building just from a single position and angle. [7]

4.1.1. Modelling from a single photo

Many cultural architectural heritage objects do not have a lot of useful documentation that can be used to create a model. There are, however, many cases where at least one image is available that might be useful for creating a model. In a situation where only one picture is available, two modelling solutions can be applied:

1. Create a model from a photo in perspective

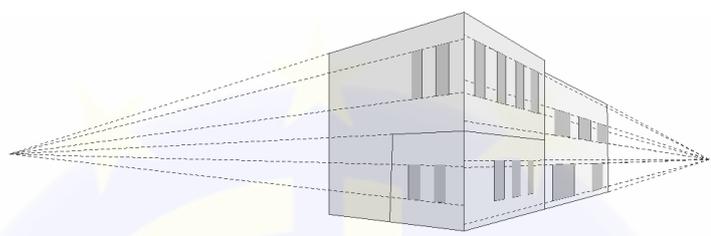


Figure 4.1 Basic perspective principle [author]

2. Apply a photo on a flat, manually designed model.

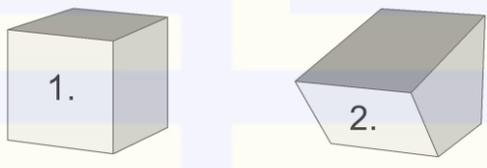


Figure 4.2 Modelling surface [author]

4.1.2. Modelling from two photos

In cultural heritage archive documentation many stereophotos are available. Stereophotogrammetric recordings allow 3D documentation and evaluation of uneven objects and freeform object surfaces. For many years there was a needed spatial perception at stereoscopic viewing, however, now integration of automated image analysis techniques is more user-friendly. [8]

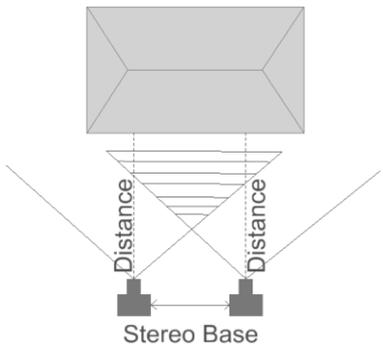


Figure 4.3 Distance between camera positions [author]

Results of stereographic restitution can be:

- 2D-plans of single facades,
- 3D-wireframe and surface models,



- A simple list of coordinates.

4.1.3. Modelling from multiple photos

This method for object reconstruction is based on using unlimited number of photos. For this kind of image-based virtual reconstruction many images from different points of view are required. This modelling method allows to use analog or digital data from one or many different cameras and from video cameras. Photos can be taken with various techniques.

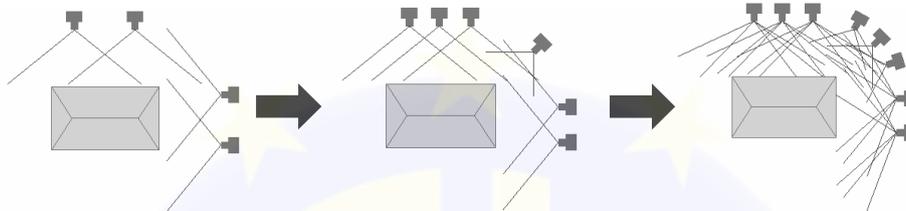


Figure 4.4 Image capture variations from the worst to the best possible scenario. [author]

4.2. 3D modelling from architectural plans

For 3D model creation, most existing approaches use vector form of the plans. As already mentioned in previous chapters, architectural plans can be in vector or raster format and plans can be drawn on paper or digital. If the plans are paper format then at first they must be digitalized with professional, high resolution scanner. For the output file it is better to use TIFF format, because in conversion process other file formats can give more speckles and unnecessary distortion of the plan.

Secondly plans must be vectorised and it can be done manually or automatically. Manually, it is very time consuming as the information can be interpreted and undeniably the human factor is also added to this process. Converting images of technical drawings automatically, such as architectural plans, must be done as accurately as possible to avoid losing an extra precision and data. Many programs that use image processing algorithms can be used to automate raster vectorisation.

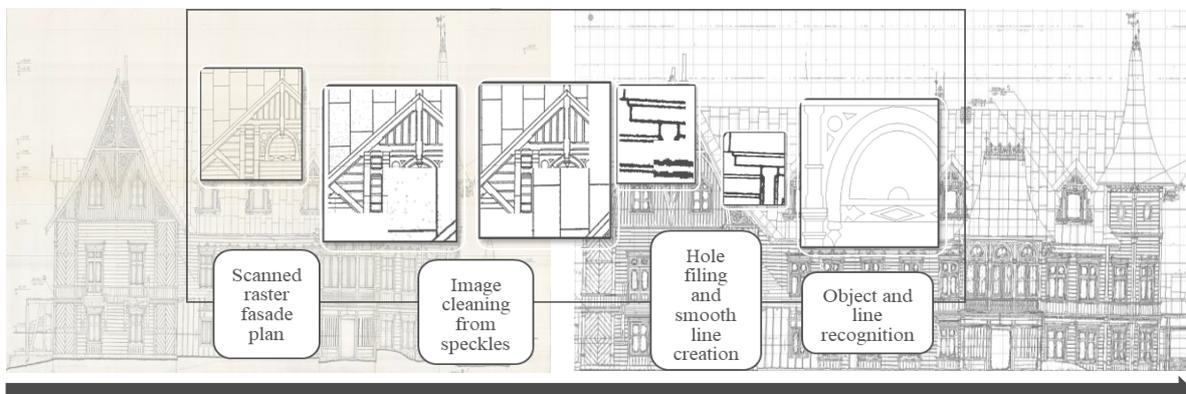


Figure 4.5 Raster digitization and vectorisation process [author]

There are several 3D modelling technical solutions using architectural plans:

- Floor generation and wall extrusion from vector data
- Modelling from floor plan and elevating plan using vectorized 2D data, in CAD software
- Modelling from floor plan and elevation plan using raster data

5. CASE STUDY

5.1. Manor House «Sēja» 3D reconstruction using single photo

For the case study Manor House “Sēja” was chosen. It was built at the end of the 18th century. At the end of the 19th century, the house was rebuilt, its modest baroque style was modernized with exquisite neogothic decorations. Nowadays the manor house is in a state of collapse. One photo was chosen to reconstruct this building, which was suitable for this modelling method. This photography was in a paper format, which is why before starting the modelling process it was necessary to scan digitize the photo.



Figure 5.1 Illustration shows degradation of Manor House Sējas over the years [author]

In this case building was modelled from only one photo using modelling in perspective in SketchUp. To understand how modelling from photo works in SketchUp and why this specific program is suitable for this kind of modelling it is necessary to understand the basic principles of perspective and how they apply.

Basic perspective principle is that lines will appear to converge toward the horizon when viewed in perspective. Many of the features of the building are parallel so if we extend imaginary lines we can see how they appear to converge toward the horizon when viewed in perspective. [9]

There are some basic steps that should be followed when modelling historical architecture in SketchUp:

1. Set up construction guides for a structure we plan to model using primary sources as needed,
2. Add measurements that were taken in Photoshop, set proper scale for the image, by drawing base lines in previously measured length and just then importing the raster file,
3. Draw a 2D section of the structure's base,
4. Add the 2D geometry to groups and layers,
5. Extrude individual 2D sections into 3D,
6. Add architectural details,
7. Export model in necessary format (if it's relevant to the assignment, before exporting, add textures, lighting, and animation).



Figure 5.2 Digitized paper photo Figure 5.3 Screenshot from 3D model in SketchUp [author]

5.2. Wooden Castle «Valdeka» 3D reconstruction using architectural plans and photographic materials

For the study “Valdeka”, a wooden castle was chosen. It was built in 1896 as a summer residence of baron Wulf. It was a very luxurious, extravagant building with spacious glazed loggias, bay windows, tin roof and pointed towers. This was the only wooden palace of this size with such luxurious wooden finishes in Latvia. During the Soviet times, the castle used as in workers apartments. Gradually the castle was burnt down. Surrounding residents used the castle's wooden constructions as a heating material for winter. In 1988, the State Committee Restoration Institute carried out the documentation of the Valdeka wooden castle. By 2002 the castle was destroyed. Because of the photo fixation and survey materials carried out by the Restoration Institute, it is possible to reconstruct a 3D model for this building.

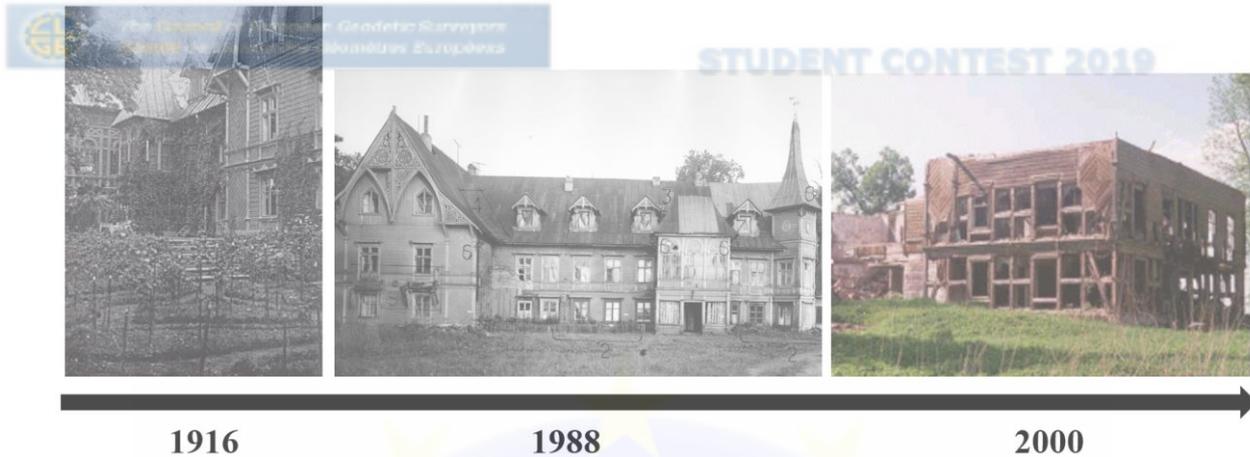


Figure 5.4 Illustration shows degradation of wooden castle Valdeka [author]

Available materials for reconstruction

- 13 photographic glass plates
- 40 paper photographs
- Photo fixation plan
- Architectural plans for every facade and floor plan with dimensions

5.2.1. 3D reconstruction using architectural plans

Modelling from floor plan and elevating plan using vectorized 2D data, in CAD software

For this case study, the architectural elevation plan was used. This plan is plotted at a scale of 1:50 and the main building was plotted using photogrammetric methods. All data was digitized and vectorized using methods described before. It should be noted that details for this specific project were revised on-site. Therefore, it should be remembered that hand taped measurements can be interpreted and in this case for better understanding, when going for higher level of detail, a professional from an architectural history field should be consulted.

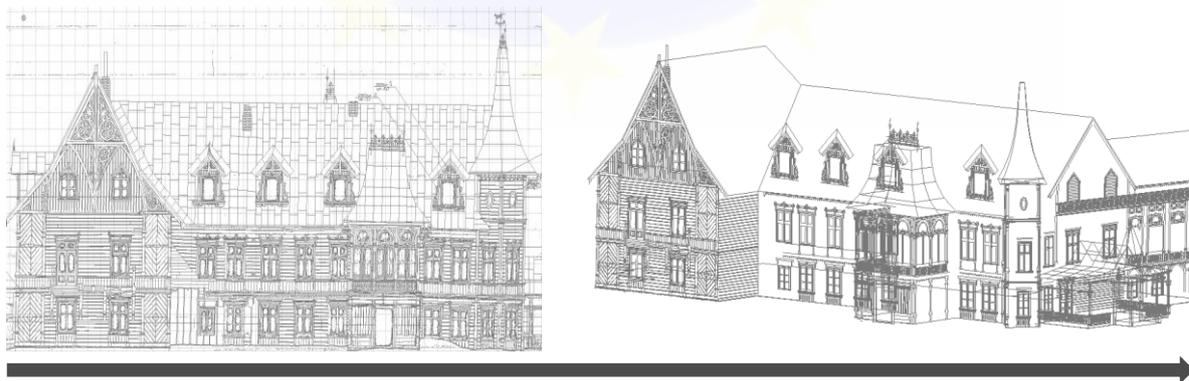


Figure 5.5 Vectorized elevation plan transformed in to a 3D vector model [author]

Modelling from floor plan and elevation plan using raster data

This modelling method is like previously described modelling techniques in Sketchup Pro when modelling from images, but not the same. In this case different rules are applied. For implementation of this method, four elevation plans and one floor plan from the Valdeka wood

castle documentation materials were selected. For the floor plan dimensions were available, therefore they were also applied to the elevation plans.

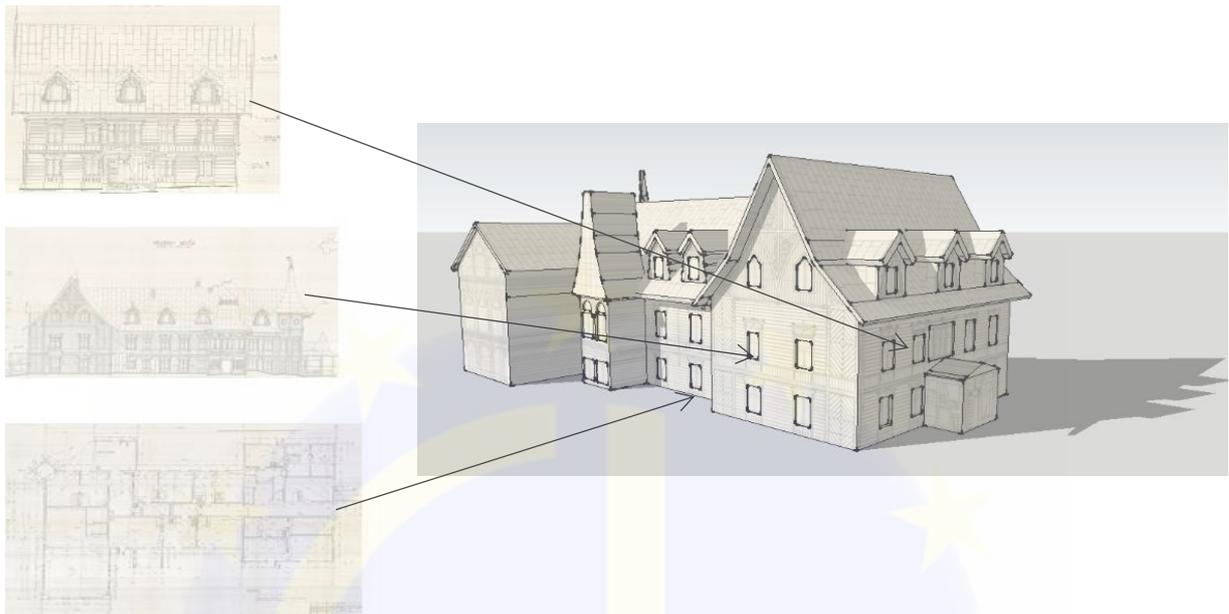


Figure 5.6 Modelling from architectural raster format plans [author]

In this case modelling starts with drawing the baseline from the floor plan. Afterwards elevation plans one by one are properly scaled, rotated and matched to the whole construction. All the plans must be correctly aligned. This step in this modelling method is the most important. Each of these steps must be done with great accuracy.

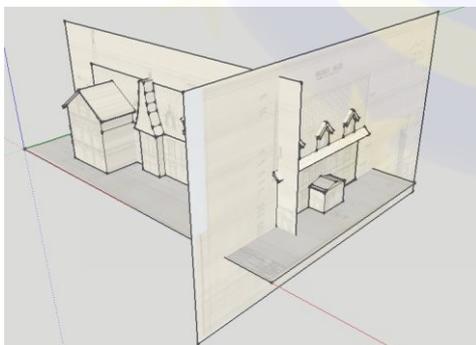


Figure 5.7 Aligning elevation plans [author]

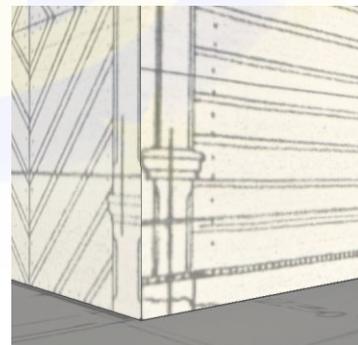


Figure 5.8 Example of bad elevation plan alignment [author]

Once the modelling process has begun, it is no longer possible to add any corrections to raster data alignment. The further process should start from modelling the larger parts to the smaller ones.

5.2.2. 3D reconstruction using photographic materials

Many images of different angles were available for this building that is why for this reconstruction bundle processing technique was chosen. A lot of bundle processing applications are available today, like Bentley Context Capture, Pix4Dmapper, Agisoft PhotoScan, but they

are primarily designed to work with modern photogrammetry, that uses various digital cameras - compact, mirrorless, SLR, video, built-in.

Resolving camera parameters error

There can be cases when the archives of cultural heritage have preserved information about the documentation conditions, such as:

- Camera's inner parameters,
- Position of the camera in the field.

In this situation there were available documentation with data about known camera positions in the field. This allows to create approximate list in local coordinate system of camera positions which contains information about each image centre X, Y, and Z coordinates and image rotation parameters, omega, phi, and kappa.

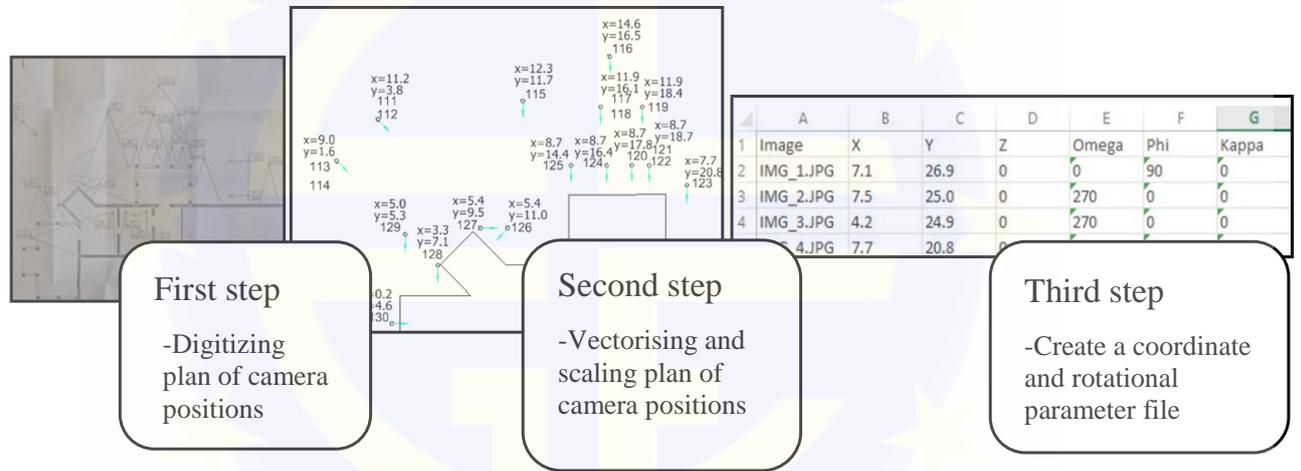


Figure 5.9 Creating coordinate and rotation parameter file [author]

Tie points

Bundle adjustment programs searches for interest points on every image and studies the local neighbourhood of every point found. Then it matches interest points based on their local neighbourhood comparison. In general, it's quite a common approach. [10]

Using masks

Usually when reconstructing a cultural heritage object, multiple different images are used that are taken at different times and are in different conditions. Also, there are many cases when photo contains a lot of distracting information, for example, in the picture below, half of the photo is covered by the ground and trees. This complicates photo aligning processes for the program. Mask is a covering tool, that is used to define the specific building areas on the photos which can otherwise be confusing to the program or lead to incorrect reconstruction results.

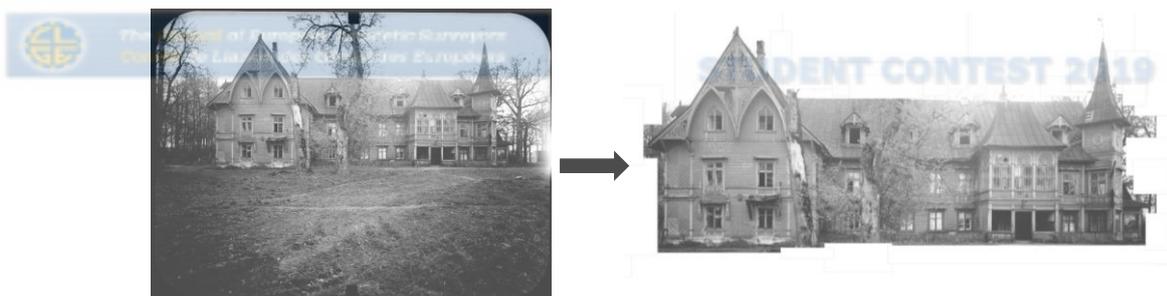


Figure 5.10 Applying mask to the photo [author]

In cases where archive documents are used it is hard to predict how programs are going to calculate information from the raster data. In this case the better quality is available using less images from just one part of the building and then combining the resulting data into one.

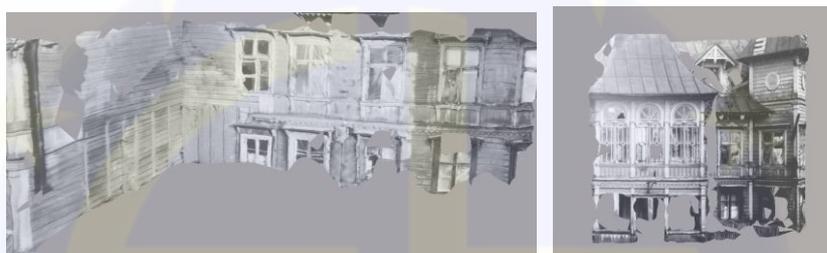


Figure 5.11 Creating separate sections of building and afterwards combining them together. [author]

5.3. Manor House «Endzele» 3D reconstruction using photographic materials

For the case study Manor Endzele was used. Manor Endzele was built in 1880 and was proud of its tower and various facade decorations, even on console sculptures. Gothic motifs in the building were subordinate to the aesthetics of brickwork, masonry and large planks.

During the Soviet times the tower was demolished and then rebuilt. To reconstruct the house in its original appearance it was necessary to find as many images as possible with the historical tower.



Before tower reconstruction



After tower reconstruction

Figure 5.12 Manor Endzele before and after tower reconstruction [author], [Manor Endzele archive]

- 3 photos representing demolished tower
- On the sight 305 new images were taken

Since the rest of the building has not changed over the years, it can be measured and documented using the techniques available today. In this case photogrammetric technique was chosen as the main documentation technique.

In the first step with a professional digital camera Sony ILCE6000, on the sight, 305 new images were taken. Three photos, of which it is possible to reconstruct the tower, were found with the help of the Valmiera City Museum and the Museum of Endzele manor. Since the images were collected from a variety of resources, they were digitized with different scanners.

In the second step, a 3D model of the main building was created using bundle adjustment technique (from 305 newly taken images). In this step, the building was properly scaled using measured dimensions. Dimensions were derived from architectural plans and some of the most significant distances were measured with the measuring tape. The architectural plans were derived from the archives of the Museum of Endzele. In the next step using method described in Chapter 3.1.3. from the only three images available a Sketchup model was created.

As the images below in Figure 3.28 shows, over the years first floor of the Manor house tower didn't changed, therefore the first-floor elements were used to tie the two created models together.

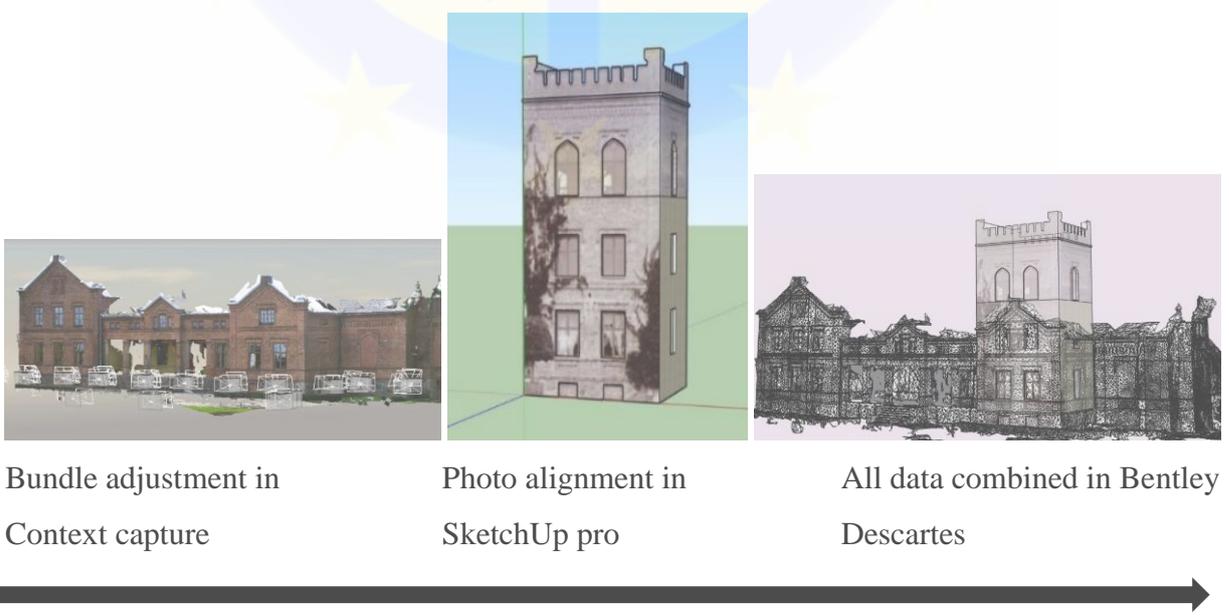


Figure 5.13 Creating 3D model of Manor Endzele [author]



For a more highly detailed and accurate model, pictures with the roof of the manor house would be needed. This is possible with both drone and LIDAR technology. As well as for more accurate tie points, it would be advisable to take measurements with a tachimeter.

5.4. Evangelic Lutheran Church of Carnikava - 3D reconstruction using crowdsourcing

For the case study Evangelic Lutheran Church of Carnikava was used. It burned down on December 10, 2017. This was one of the oldest wooden churches in Vidzeme and it was built in 1728. For research all available images were collected all available images on the internet. Also, respondents who were interested in creating this 3D model were invited to send the photos from their personal archive and some of them responded by sharing the materials via email.

Possible disadvantages of the data obtained

There were many images available, therefore the best solution was to use bundle adjustment programs. Undeniably it is a big challenge to use crowdsourcing data, because usually data may not meet the minimal requirements. The following possible disadvantages were found during image research and further processing:

- Images can be acquired from a viewpoint too close to the object,
- Large illumination variations due to natural light (bright sunshine, clouds, shadows, dusk light),
- In the image seasonal effects can appear, such as rain, snow or coloured leaves,
- Natural or human obstacles can appear in front of the picture,
- Photos can be taken faced vertically or horizontally,
- Other typical aspects such as resolution, occlusions and distortion,
- Photos can be modified, enlarged or reduced, some colour improvements can also be done.

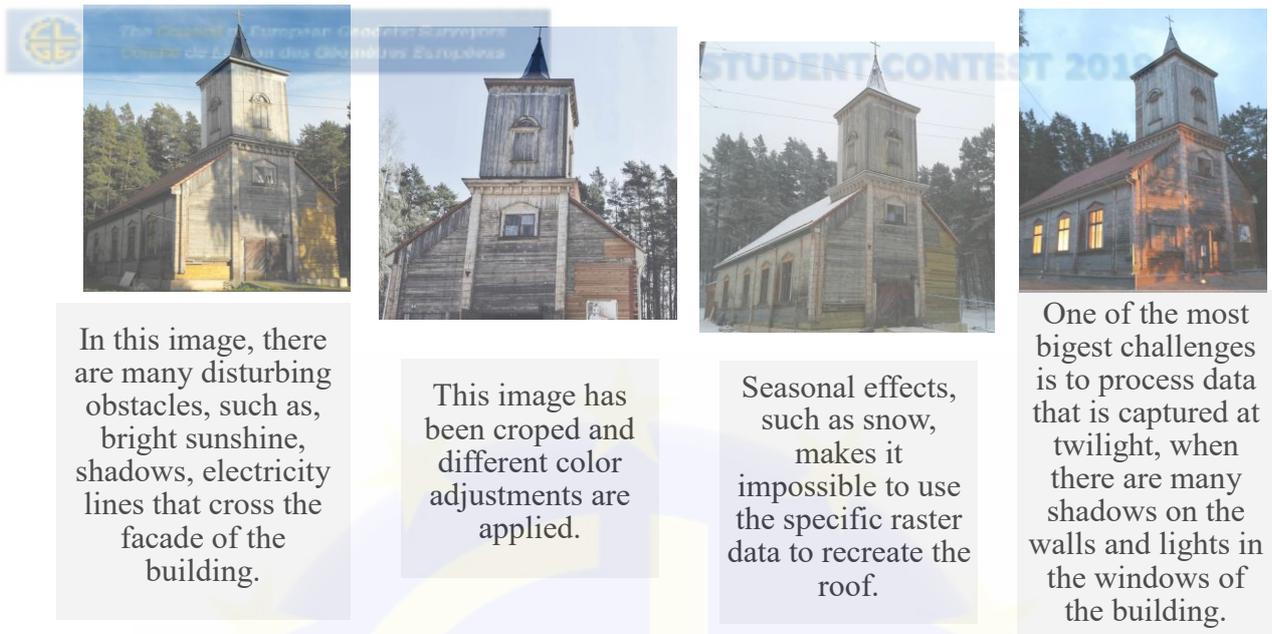


Figure 5.14 Examples from the case study of possible disadvantages of the data obtained [author]; [11]; [12]; [13]

Since most of the photos were taken from the front of the Church, in the postprocessing the 3D model most accurately depicted the tower and entrance of the building. In the 3D model the roof and the back of the building were depicted with a lot of distortion.



Figure 5.15 The obtained 3D model using crowdsourcing data [author]

6. CONCLUSION

This thesis reviewed the possibilities of 3D reconstruction methods of cultural heritage using collected data from various archives – public and private, internet resources and crowdsourcing.

Modern data processing methods were used to create 3D models of cultural heritage objects, but using historical materials author had to face many different challenges. Those different challenges include using crowdsourced data captured in different time periods and in different weather conditions that make data post-processing complicated. Another challenge, when using scanned glass plates or paper photos, is that there was no information available on the position of the camera or the camera's internal parameters.



This thesis proves that many different 3D reconstruction methods can be used to achieve the main goal – create 3D model of lost or partially lost cultural heritage. That gives us better understanding of lost values and gives hope of restoring them one day.

REFERENCES

1. LeBlanc, F., Eppich, R., *Documenting Our Past for the Future*, [online], Published by Getty Conservation Institute, 2005, [Accessed 22.11.2018.] Available: http://www.getty.edu/conservation/publications_resources/newsletters/20_3/feature.html
2. Andrew, D., Bedford, J., Bryan, P., *Metric survey specification for cultural heritage*, Published by Historic England, UK, 2015, pp. 22
3. [Wiedemann, A., Hemmleb, M., Albertz, J., *Reconstruction of historical buildings based on images from the meydenbauer archives*, \[online\], Technical University of Berlin, Germany, 2000, \[Accessed 01.11.2018.\], Available: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.469.3990&rep=rep1&type=pdf>](#)
4. Hendricks, M.D., *Topographic map*. In: Kemp, K.K. (ed.) *Encyclopedia of Geographic Information Science*, SAGE, London, 2008, pp. 479–481.
5. [Pandey, J., Sharma, O., *Fast and Robust Construction of 3D Architectural Models from 2D Plans*, \[online\], Delhi: Journal IIITD, 2011, \[Accessed 17.10.2018.\] Available: <http://wscg.zcu.cz/wscg2016/short/F13-full.pdf>](#)
6. Babalola, O., Eastman, C., *Semantic Interpretation of Architectural Drawings*, [online] Georgia Institute of Technology, USA, 2001, [Accessed 05.11.2018.] Available: <http://papers.cumincad.org/data/works/att/ef4b.content.pdf>
7. Niebling, F., Maiwald, F., Barthel, K., Latoschik, M., *4D Augmented City Models, Photogrammetric Creation and Dissemination*, Published by Springer, 2017, pp.196-212
8. [Henze, F., Siedler, G., Vetter, S., *Integration of digital image analysis for automated measurements into a photogrammetric stereo evaluation system*, \[online\], Brandenburg Technical University of Cottbus, Germany, 2012, \[Accessed 03.11.2018.\]](#)
9. [SketchUp Training Series: Match Photo part 1](#), [online video], 2014, [Accessed 19.10.2018.], Available: <https://www.youtube.com/watch?v=2hSyw6bobpc>
10. [Agisoft PhotoScan - Tips and Tricks](#), [website], 2018, [Accessed 06.11.2018.], Available: <http://www.agisoft.ru>
11. [Sigulu Church](#) [website], 2018, [Accessed 25.11.2018.], Available: www.baltezerabaznica.lv



12. [Sigulā Church \[website\]](http://www.carnikavasbaznica.lv), 2018, [Accessed 25.11.2018.], Available:
www.carnikavasbaznica.lv

STUDENT CONTEST 2019

13. [Sigulā Church \[website\]](https://foursquare.com), 2018, [Accessed 25.11.2018.], Available:
<https://foursquare.com>

