

# Visualization of laser scanner point cloud as 3d panorama

Using laser scanning to reconstruct the facade of the Pellerhaus Nürnberg in its historic state

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# Declaration

I hereby declare that I have created this work completely on my own and used no other sources or tools than the ones listed, and that I have marked any citations accordingly.

Hiermit versichere ich, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt sowie Zitate kenntlich gemacht habe.

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*Nuremberg, July 2015*  
*Adam Kalisz*

# Abstract

In this work the interested reader will learn about my research on the 3D-model reconstruction of the historic Pellerhaus in Nuremberg, Germany, as it looked before its destruction during World War II. The title of this paper is "Visualization of laser scanner point clouds as 3D panoramas".

In the first chapter I will describe the background research that provided me with the necessary fundamentals to start the project. The second chapter presents the development process of the software tools applied to achieve the goal of reconstructing historic 3D models from various data such as images and laser scans. To accomplish this, I decided to improve the open source software Blender. Details on the production of a three-dimensional mesh from laser scans via LIDAR devices can be found in Chapter Three. Chapter Four concludes the work and also presents future work. It contains the results, failures and successes of my research. Furthermore it discusses different possible ways to build upon the fundamental insights gained from this report. Due to our modern open culture with several open software, hardware and movie projects - mainly inspired by the Blender Foundation - I also want to make my research available to the public. During the time I am writing my thesis I will therefore be publishing my progress online at <http://bachelor.kalisz.co>.

# Acknowledgements

This research could not have been performed without the assistance, patience, and support of many individuals.

On behalf of the historical expertise required for this research, I would like to thank the Geschichtsarchiv Langwasser, including Mrs Edith Schroth and Mr Alfred Schroth for their constant support in providing old photographs, material and making contact to various institutions like archives, museums and companies. They initiated the contact with the Altstadtfreunde Nürnberg e.V. as well. Therefore I would like to thank the Altstadtfreunde Nürnberg e.V. for a huge amount of historic pictures and professional guidance regarding the history of the Pellerhaus. I am happy to get the opportunity to be supported by chairman Mr. Karl-Heinz Enderle during my research.

Secondly, I have to thank my thesis advisor, Mr. Prof. Dr. Stefan Röttger for mentoring me during my undergraduate studies. Not only did he prove his confidence in me by encouraging me to teach computer graphics to other students by letting me show how much fun it can be creating graphics with the open source 3D graphics suite Blender and offered me several jobs in 3d animation. His insight lead to the initial proposal to examine the possibility of reconstructing the Pellerhaus facade. In addition I would like to extend my gratitude to Mr. Prof. Dr. (USA) Ralph Lano for supervision during my studies. His teaching style and enthusiasm made a strong impression on me and I have always carried positive memories of the classes I attended. Although, the classes I took have not been mandatory and rather seldom they made a lot of fun (e.g. XBox programming with Unity), he was always very helpful and friendly. I would like to thank you very much for your support and understanding over these past four years.

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# Chapter 1

## Introduction

### 1.1 Motivation

The field of 3D computer graphics has always been a fascinating subject to me....  
...image processing in computer vision... ...high interest in historical topics, because  
member of citizens association and representative of settlement, thus learning a  
lot about interesting historical facts and development of culture. For example old  
railway station in district Langwasser has formerly been used for deportation of  
people after start of the second world war. ...

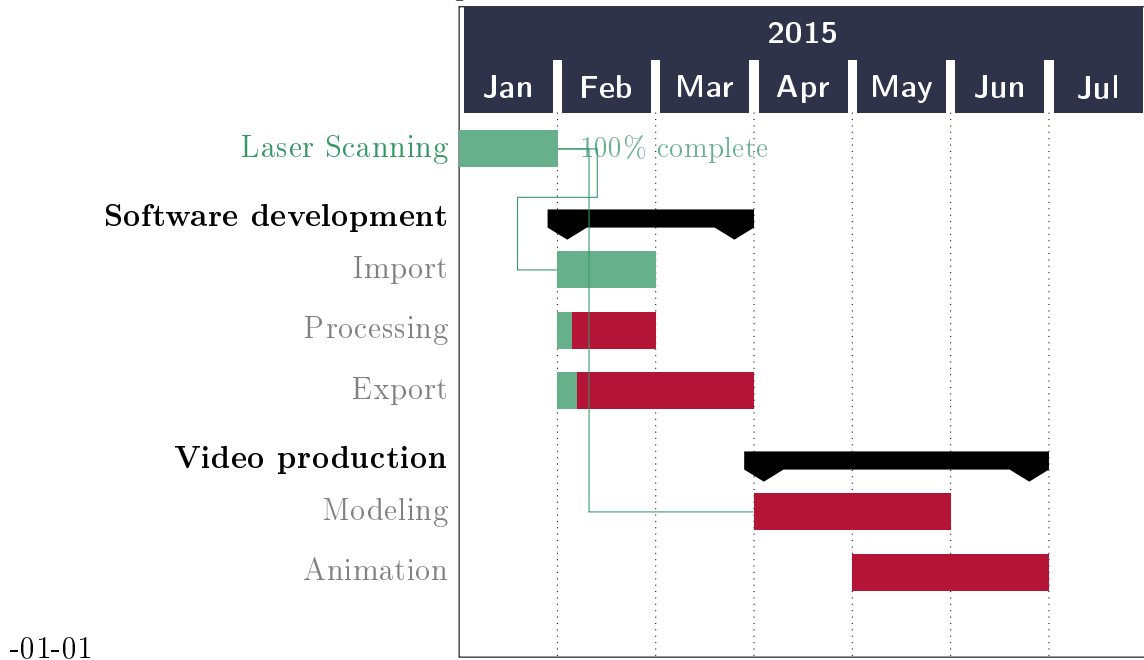
### 1.2 Initial project specification

The idea for this research started with the personal concern of reconstructing a  
historical site like the old railway station in Langwasser in its historic state. Due to  
the fact that this railway station has never been fully finished and therefore poor  
historical documentation, a 3D reconstruction wouldn't be complete. Luckily the  
famous Pellerhaus was the perfect candidate for this research. After its destruction  
during World War II, it was rebuilt quite differently to the original state. While the  
inner courtyard is almost finished with reconstruction at the time of this writing,  
the facade is still looking modern. At that point, it was clear that the main research  
topic is going to examine ways to reconstruct the Pellerhaus in its historic state. A  
more concrete specification was defined by considering how this is going to be done.  
The current state of the building has to be captured with laser scanning technology  
to get the correct measurements from the real world reference. This point cloud data  
needs to be processed then. To do so, a custom software is required to be written,  
which can read a file format exported from the proprietary Faro SCENE application,  
create a panoramic image representation of the data, use it to generate a 3D mesh  
and export this mesh to a widely supported file format. This research will mostly  
rely on the open source software Blender to model and animate the historic state  
of the Pellerhaus, thus it is crucial to provide a compatible output to be used as a  
basis for the design process. By creating a surface from the point samples, a bug  
in Blender, which is making it not capable of displaying or rendering colored point  
clouds[see Ble14a, p10], this research will overcome this problem. The goal of this  
research is to get a 3D model of the Pellerhaus in its historic state from 1605 by  
utilizing panoramic projections as described before.

### 1.3 Project schedule

This project is divided into two phases. The first phase is developing the software for converting laser scanner point clouds as 3D panorama meshes. The second one is designing the historic 3D model from this initial mesh.

This is visualized in the following GANTT chart:



### 1.4 State-of-the-art methods for 3D reconstruction

There are several methods that allow for the generation of 3D meshes from various data. One can either use several still images or videos, sample the real world with modern sensor technology. This is described as follows:

#### 1.4.1 Light Detection And Ranging (LiDAR)

The term Light Detection And Ranging (in short LiDAR) is commonly used with high precision applications, such as scanning and mapping. It uses a laser beam emitter and receiver. The time between sending a signal and receiving it is measured and multiplied by the speed of light. This returns the meters the light traveled from the emitter to the obstacle and back. Dividing this distance by two yields the range to the obstacle in meters.[see Sch14, p8-9]

As this only gives the meter to one specific point, it is necessary to keep measuring from different viewpoints. This can be done by rotating the scanning device horizontally and vertically simultaneously. To keep cables from winding up by using two motors, devices usually use only one motor for the horizontal and a flat mirror on an elliptical mount for the vertical rotation. That way it is possible to sample a lot of points around the device position quickly and effectively.

In this work the LiDAR scanner Faro Focus 3D is being used. It is capable of capturing 976,000 points per second with a vertical and horizontal field of view of

305 and 360 degrees, respectively<sup>1</sup>. For allowing a better registration it can also use GPS for localization and a barometer for height measurement. The measured points can be colored with a built-in camera of around 70 Megapixels. The price for the Focus 3D totals at 61,404.37 Euro<sup>2</sup>.

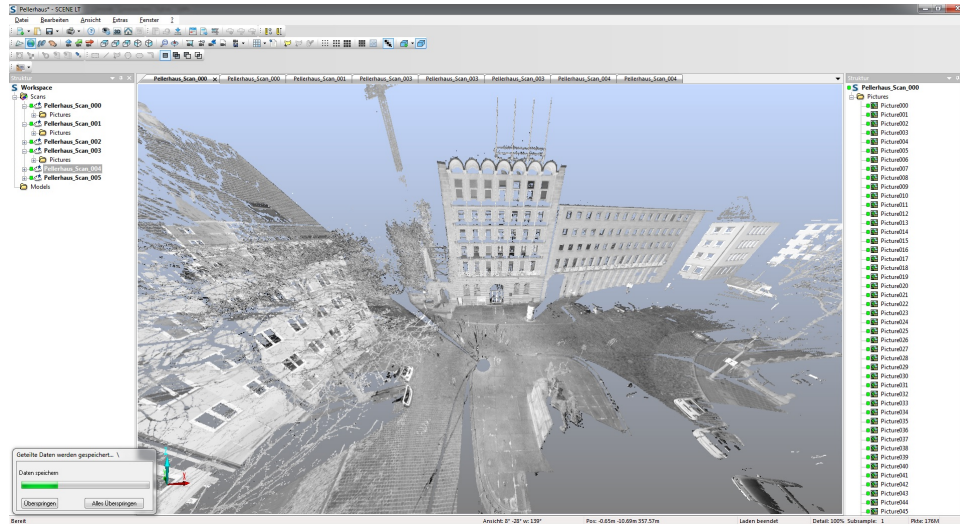


Figure 1.1: LiDAR Scanner Point Cloud of the Pellerhaus

Besides using a stationary device, portable devices are also available. Recently a new technology has been revealed by Csiro and is called *Zebedee*. This handheld laser scanner can be used in challenging environments where a stationary device would require several scans to cover the whole area (e.g. caves, staircases) while the operator is walking. It samples over 40,000 range measurements every second and consists of a 2D laser scanner mounted on a spring system<sup>3</sup>. Especially the visual effects field has a great use for this device, since the environments can vary a lot during video shootings and a 3D mesh representation is ubiquitous today. The price for the ZEB1 handheld laser scanner is 17,000 Euro<sup>4</sup>.

Although measuring with laser technology can be found in household devices as an alternative for tape measuring, it is still quite complicated to reverse engineer such devices to get the raw distance reading. Fortunately a group of engineers tried to bridge the gap by starting a crowd funding campaign for a low-cost laser range finder, called the LiDAR-Lite<sup>5</sup>. It has a total range of 40 meters with a resolution of 1 cm. During this research this sensor is being used with a custom arduino build to examine how it can be used as a cheap alternative to the examples mentioned in the beginning. The price for one module is at 82 Euro.

### 1.4.2 Ultrasonic

In contrast to LiDAR, most ultrasonic sensors are cheap, but generally are not used for higher distances at several tens of meters (though, there are products for a range

<sup>1</sup>Techsheat Faro Focus 3D: <http://www2.faro.com/site/resources/share/944>

<sup>2</sup><http://surveyequipment.com/faro-focus-3d-x-330-laser-scanner/>

<sup>3</sup><http://www.csiro.au/Organisation-Structure/Divisions/Computational-Informatics/Zebedee-3D-mapping.aspx>

<sup>4</sup>Source: Personal contact to sales team

<sup>5</sup><http://pulsedlight3d.com/>

higher than 100 meter<sup>6</sup>). The reason for this is that sound is usually affected stronger by environmental properties than light<sup>7</sup>. Due to this they are often used for shorter distances e.g. for near field obstacle recognition in robotics or in small desktop laser scanners<sup>8</sup>. Typical ultrasonic sensor modules with a maximum range of around 5 m can be purchased for 5 Euro already.

### 1.4.3 Photogrammetry

Photogrammetry (also referred to as multi-view reconstruction) is a technique from the Computer Vision field and presents a cost-effective alternative to laser scanning. A real 3D object can be reconstructed as a virtual 3D model by using photographs of the scene and feeding them into such software. This works by detecting image features (for example by using Harris Corner Detector or SIFT algorithms), matching those between image pairs, computing the respective camera positions and re-projecting the reconstructed 3D points to get a point cloud representation of the real photograph[compare Sol12, p29]. The computer vision algorithms get better each day and there is plenty of software using them.



Figure 1.2: Multiview Reconstruction from historic stereo pairs

Photogrammetry will be used in this project to try reconstructing surfaces from historical images. Fortunately stereographic image pairs are provided through the Altstadtfreunde Nürnberg e.V. By matching the laser scanner data with the Photogrammetry output a good groundwork is expected to be done for the final surface reconstruction.

### 1.4.4 Google Maps (R)

The commercial application allows viewing cities from the sky with a rough representation of 3D building shapes<sup>9</sup>. While this service had gray boxes some years ago, today the visualization is getting more accurate. It is possible to see small details with better modeled and textured buildings.

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<sup>6</sup>VEGAPULS 69: <http://www.vega.com/downloads/AL/DE/34137-DE.pdf>

<sup>7</sup><http://www.sensorsmag.com/sensors/acoustic-ultrasound/choosing-ultrasonic-sensor-proximity-or-distance-measurement-825>

<sup>8</sup><https://www.youtube.com/watch?v=saWWhEYQxTg>

<sup>9</sup><https://www.youtube.com/watch?v=5iolZU8LwPU>

### 1.4.5 Open Street Map (R)

The open source alternative to the commercial service above offers the basic functions for map viewing and navigation. OpenStreetMap (OSM) offers very detailed access to its data, like boundaries, streets and building footprints. That way it is possible to extract simple building shapes<sup>10</sup> that can be used in custom software free of charge.

To allow for a better mapping of buildings there are also proposals on an indoor version of OSM<sup>11</sup>. Having this data available is a helpful thing for applications such as indoor navigation at railway and subway stations, mobile emergency exit information and robotics.

### 1.4.6 Bavarian State Office for Survey and Geoinformation

Geodata and city plans are also provided officially through governmental institutions. They provide various types of data, among others historical aerial photographs, digital elevation models (DEM) and also 3D building shapes. For educational purposes (like i.e. this research) they offer a university discount for the data of 25 percent. A usual dataset without any discounts containing 7580 buildings of Langwasser, district of Nuremberg in Germany, costs 1158 Euro<sup>12</sup>.

### 1.4.7 Autonomous mapping with UAV's and SLAM

Drones, or unmanned aerial vehicles (UAV's), are getting more popular each day. Most of them are also equipped with a camera which allows for taking pictures or videos from viewpoints a human cannot reach easily. More expensive drones have LiDAR systems attached<sup>13</sup> which allow - together with the IMU (Inertial Measuring Unit) and GPS (Global Positioning System) to localize it and map its environment. A popular term for this is Simultaneous Localization And Mapping (SLAM).

### 1.4.8 Manual methods

If all other methods fail, there is still the chance to get a reconstruction done roughly by taking measurements of real objects with measuring tapes or eyeballing. Loading pictures from the front, side and top view into a 3D software can already yield decent results.

## 1.5 Defining the scope of this research

Although this work uses a combination of several techniques (briefly presented above), the main focus is put on examination if panoramic projection of laser scanner point clouds will be an aid for 3D reconstruction or not. This will be evaluated by using the result from the converter in a real world use case of using the reconstructed mesh in the design process.

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<sup>10</sup><http://demo.f4map.com/#lat=49.4559869&lon=11.0762814&zoom=18>

<sup>11</sup>[http://wiki.openstreetmap.org/wiki/Indoor\\_Mapping](http://wiki.openstreetmap.org/wiki/Indoor_Mapping)

<sup>12</sup>Personal research

<sup>13</sup><https://www.youtube.com/watch?v=IMSozUpFFkU>





# Chapter 2

## Background Research

### 2.1 History

#### 2.1.1 Renaissance

The Renaissance is a historical period from 14th to 17th century, which started as a cultural movement in Italy in the Late Medieval period and later spread to the rest of Europe. This period is considered as the bridge between Middle Ages and Modern History. Even though the renaissance had a major impact all over Europe, the spread of its principles was not made in an uniform fashion. The word Renaissance, literally meaning "Rebirth" in French, first appears in English in the 1830s. The Renaissance is mostly known for the cultural revival of the principles developed in the ancient Greece and Roman Empire. This revival brought a gradual a widespread educational reform. Renaissance had a major role in politics, its principles being the base of the conventions of diplomacy. In science, the renaissance brought an increased reliance on observation, rather than superstition. Even though the renaissance had a major impact in all aspects of life between 14th and 17th century, this historical period is mostly known for the impact it had on arts. The most famous examples are the artistic developments and contributions of such polymaths as Leonardo da Vinci and Michelangelo, who inspired the term "Renaissance man". The Renaissance started in Italy in the 14th century, under the patronage if powerful, dominant families as Medici. The Fall of the Constantinople at the hands of the Ottoman Turks started a migration of Greek scholars towards west. This scholars brought with them the wisdom and knowledge of the ancient Greece and Rome and spread it though the Italian peninsula, in all the major city states, such as Florence, Venice, Genoa, Bologna, Milan and finally Rome, during the Renaissance papacy. Renaissance influence was felt in literature, philosophy, art, music, politics, science, religion, and other aspects of intellectual inquiry. Renaissance scholars employed the humanist method in study, and searched for realism and human emotion in art. Renaissance could be considered as an attempt to study and improve the secular and worldly, both through the revival of ancient ideas and principles, and though new approaches to thoughts. Another major influence of the Renaissance was felt in the economy. One of the best example could be the banking system pioneered by the Medici family in Florence. While the great states of Europe, France and Spain were absolutist monarchies and ma other states were under direct papal control, the independent city republics of the Italian peninsula took over the capitalist principles developed

on the monastic estates, and set off a vast unprecedented commercial revolution and financed the Renaissance.

Renaissance Architecture, is the architecture of the period between 15th and 17th century. This period is characterized by a conscious revival and development of ancient Greek and Roman thought and material culture. Stylistically, Renaissance architecture followed Gothic architecture and was succeeded by Baroque architecture.

"Renaissance style places emphasis on symmetry, proportion, geometry and the regularity of parts as they are demonstrated in the architecture of classical antiquity and in particular ancient Roman architecture, of which many examples remained. Orderly arrangements of columns, pilasters and lintels, as well as the use of semicircular arches, hemispherical domes, niches and aedicules replaced the more complex proportional systems and irregular profiles of medieval buildings." Renaissance in Germany Renaissance arrival in Germany and the Low Countries coincided with the development of the printing press (ca. 1450) and was inspired first by German philosophers and artists such as Albrecht Dürer and Johannes Reuchlin who visited Italy. In the early Protestant regions of the country, the humanism became closely related with the religious turmoil caused by the Protestant Reformation. Various aspects of this turmoil were frequently depicted in the art and the literature from this period. However, the gothic style and medieval scholastic philosophy remained dominant until the turn of the 16th century. With the rise to power of the Emperor Maximilian I of Habsburg (1493-1519), renaissance became the main trend in the land. The emperor was the first truly Renaissance monarch of the Holy Roman Empire, later known as Holy Empire of the German Nation. One important early example of renaissance architecture is Landshut Residence. In 1536 Louis X, Duke of Bavaria laid the foundation stone for a new residence in the inner city of Landshut. It was the beginning of German Renaissance style under the architect Bernhard Zitzel from Augsburg; this palace is today known as the "German building". During a journey to Italy, the duke got inspiration for an additional building, the so called "Italian building", which was constructed from 1537 to 1543 in Italian renaissance style. Another important example of renaissance architecture in Germany is the Augsburg Town Hall. The Town Hall of Augsburg is the administrative centre of Augsburg, Bavaria, Germany, and one of the most significant secular buildings Convention for the Protection of Cultural Property in the Event of Armed Conflict. The largest renaissance church north of the Alps is St. Michael's Church in Munich. St. Michael's Church is a Jesuit church built between 1583 and 1597 by William V, Duke of Bavaria. The style in which this church was built will have an enormous influence on Southern German early Baroque architecture. This church was built as the spiritual center for the Counter Reformation. In order to build the church and the adjoining collage, Duke William had to pull down 87 houses, ignoring the protests of the citizens. Weser Renaissance is a style formed around river Weser in central Germany. The style is very well preserved in the towns and cities of that region. Between the start of the Reformation and the Thirty Years War, the Weser region experienced a construction boom, in which the Weser, playing a significant role in the communication of both trade and ideas, merely defined the north-south extent of a cultural region that stretched westwards to the city of Osnabrück and eastwards as far as Wolfsburg. Castles, manor houses, town halls, residential dwellings and religious buildings of the Renaissance period have been

preserved in unusually high density, because the economy of the region recovered only slowly from the consequences of the Thirty Years War and the means were not available for a baroque transformation such as that which occurred to a degree in South Germany.

The Pellerhaus The Pellerhaus on Egidienplatz 23 in Nuremberg was once considered one of the most magnificent examples of a town house of the German Renaissance architecture. The house was commissioned by Martin Peller in 1602 and remained in the possession of the Peller family until 1828.

During the next 100 years the house changes hands several times until 1929 when it was bought by the city of Nuremberg under the mayor Herman Luppe. The acquisition of the house by the city assured a proper maintenance of this historical landmark. Between 1931 and 1934 the city starts a reconstruction program for Pellerhaus, restoring to the old grandeur the yard and the rear facade. The detailed plans of the rear facade, drawn for this project survive until today. On January 2nd, 1945, Pellerhaus was destroyed in an ally bombing. In fact a huge part of the city was transformed into a leveled surface by bombing and debris removal. The elegant and dignified image of Egidienplatz, is not distorted by the flat-roof building of the City Library built between 1955 and 1957. The new reconstruction project is launched in 1955, only this time it was decided to restore to its former glory only the ground floor. The rest of the building will serve only a pure functional role and serve as a library for many years. In 2005 a new initiative was launched, to help with the reconstruction of Pellerhaus. This project is still active today.

See Wikipedia: [http://en.wikipedia.org/wiki/The\\_Renaissance](http://en.wikipedia.org/wiki/The_Renaissance)

### 2.1.2 Architects

**Wolff, Jakob d. Ä., builder, sculptor, \*1546 Bamberg, † 4.4.1612 Nuremberg**

Wolff became the city architect of Nuremberg in 1596, where he and his son W. d.J. built the Fleischbrücke. During 1601-05 he took part in the new build of the stronghold Marienberg in Würzburg and in the reconstruction of the Echartor. His principal work is the Pellerhaus in Nuremberg (1602-07), one of the most noble private properties during the German Renaissance (destroyed in the Second World War; the remaining parts of the arcade court have been included in the modern building)

**Wolff, Jakob d. J., builder, \*1572 Bamberg, † 24.2.1620 Nuremberg**

Wolff was the student of his father W. d.Ä., was given the job of a (royal adviser?) city builder in 1605, had the permission from the council to stay in Bayreuth, Frauentaurach and Schwabach and started, influenced by the Dutch and Italian Renaissance, 1616 with the new build of the city hall in Nuremberg, which was finished in 1622 by his brother Hans.

[Gru05, translated from German]

### 2.1.3 Pellerhaus

Before destruction, the Pellerhaus was one of the main sights of Nuremberg. The architecture seems to be the most honorable performance of the local art of construction. Its inner court was considered the probably most beautiful arcade court. As the city descended into shatters in 1945, there were only a few remains of the Pellerhaus. The front-facing house was rebuilt in a modern form 1957 on top of the reconstructed hall. An enormous effort was done by complementing the courtyard, it was discontinued 1959, though.

Not until 2005, 60 years after the destruction, the Altstadtfreunde took the initiative to continue the former abandoned construction of side wing and rear house facade. With the accurate documentation of the pre-war level it is possible to do those court additions with extraordinary accuracy. October 2008 laid the foundation block of building the courtyard completely via donations.

Since then with the well corner, side wings and eastern backyard gallery crucial parts have been able to get restored from the old building.

With your donation or by purchasing a symbolic block of stone you can help to make one of the greatest achievements of German Renaissance in its historic state come alive.

At the time when the merchant Martin Peller started with building his house in 1602, he also laid the foundation block to what later entered as the most magnificent bourgeois house into the history of art. The notion of building an arcade court was not new in Nuremberg. There have been hundreds of gallery courts in the city. Many of them with tracery breastwork made of stone. Though, the Pellerish courtyard bested everything that has been known at that time:

On the two long sides it was flanked by noble three-story arcades, with a clear and symmetric structure, though with a rich and filigreed ornamentation. While skimming along it, ultimately the show façade caught the eye with a glorious gable. Seldom one can find forms of the Italian Renaissance merged with local sensuous enjoyment in such a happy way. Antique style pillars accompany the individual floors, obelisks stretch up into the sky and still the appearance was entirely different than in Italy. The Pellerhof, as a Middle European counterpart to the wonderful arcade courts of Italy, is an indispensable part of European architecture [eV, translated from German].

First reconstruction was finished in 1934. Destruction in 1945. 1955 beginning of new reconstruction. 1955-1957 reconstruction of the base floor finished, but destruction of the upper floors (storey heights also differ from the original). 1960 End of all reconstructions, though people realized that a full reconstruction might happen 1972/73 Building a secondary school on top of the back-facing house area pretty much killed every hope of reconstruction of the Pellerhaus. The Pellerhof has groined vault.[eV12]

The Pellerhaus was bought by the Major of Nuremberg in the year 1929. Reconstruction was estimated to need a budget of a Martin Peller to succeed. It was a real mess. But the city felt responsible to finance the reconstruction at that time and fundamentally restored it from 1931 to 1934. The red facades have been cleared up

and new stone details have been redone by hand. They were really careful to keep all of the small details and not to recreate the house according to a recent art period. The Pellerhaus was saved. Ten years later, it was hit by bombs. Though, the former restoration is incredible worthy today. Hundreds of plans and photos document every detail of its facade. Without that documentation a reconstruction would have been extremely difficult today. Why wasn't the Pellerhaus reconstructed? After the Second World War it was important to find room for e.g. the city archive and a library. It was almost decided to completely embed the Pellerhaus into the library which was built to the right of it. But there was a certain force within the city that didn't allow that. So in the end, the old style Pellerhaus was combined with a new style to allow experiencing the old state a little.[eV13]

Right to the Pellerhaus there was a library built in 1955. An old arc was destroyed which was senseless. Only some column bases and capitals were still laying in the inner courtyard and were ready to be built into the southern part of the court. So, all six arcs, the little passage next to the front-facing house and the adjacent facade part of the northern court facade needed to be recreated. The build process was mainly based on photos and the remains of the western side. Measurements have been extracted by examining the remains. Also profiles and design of capitals and ending stones. Overall forms were reconstructed with the help of historic photos. New constructions were needed for the differing tracery of balustrade areas. It was a stroke of luck that the historic documentation of the house is extensive. This helped even with differences of geometric correct constructions with the new build. Also the Chörleins are documented well enough to allow for a reconstruction. For example, there is a massively wrong ornamentation of Chörleins at window lintels, sockets, and volutes when comparing the rebuild from 1950 with the original. On the contrary, we are much closer at the renaissance original with our new build. We can proudly say that with our restored state the two time layers 1605/07 and 1957/59 form a harmonic unit. From April 2013 we moved newly produced stone blocks and a fully donated arc in the Pellerhaus. Once again, we noticed the reckless deviation of any regularity. All of the six arcs have different spans and the alignment of the arcade row is not straight, but has been – in its old parts – slightly bulged out. Though, this might be due to the bombing destruction, just as the fact that the arc row doesn't continue horizontally but considerably descends from the front-facing house into the courtyard. The facades of the buildings in Nuremberg have been painted red with white rectangles some times. The reason for this was that the look of mined stones varied quite a lot. So by painting them the houses had a united look. This color is also called the „Nürnberger Rot“ (Terra Norimbergensis rubra), because it is looking like the local sand stone and the color powder is coming from the rural area of Nuremberg. Unfortunately only a few color remains are left until the reconstruction but it is enough to prove the colorfulness of the facade. After finishing the reconstruction in the courtyard repainting the facades in the „Nürnberger Rot“ would be the right decision.[eV14]

Nuremberg had substantial achievements in the field of architecture around 1600. Significant public and private buildings have been built between the end of the

Second Margrave War and the beginning of the Thirty Years' War. The first big construction project after the end of the war against Albrecht Alcibiades was the fortification of the defense structures. During 1556-1564, the wall ring was improved and the towers of the five main gates (Laufer Tor, Spittlertor, Frauentor, Neutor, Vestnertor) were surrounded by a stone wall. This was inspired by the towers of Castle Sforza in Milano, Italy.

Additional important public buildings were realized by the (royal adviser?) city builder Jacob Wolff der Ältere (1596-1612) and his son Jacob Wolff der Jüngere (1612-1620) during that time. The most important ones have been the construction of the Fleischbrücke inspired by the Ponte Rialto in Venedig (after 1596), the Wöhrder Torbastei (1613/1614), the master builders' house on the Peunt (1615) and especially the city hall, which was inspired by late renaissance style palaces in Italy (1616-1622).

Besides the public buildings there were created several considerable private structures around 1600. They mostly haven't been commissioned by patricians but rich merchants. The most important ones have been the Töplerhaus (1590), the Fembohaus (1591) and the Pellerhaus (1602-1607). At the same time many manors in the land domain of Nuremberg have been rebuilt in the following decades after the Second Margrave War.

[Mäh00, translated from German]

## 2.2 3D Panorama

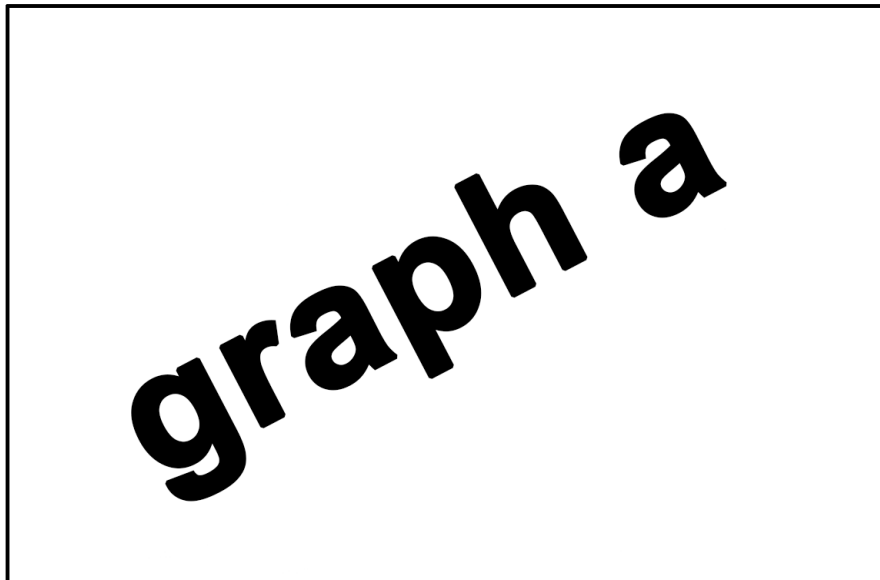


Figure 2.1: 3D Panorama Sphere

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tum. Aliquam vehicula faucibus sapien non convallis see 2.2. Nullam consectetur sagittis sollicitudin. Nulla mollis laoreet metus et consectetur.

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One of the most basic types is the equirectangular projection see 2.2a

## 2.3 Types of projections

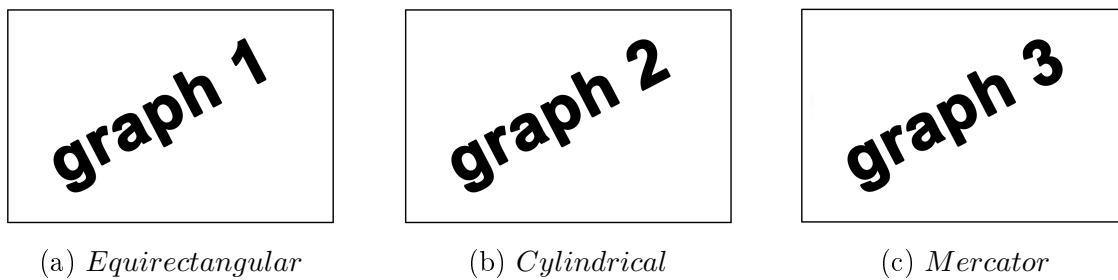


Figure 2.2: Three example projections

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# Chapter 3

## Converting: From point cloud to Blender 3D

### 3.1 Concept

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#### 3.1.1 Use case diagram

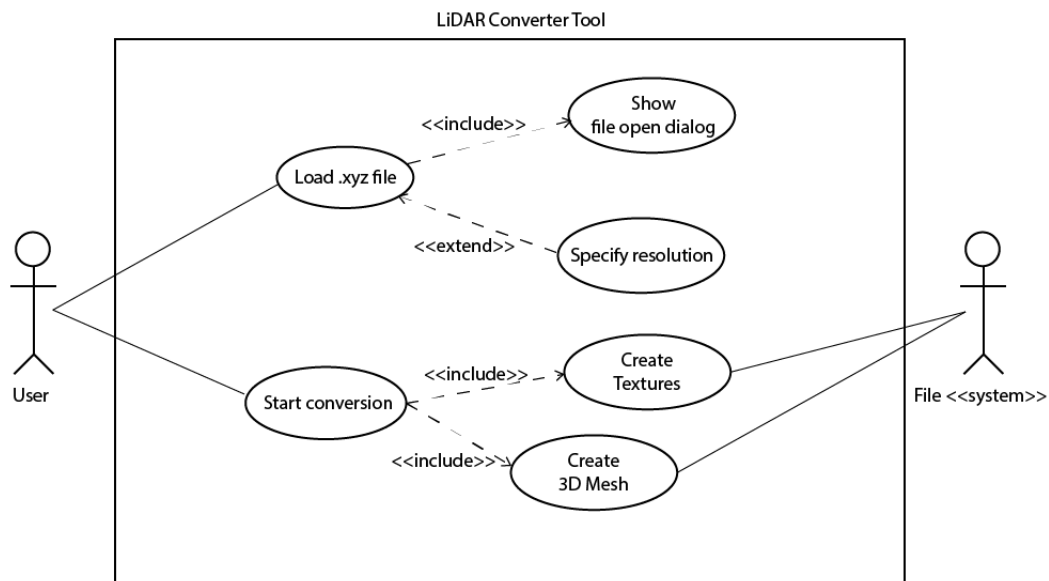


Figure 3.1: Use Case Diagram

### 3.1.2 Laser scanning on location

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Figure 3.2: Scanning with Faro Focus 3D

A	B	C
1	3	4
1	3	4

Table 3.1: very basic table caption

## 3.2 Generating data and testing algorithms

### 3.2.1 BlenSor

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pellentesque odio at nisl placerat porta. Donec urna risus, iaculis vitae justo quis, tempus ullamcorper diam. Integer eu gravida est. Phasellus eu ex tincidunt urna tempus pulvinar in in metus. Mauris tempus magna ac finibus suscipit. Praesent malesuada magna nibh, at rutrum felis semper a.

### 3.2.2 Test-Addon for Blender

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## 3.3 Prototype

### 3.3.1 Point Cloud Importer

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#### Point Cloud data formats

Day	Max Temp	Min temp	Day	Max Temp	Min Temp
Mon	20	13	Mon	17	11
Tue	22	14	Tue	16	10
Wed	23	12	Wed	14	8
Thu	25	13	Thu	12	5
Fri	18	7	Fri	15	7
Sat	15	13	Sat	16	12
Sun	20	13	Sun	15	9

(a) First Week
(b) Second Week

Table 3.2: Max and min temp recorded during the first two weeks in January

### 3.3.2 Projecting 3D points onto a 2D plane

This is inside the text  $\cos(2\theta) = \cos^2 \theta - \sin^2 \theta$ .

And this is a separate formula:

$$\cos(2\theta) = \cos^2 \theta - \sin^2 \theta$$

### 3.3.3 Saving textures

### 3.3.4 OpenGL Point Cloud Viewer

This russian video tutorial was very helpful with the basic setup with the Qt framework.

[Enz14]

### 3.3.5 Meshing

Using the current pixel inside two for-loops in combination with the neighboring pixels to the right, bottom-right and bottom makes up a quad, which can be textured.

### 3.3.6 Texture Coordinates and Normals

Texture Coordinates go from 0.0 to 1.0 in the x and y direction, respectively. Usually the texture coordinate axes are referred to as s and t. By dividing the current coordinate by the width and the height of the image, respectively, the coordinates can be normalized.

Calculating normals is accomplished by using the cross product of the two vectors forming the current quad.

### 3.3.7 Mesh Exporter

There are different formats, one had to be chosen that supported at least vertices and faces.

#### **.obj**

The .obj format is the most popular and can be one of the easiest to understand file formats to save 3D geometry with not only points, but vertices, normals, texture coordinates and much more. It was the first choice when testing mesh exporting from the converter software and examining it in Blender.

#### **.blend**

A personal goal for this research was to implement a .blend export feature to allow for a native importing of the panorama mesh into Blender. However, this goal was not reached in this project. As it turned out, exporting the binary Blender file format was quite complicated, due to its versatile structure. An experienced Blender Developer, Jeroen Bakker, stated in 2009 “When implementing loading and saving blend-files in a custom tool the difficulty is the opposite. In a custom tool loading a blend-file is easy, and saving a blend-file is difficult.” [Bak09, see]. At least implementing it with the limited time for the thesis it was not feasible.

#### **custom format**

Even the Blender community suggested to not use the .blend format directly, but rather try a custom binary format. [Ble14b, compare]

### 3.3.8 Optimizations

The initial algorithms and approaches had some flaws, which needed to get eliminated to get a clean mesh out of the converter. Those are presented as follows:

#### **Flip horizontal direction of panorama**

The panorama is flipped horizontally.

#### **Panorama pixel depth testing**

It can happen that two points from the point cloud happen to result in the same pixel in the 2D panorama. This might result in a noisy image result, if not handled with care. To avoid any errors, it is important to take only the closest point to the camera, instead of letting every point override the corresponding pixel in the image.

#### **Panorama noise reduction**

Since there is only a limited number of points, the panorama texture gets quite noisy, especially with a higher resolution option set in the converter. A harsh change from light gray to black values in the depth map will result in a noisy 3D structure as well. To solve this issue, the image is blurred by a user setting or automatically (TODO!).

#### **Remove doubles**

The meshing technique resulted in a very high point count for the .obj file. Example: For a 4x resolution panorama with 2,198,528 vertices, using the "remove doubles" option in Blender 3D automatically removed 2,100,716 vertices. Solution: several passes for vertices, texture coordinates and normals (TODO!).

#### **3D Distortion**

The generated 3D mesh from the 2D panorama results in a distorted one, the more it touches the top. Solution: None yet.

#### **Tiling**

Due to the higher resolution meshes having several megabytes in size and taking some time to import in Blender, this has to be optimized somehow. Solution: Create tiles when higher resolution is set. E.g. with a 4x resolution, create four tiles (that's four separate .obj files).



# Chapter 4

## Production: Recreating the Pellerhaus from 1605

### 4.1 Modeling the current Pellerhaus facade

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#### 4.1.1 Using the converter

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#### 4.1.2 Using UAV references with photogrammetry

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## 4.2 Modeling the original Pellerhaus facade

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### 4.2.1 Using historic images as guide

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### 4.2.2 Using historic stereoscopic images with photogrammetry

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## 4.3 Modeling the destructed Pellerhaus

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urna finibus scelerisque sit amet vel erat. Nullam nec maximus erat. Duis ante mi, posuere ut lobortis nec, posuere eu ligula[e.g. Sch14, page300].

## 4.4 Animating between the states

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## 4.5 Lighting and Rendering

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## 4.6 Animating between the states

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# Chapter 5

## Conclusion and Future Work

### 5.1 Conclusion

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### 5.2 Future Work

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# Appendix A

## Appendix Title

### A.1 Software used

#### A.1.1 L<sup>A</sup>T<sub>E</sub>X

This paper was written in L<sup>A</sup>T<sub>E</sub>X. On Windows, TeXstudio in conjunction with MikTeX (both portable versions) have been used for visual creation of the document. I decided to switch from the free version Adobe InDesign CS 2.0 to L<sup>A</sup>T<sub>E</sub>X in favor of it being cross-platform and hoping to make it easier to publish the thesis online in the future. Since I have never worked with L<sup>A</sup>T<sub>E</sub>X before, various tutorials [Sha13; Vel15] on the internet have been a great help.

#### A.1.2 Blender 3D

To cleanup the generated mesh, retopologize it and create the 3D animations of the Pellerhaus, Blender was used.

### A.2 Programming libraries and frameworks

#### A.2.1 Qt 5.4

Qt is an open source framework ...



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