Visualization of laser scanner point clouds as 3D panorama

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

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Declaration

Plagiarism Declaration in Accordance with Examination Rules

I herewith declare that I worked on this thesis independently. Furthermore, it was not submitted to any other examining committee. All sources and aids used in this thesis, including literal and analogous citations, have been identified.

Signature

Abstract

This study examines a novel approach to convert point clouds generated via laser scanning into textured 3D-meshes. The title of this paper is "Visualization of laser scanner point clouds as 3D panorama". The approach is field-tested with a use case scenario where the interested reader will learn about our research on the 3D-model reconstruction of the historic Pellerhaus in Nuremberg, Germany, as it looked before its destruction during World War II.

Initially, the motivational force, details about the project and existing solutions for creating virtual reconstructions are introduced in Chapter One. The background research that provided necessary fundamentals to start the project, for example how the Pellerhaus evolved or what exactly a 3D panorama is, is described in the second chapter. The third 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, a custom converter software has been written, which reads point cloud files and outputs the meshed and textured 3D-object file. The working title of this software is "PointCloud2Blender", *PC2B* in short. As a real world use case the creation of a photorealistic three-dimensional mesh from laser scans via LIDAR devices is described in detail in Chapter Four. Chapter Five concludes the work and presents future work. It contains the results, failures and successes of this 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 - this research is being made available to the public. During the time of the writing of this thesis the progress is therefore published 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 demonstrate 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.

Finally I would like to extend my deepest gratitude to my family without whose love, support and understanding I could never have completed this bachelor's degree.

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Chapter 1

Introduction

1.1 Motivation

The field of 3D computer graphics has always been a fascinating subject to me. Creating virtual worlds and being able to inspect those from every possible viewpoint is a great way to present almost any object one can think of to a wider audience. I finished my apprenticeship as a A/V media designer, so computer graphics are a helpful tool to e.g. previsualize camera work. The best fact about 3D is that it has so many versatile applications in many fields. 3D information can be retrieved from 2D images, taken with a real photo camera, via photogrammetry and can, in turn, be rendered onto a flat computer screen by rendering a scene with a virtual camera. At the point a object is available as a 3D model, it can be postprocessed in various ways. It can be animated, physically simulated and eventually rendered as a video. With modern display technologies the movie can be played out as a stereoscopic one and viewed with anaglyph (red, cyan), polarized, shutter or even without glasses by using e.g. a parallax barrier display (Wikipedia, [Wik14]). Furthermore objects can become tangible via 3D printing or can be inspected interactively in games with the help of virtual reality glasses like the Oculus Rift (Oculus VR, [Ocu15]). It is amazing that anyone can create and enjoy those virtual worlds today.

Additionally, I am highly interested in historical topics. As an active member of a local citizens association and representative of a settlement, where I am always available for any citizenship matters that people might have, I get to know many interesting people and the projects they are working on. Thus I am learning a lot about interesting historical facts and development of culture. Of course, not only about positive history. Especially the history of Langwasser, district of Nuremberg, Germany, is very terrifying and shocking. The district has been formerly used for tent cities and the Märzfeld ("March Field", a representation and parade ground) during the Reich Party Congress in Nuremburg, Germany, between 1933 and 1938 (Wikipedia, [Wik15a]). The construction of a railway station, called Bahnhof Märzfeld and placed right in the center of Langwasser, was partly finished in 1938. That station has been used initially to transport the members of the Reich Party Congress to the event. During World War II it was used for the deportation of about 940 people to concentration camps, where only 17 of them survived (Stadtteilforum Langwasser, [Sta15]). This railway station is in a ruinous condition at the moment. People go by, without noticing that this is real history, that passes them by. This was a big concern for me, so I started to search for ways to make the history become real again, in an enjoyable way.

And then there was the day I talked to my professor, Mr. Dr. Stefan Röttger, about my wish to use laser scanning for historic 3D reconstruction. Suprisingly my professor told me, that we have a laser scanning device at university which could be used for a thesis. The moment he told me that, was the moment I made my decision to center my thesis around laser scanning.

Lastly, a strong motivational force was discovered after researching how the laser scanner point cloud can be used to create the historic building model based off of a recent laser scan. 3D software enables a user to tweak automatically generated meshes or even to add new geometry. Due to my personal experience with the open source 3D graphics suite Blender and the decreasing interest in other software like Autodesk 3ds Max or Maya in favor of Blender (Google Trends, [Goo15]) it was necessary to work with point clouds in Blender. Unfortunately Blender is not designed to work with point clouds at the time of this writing.

As will be described in greater detail hereafter, the aforementioned facts lead to an initial project specification.

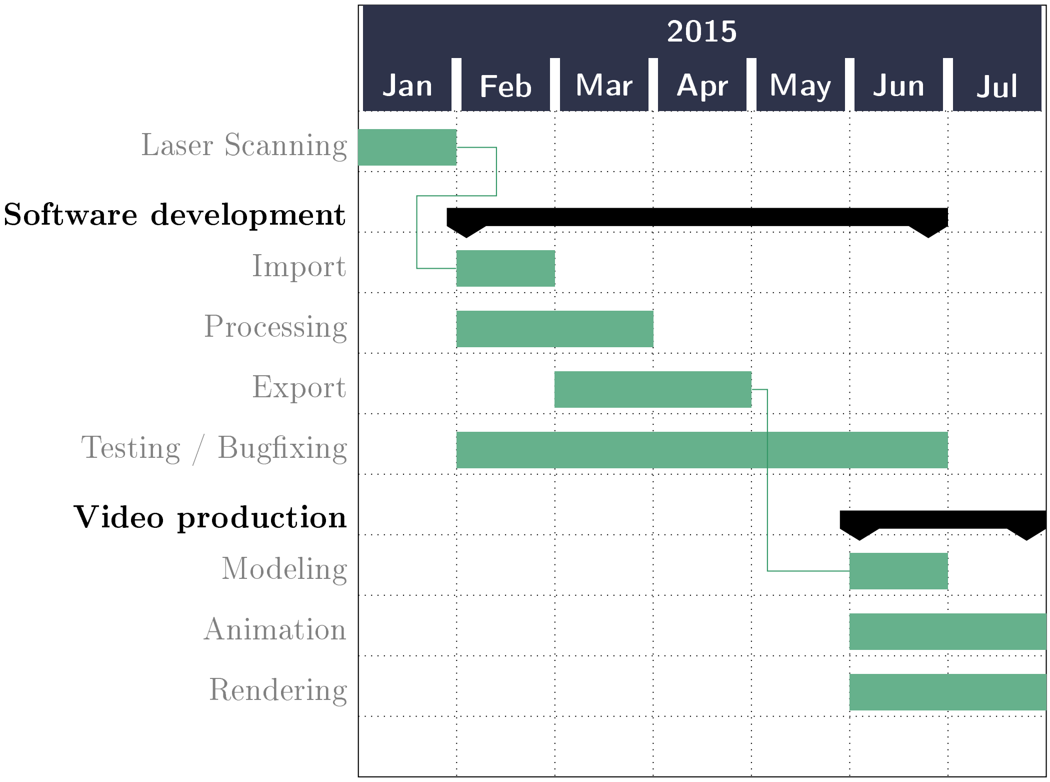
1.2 Initial project specification

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 facade 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 textured surface from the point samples, this research will provide a way for the artist to overcome a bad design decision in Blender, which is making it not capable of displaying or rendering colored point clouds at all (see thread by author on BlenderArtists [Ble14a]). The goal of this research is to get a 3D model of the Pellerhaus in its historic state from 1605 by utilizing point clouds generated via laser scanning as described before.

1.3 Project schedule

This project is divided into two main 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 or use open data for generating geometry of varying complexity. 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 of indoor and outdoor environments. It uses a laser beam emitter and receiver. By using the Distance-Speed-Time formula it is very easy to compute how far away an object is:

$$speed = \frac{distance}{time} \iff distance = time * speed$$

The time between sending a signal and receiving it is measured and multiplied by the speed of light ($c = 299,792,458\ \frac{m}{s}$, Wikipedia [Wik15b]). 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 (Schroeder [see Sch14, p8-9]).

As this gives the meters to only 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 (Techsheet Faro Focus 3D, [FAR13]). 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 (Opti-cal Survey Equipment Ltd. [Opt15]).

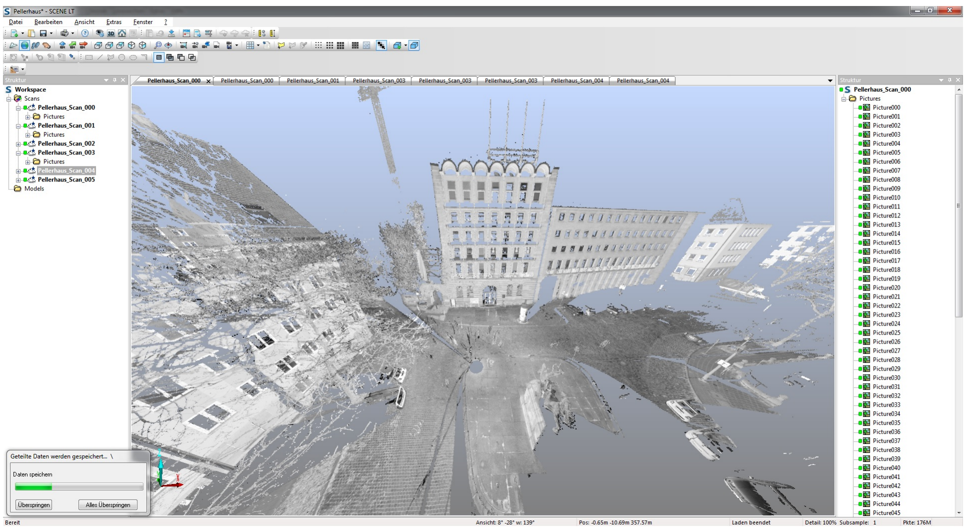


Figure 1.1: LiDAR Scanner Point Cloud of the Pellerhaus

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 (Mail Online, [Vic14]). 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[1].

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

[1] Source: Personal contact to sales team

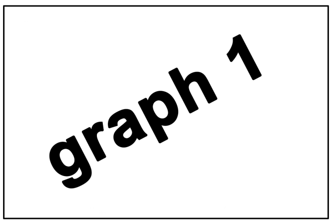
to bridge the gap by starting a crowd funding campaign for a low-cost laser range finder, called the LiDAR-Lite (PulsedLight [Pul15]). It has a total range of 40 meters with a resolution of 1 cm. During this research this sensor is being used with a custom arduino build to examine how it can be used as a cheap alternative to the examples mentioned in the beginning. The price for one module is at 82 Euro.

1.4.2 Ultrasonic

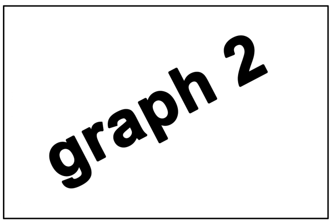
In contrast to LiDAR, most ultrasonic sensors are cheap, but generally are not used for higher distances at several tens of meters (though, there are products for a range higher than 100 meter, compare VEGAPULS 69 [VEG15]). The reason for this is that sound is usually affected stronger by environmental properties than light (compare Sensors Magazine [Sen15]). 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 (compare Dinh [Huy13]). Typical ultrasonic sensor modules with a maximum range of around 5 m can be purchased for 5 Euro already.

1.4.3 Photogrammetry

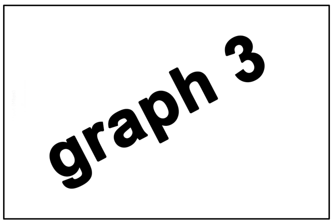
Photogrammetry (also referred to as multi-view reconstruction) is a technique from the Computer Vision field and presents a cost-effective alternative to laser scanning. A real 3D object can be reconstructed as a virtual 3D model by using photographs of the scene and feeding them into such software. 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 Solem [Sol12, p29]). The computer vision algorithms get better each day and there is plenty of software using them.



(a) $OpenSource : VisualSFM + Meshlab$



(b) $Free : Autodesk123DCatch$



(c) $Commercial : AgisoftPhotoscanPro(Demo)$

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 (compare Zamora [Ric14]). 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.

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 (compare F4 [F414]) 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 (compare OpenStreetMap Wiki [Ope15]). 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[2].

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 (Shen et. al. [She10]) 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 reference pictures from the front, side and top view into a 3D software can already yield decent results.

[2]Personal research and contact

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 generated mesh in the design process.

Chapter 2

Background Research

2.1 Historical fundamentals

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, litterally 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 Zwitzel 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 Wiliam 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 occured 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 achitecture. 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 is 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`

2.1.2 Architects

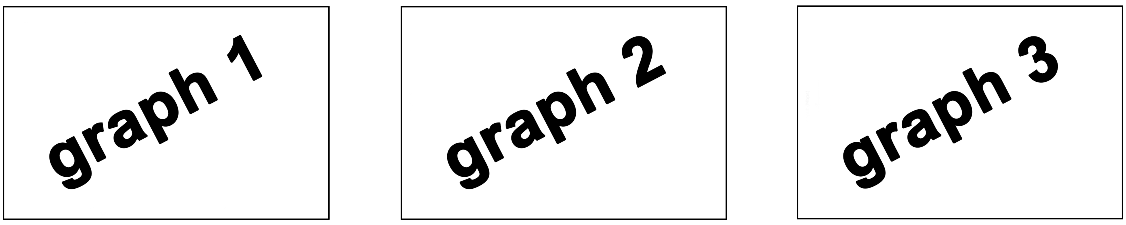
A detailed biography of the architects can be found in the Appendix (A.1).

2.1.3 Pellerhaus

The association Altstadtfreunde e.V. created a flyer [Alt] where a wonderful description was written that has been translated by the author from German:

> 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 enourmous 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 layed 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 layed the foundation block to what later entered as the most magnificient 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 know 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 .



(a) $before$1945 (b) $Pellerhaus$1945 (c) $after$1945

Figure 2.1: The Evolution of the Pellerhaus

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.[Alt12]

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. The 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 build 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.[Alt13]

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 build 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 reconstruced 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 arcarde 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.[Alt14]

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 Toplerhaus (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

In 2D words, a panorama is an image.

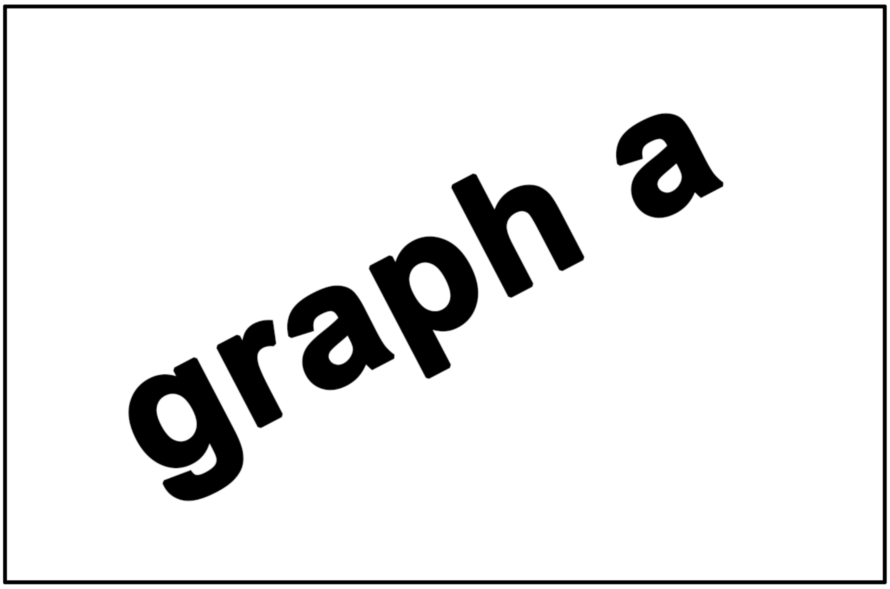


Figure 2.2: 2D Panorama of the Pellerhaus

A 3D Panorama is a two-dimensional image mapped onto a 3d sphere. With such an image it is possible to visualize the complete three dimensional environment from one viewpoint.

3D Panoramas got a great new use by the introduction of the occulus rift (https://www.oculus.com/). They are used in film production as well, this is a very sophisticated use of integrating a 360 panorama video with virtual 3d objects (http://www.cgmeetup.net/home/google-atap-help-behind-the-scenes/).

There are several types of projections used for 3D panoramas, see 2.4.

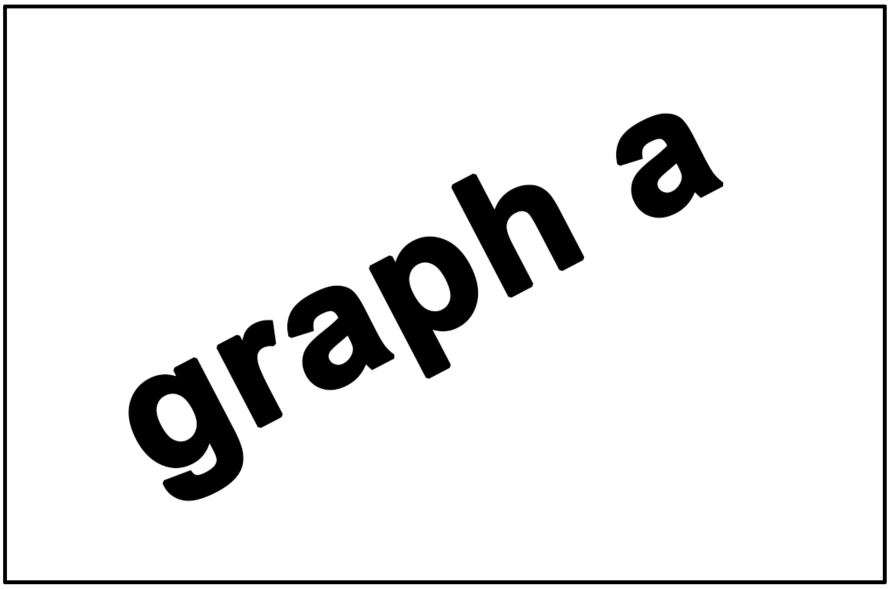
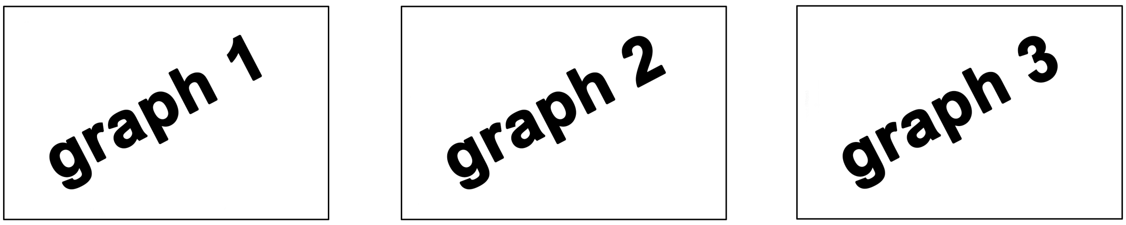


Figure 2.3: 3D Panorama Sphere

2.3 Types of projections

Only equirectangular provides a 100 percent coverage! (see `http://www.cambridgeincolour.com/tutorials/image-projections.htm`)

You can never have perfect "lfat" (2d) representations of a sphere. There are always limitations, but you could choose the right projection for your project. More info `http://www.progonos.com/furuti/MapProj/Normal/CartDef/MapDef/mapDef.html`



(a) *Equirectangular* (b) *Cylindrical* (c) *Mercator*

Figure 2.4: Three example projections

One of the most spread types is the equirectangular projection see 2.4a. Due to this reason we will use it primarily in this project.

Chapter 3

Conversion: From point cloud to Blender 3D

3.1 Concept

Based on the initial idea to somehow move from a dense point cloud to a 3D mesh that can be used in the 3D graphic suite Blender, it was important to plan ahead. When looking at previous research papers (references?) some approaches try to solve problems by applying a transformation of some sort to the original state to get a modified one, which reminds of how the Pellerhaus changed during the last 400 years.
It is possible to mesh a 3d point cloud with several algorithms by trying to find the nearest neighbour of a point in 3d space. One such algorithm is called Delaunay Tetrahedralization (see: http://www.cs.berkeley.edu/ jrs/papers/cdtbasic.pdf) and is used in the free multi-view reconstruction software "Visual SFM", for instance.
With our method we try to utilize the characteristics of laser scanners in such a way, that we know every aquired point can be described by scaling and rotating a unit sphere. In mathematical terms we can determine the spherical coordinates of every point in our point cloud. The 3d points need to be converted from their cartesian coordinate system to the spherical coordinate system first (see http://en.wikipedia.org/wiki/Coordinate_system). Using this simple principle we can not only mesh a point cloud generated by a laser scanner, we can texture it, too. With the coordinates ranging from 0 to 360 degrees horizontally, 0 to 180 degrees vertically and a depth coordinate ranging from 0 to the maximum scan distance we are able to create two images, namely a depth map and a color map. Those images are then being used to create a regular grid which is used for meshing and texture coordinates. By applying the inverse transform to the spherical coordinates it is possible to get the model in cartesian space and export it to any 3d file format. This process is explained in more detail in this chapter.
Furthermore it was neccessary to know how the user will be operating with the software. Usually a use case diagram is created to determine the required functions the software must provide in order to let a user accomplish his desired goals.

3.1.1 Use case diagram

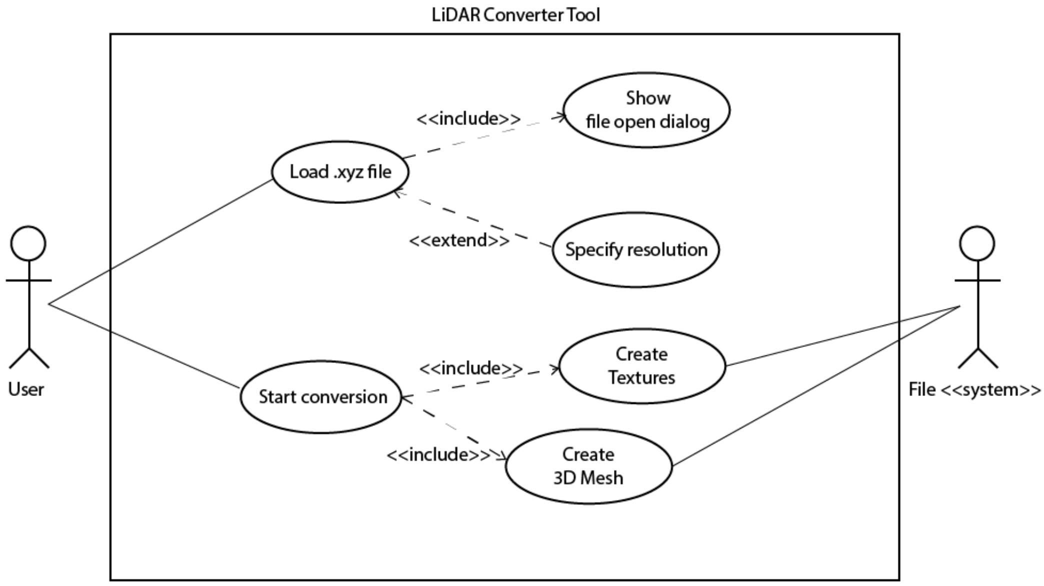


Figure 3.1: Use Case Diagram

3.1.2 Laser scanning on location

For data aquisition we used the Faro Focus 3D laser scanner on the 21.1.2015 16:39:15. First, the device should be configured by setting e.g. the desired resolution (for scan and photos), maximum scan distance (which results in a change of the eye-safety distance), a project name and GPS location (if no GPS module is available like in our case). This configuration can be done in the office or on-site. After the device was set up, the scan process was started. During scanning the main body rotates horizontally and a mirror mounted inside the body rotates vertically. This creates the uncolored point cloud. After the scanning process, several pictures are taken by the built-in camera to color the point cloud. Beforehand the scanner measures the exposure to avoid under- or overexposured photographs. Finally, the inclination is measured with an inclinometer to level the point cloud properly. This procedure was repeated five times to get additional scans covering viewpoints that have been obstructed by obstacles.

While scanning a site we faced problems we didn't expect. We encountered people randomly walking in the laser beam (resulting in vertical lines in the final scan), a suprisingly occuring crash of the device's operating system leading to a terminal output (wrecking the sd card with all previous scans) and a man asking if we took a photo of him while he was entering the building(?!).

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

The Blender Sensor Simulation Toolbox (compare [Gsc+11]) is a custom version of the open source software Blender allowing to simulate different types of scanning within a virtual 3d scene. It is being developed by the Department of Computer Sciences, University of Salzburg, Austria. The goal of this project is to provide a tool, mostly aimed at researchers, that can help with testing algorithms for fields such as obstacle detection and tracking, range data segmentation or surface reconstruction. We found this software very useful to begin with the development of PC2B. With a number of scanner presets it is possible to generate a point cloud of the virtual environment from different types of scanner devices.

3.2.2 Test-Addon for Blender

During the beginning of the software development process the point cloud projection didn't seem to be correct. Testing the algorithm responsible for projecting from

cartesian to spherical coordinates was very tedious, because it involved importing the files, waiting for the images to get generated and then either look at the image files to find mistakes or continue with the meshing process. This pipeline was prone to errors which might affect the result.
Hence, a custom addon for Blender was developed to test the algorithm for the correct mathematics. The language used for addons is Python 3 and enables for developing powerful extensions to the Blender core.

A more efficient approach would be to develop a new modifier in C/C++ that integrates directly into Blender. Unfortunately diving into Blender Core Development is not very easy due to its huge code base. In addition the time constraint didn't permit experimenting with this approach.

3.3 Prototype

The working title of the converter software was defined as "PointCloud2Blender", PC2B in short, because this was the main goal of the software project.

3.3.1 Point Cloud Importer

A crucial part of the PC2B converter software is the ability to import point clouds saved as files. There is a huge amount of file types that can accomodate such a data structure. Points can be stored in ASCII or Binary form. Importing binary formats requires to know the exact structure of the file and the bytes used for certain values. Documentation was limited for many of the file formats, so using ASCII files was a better choice from the beginning. Initially it was planned to only import the .xyz file format, since this is a very simple file format that can be exported in ASCII form from the proprietary Faro SCENE 5 software which is needed for preprocessing the raw point cloud stream produced by the Faro Focus 3D.
During development it turned out that support for the .ply file format is desirable, since scientific websites that provide models (see) widely provide this file type. Also Blender can export a 3D model to this file format. This fact was extremly useful for testing the algorithm, which is described later.

Point Cloud data formats

Working with such file structures like in our case is very easy. See 3.2.

3.3.2 Determine original point cloud resolution

Users of PC2B have the option to determine the resolution of the 3D panorama. It can either be set to fixed multiples of 360 by 180 pixels or set to a custom resolution. We have implemented an algorithm to help the user find the best resolution for his particular point cloud. It works as follows:

3.3.3 Coordinate system representations

We can express points in different coordinate systems. For example cartesian, cylindrical and spherical.

```
-59.43620000 -31.36650000 302.80950000 59 46 55
-60.34600000 -31.80190000 302.85280000 58 45 54
-60.51810000 -31.88870000 302.71900000 58 45 54
-59.50470000 -31.39880000 302.68240000 56 47 50
-60.32350000 -31.79130000 302.89580000 59 46 54
-59.40940000 -31.35360000 302.85200000 61 48 57
-67.58220000 -29.73320000 302.12780000 73 55 58
-67.51000000 -29.59980000 302.04520000 63 43 54
-66.18880000 -29.78650000 299.88830000 100 87 80
-67.54620000 -29.66590000 302.08650000 64 47 56
-67.50660000 -29.59690000 302.00010000 62 43 51
-67.51970000 -29.60540000 302.09000000 64 46 57
...
```

(a) Sample .xyz file

```
ply
format ascii 1.0
comment VCGLIB generated
element vertex 2900882
property float x
property float y
property float z
property uchar red
property uchar green
property uchar blue
property uchar alpha
element face 0
property list uchar int vertex_indices
0.480478 -0.877007 0.000000 -0.479092 0.877764 0.000000
0.477702 -0.878522 0.000000 -0.479092 0.877764 0.000000
0.477702 -0.878522 0.661730 -0.479092 0.877764 0.000000
0.480478 -0.877007 0.661730 -0.479092 0.877764 0.000000
-0.373352 0.927690 0.000000 0.371881 -0.928280 0.000000
-0.370417 0.928866 0.000000 0.371881 -0.928280 0.000000
-0.370417 0.928866 0.661730 0.371881 -0.928280 0.000000
-0.373352 0.927690 0.661730 0.371881 -0.928280 0.000000
0.110288 0.993900 0.000000 -0.111863 -0.993724 0.000000
0.113431 0.993546 0.000000 -0.111863 -0.993724 0.000000
0.113431 0.993546 0.661730 -0.111863 -0.993724 0.000000
0.110288 0.993900 0.661730 -0.111863 -0.993724 0.000000
...
```

(b) Sample .ply file

Table 3.2: Sample generated point cloud files

Almost all point cloud files use a cartesian coordinate system (at least the ones we are using). To get the coordinate of a point in an image plane from a point in cartesian space, we simply convert its coordinate space from cartesian to spherical. We then have the points horizontal position in a range of 360 degrees and its vertical position in a range of 180 degrees. In that way we create the image files from the point samples and then use those images to convert back to the cartesian space.

3.3.4 Converting from cartesian to spherical and vice versa

To convert from Cartesian space to spherical coordinates, we use the following equation:

$$radius = \sqrt{(x^2 + y^2 + z^2)}$$
$$\theta = \text{atan2}\,(y, x) + \pi$$
$$\phi = \cos^{-1}(z/radius)$$

(see [PH10], page 114)
Conversely, to get from spherical to cartesian coordinates, we use:

$$x = r * \sin\theta * \cos\phi$$
$$y = r * \sin\theta * \sin\phi$$
$$z = r * \cos\theta$$

(see [PH10], page 114)
This is inside the text $\cos(2\theta) = \cos^2\theta - \sin^2\theta$.

And this is a separate formula:

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

3.3.5 Types of projections

To convert from Cartesian space to spherical coordinates, we have the option to use various projection types, as already briefly introduced in 2.3.

Equirectangular projection

$$\theta =$$

$$\theta =$$

Cylindrical projection

$$\theta =$$

$$\theta =$$

Mercator projection

$$\theta =$$

$$\theta =$$

3.3.6 Saving textures

The generated depth and color maps are stored with 8-bit unsigned integer values ranging from 0 to 255. After the file has been imported they can be saved directly as .jpg image files.

3.3.7 OpenGL Point Cloud Viewer

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

[Enz14]

3.3.8 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.

3.3.9 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.

3.3.10 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 it's 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 feasable.

custom format

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

3.3.11 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 seperate .obj files).

Chapter 4

Production: Recreating the Pellerhaus from 1605

The generated mesh may still need additional cleanup and detail. The topology is dependend on the used meshing algorithm, naturally. The laser scanner beam cannot sample reflective or transparent structures. It can only provide a great reference for manual tracing.

4.1 Modeling the current Pellerhaus facade

The lower part of the Pellerhaus facade is very similar, almost identical, to the historic one. Thus modeling the modern facade based on LiDAR, photogrammetry and photographic reference appeared to make sense.

4.1.1 Using the PC2B converter software

Firstly, the LiDAR data was preprocesed in PC2B. We created five scans on location, so all scans have been preprocessed and imported into Blender.[Sch14].

4.1.2 Using UAV references with photogrammetry

Unmanned Aerial Vehicles (UAV's or simply drones) are getting affordable, even very good quality models. In our research we use the DJI Phantom 2 with a GoPro Hero 4 Black mounted on a 3-axis DJI Zenmuse H3-3D Gimbal to create photographic aerial references of the Pellerhaus Nürnberg.

Flying a drone inside the city center of Nuremberg is not as easy, as it might be assumed at first. Before even being able to take off with a UAV, German law requires a general permission for just entering the air space. In addition every UAV pilot needs an UAV insurance.

Regarding the usage of drones in the city center, there are more restrictions. The city center of Nuremberg is covered by the controlled air space. Flying in that air space is not permitted until the starting permission from the bavarian aviation authority and UAV insurance are upgraded to commercial ones. Furthermore pilots need a clearance from the Air traffic control (ATC). Additionally the starting and landing procedure requires to cordon off pedestrians and a special license from the traffic authority. Lastly, the owner of the property needs to be asked for permission to allow the starting and landing of the aircraft.

Luckily there are some laws that permit video shoots and taking photos. For example the Freedom of panorama (§ 59, German Urheberrechtsgesetz) allows taking photos from pavements and roads permanently located in a public place.

In total we made three flights on location. It was planned to use the second flight for single photos shot in an interval of 1 second whereas the other two flights are videos in 4K. Unfortunately, it turned out that the third flight wasn't recorded at all and the second flight was captured as a video file. Luckily we noticed the third video missing while still on location, having a bit of battery life left and about one hour left to use the air space, so we made at least two impressive aerial shots before ending the mission.

With having video files instead of still images, those needed to be exported as stil frames to be able to be processed by software. We tried both the free "Visual SfM" and commercial "Agisoft Photoscan Pro" software solutions to generate additional colored meshes of the Pellerhaus. The total processing time of about 20 hours for Visual SfM and 40 hours for Photoscan to get a 3D point cloud from the images. Comparing the results we noticed that Visual SfM generated a bend facade while Photoscan Pro kept it very straight. Although not recommended in (), we used a GoPro camera with a short focal length and thus a strong lens distortion for 3d reconstruction. We can confirm, that the use of this camera is not a good choice, since the radial distortion can produce errors in the feature matching phase of photogrammetry. Still the output should be a good reference for the rough shape of the reconstructed object. If available, LiDAR data should be used for accurate building reconstruction.

4.2 Modeling the historic Pellerhaus facade

Based on the modern facade it was possible to get a good feel for the size of the Pellerhaus in the renaissance. Still the main parts above the ground floor of the facade differ dramatically from the modern one. They can only be extracted from photographs.

4.2.1 Using historic images as guide

It is a huge luck that the Pellerhaus history has been documented by an enormous amount of pictures. A big load of about 190 pictures has been provided for free through the Altstadtfreunde Nürnberg e.V. association, not including about 100 additional pictures depicting the space in front of the building.

Those pictures can be traced in Blender.

4.2.2 Using historic stereoscopic images with photogrammetry

Although the historic pictures have already been a blessing, there are two images aquired by stereophotography. Trying to feed the left and right image into photogrammetry software, respectively, gives a nice 3d representation of the historic facade already. Of course, little details are still missing.

4.3 Modeling the destructed Pellerhaus

The modeling process is finished with the creation of the destructed Pellerhaus, which basically only consists of the base floor.[compare][]webLaTeX-Tutorial.

4.4 Animating between the states

Since the created models are very similar in size, it is possible to animate a simple fade between them. A more interesting solution is a fracturing simulation, though.

4.5 Lighting and Rendering

The models need to be evenly lit.

4.6 Stereoscopic Rendering as anaglyph 3d

For a better presentation, the scene can also be visualized in stereoscopic 3d. Through the newly implemented stereo feature in Blender this is now a hassle-free process.

Chapter 5

Conclusion and Future Work

5.1 Conclusion

To conclude, in this work we presented a method to process a point cloud file with a custom software to get a textured mesh ready to use in Blender (or any other 3d software package) and examined the use of the generated mesh for designers with the use case of reconstrucing the historic Pellerhaus Nürnberg. This approach led to an easy way to get a mesh from a point cloud. The goals have been met and the reaults can be worked with (TODO: correct grammar and spelling ;)).

5.1.1 Mesh generation

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nullam hendrerit interdum sagittis. Nulla facilisi. Pellentesque laoreet tincidunt semper. Pellentesque pellentesque lectus id arcu interdum cursus ut ac dui. Etiam feugiat nisl ac odio suscipit pretium venenatis eget diam. Morbi molestie ipsum sit amet sapien rutrum luctus. Proin ac dolor ut metus laoreet aliquam non id nunc. Curabitur non efficitur dolor. Donec iaculis, dui et porta iaculis, magna tellus placerat ex, sed porta sem ligula ac augue. Fusce vitae sagittis ex. Pellentesque faucibus cursus elit, et faucibus velit cursus in. Nam lobortis id neque id hendrerit. Fusce et dolor nisi.

5.1.2 Handling non-LiDAR-Data

Although the goal for this work was to

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nullam hendrerit interdum sagittis. Nulla facilisi. Pellentesque laoreet tincidunt semper. Pellentesque pellentesque lectus id arcu interdum cursus ut ac dui. Etiam feugiat nisl ac odio suscipit pretium venenatis eget diam. Morbi molestie ipsum sit amet sapien rutrum luctus. Proin ac dolor ut metus laoreet aliquam non id nunc. Curabitur non efficitur dolor. Donec iaculis, dui et porta iaculis, magna tellus placerat ex, sed porta sem ligula ac augue. Fusce vitae sagittis ex. Pellentesque faucibus cursus elit, et faucibus velit cursus in. Nam lobortis id neque id hendrerit. Fusce et dolor nisi.

5.2 Future Work

There are some further ideas how the software and how the 3D model can be used in other fields of application.

5.2.1 Realtime Conversion

Etiam non volutpat diam. Nam ac consectetur felis. Ut nec mi dictum, lobortis mauris quis, dapibus ligula. Nulla porttitor diam sed mauris dapibus posuere. Fusce 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.

5.2.2 Integration in the Blender core

Aliquam at varius elit. Suspendisse viverra ex a ipsum scelerisque condimentum. Nam ac neque luctus, ullamcorper neque sit amet, tincidunt felis. Maecenas id orci rutrum, tincidunt nisl non, aliquam sapien. Aenean vestibulum erat ut nisl vehicula, quis rutrum eros fermentum. Maecenas ut arcu elit. Cras vestibulum pharetra facilisis. Quisque non elit iaculis leo dignissim faucibus. Etiam fringilla tortor nibh, sit amet volutpat diam consequat ac. Sed consectetur metus quis suscipit sollicitudin. Morbi imperdiet scelerisque nunc, in dapibus lacus. Praesent ullamcorper condimentum augue vitae finibus.

5.2.3 3D Lenticular

Interdum et malesuada fames ac ante ipsum primis in faucibus. Cras quis pharetra libero. Pellentesque consectetur, quam vel ultrices finibus, sem enim consectetur mi, in dictum tellus leo eu ante. Maecenas consequat egestas erat, in vestibulum velit pulvinar ac. Suspendisse ullamcorper augue sapien, ac suscipit nulla dictum in. Nam sit amet congue ipsum. Aenean non felis malesuada, feugiat lectus a, tincidunt quam. Fusce nec quam egestas, vulputate est in, commodo nisi. Phasellus id nunc sit amet quam iaculis ornare eu id libero. Ut tempor nisi sed est pretium auctor. Donec in nunc turpis. Integer non tristique dolor. Curabitur a elit mollis urna finibus scelerisque sit amet vel erat. Nullam nec maximus erat. Duis ante mi, posuere ut lobortis nec, posuere eu ligula.

5.2.4 Augmented Reality

Having a 3D model of the historic Pellerhaus opens a whole new set of possible new ways to communicate the history. Example: "Timetraveler The Berlin Wall App" (`https://www.youtube.com/watch?t=75&v=CY9f6UJZlmM`)

Appendix A

Appendix

A.1 Pellerhaus Architect Biography

A.1.1 German

Körner, Hans-Michael and Jahn, Bruno (2012, p.2128) [KJ12] wrote a detailed biography about the architects of the Pellerhaus Nürnberg:

> **Wolff, Jakob d.Ä., Baumeister, Bildhauer, * um 1546 Bamberg, † 4.4.1612 Nürnberg**
> W. wurde 1596 Stadtbaumeister in Nürnberg, wo er mit seinem Sohn Jakob -> W. d.J. die Fleischbrücke errichtete. 1601-05 beteiligte er sich am Neubau der Feste Marienberg in Würzburg und am Umbau des Echtertors. Sein Hauptwerk ist das Pellerhaus in Nürnberg (1602-07), einer der vornehmsten Privatbauten der deutschen Renaissance (im Zweiten Weltkrieg zerstört; die Reste des Arkadenhofs wurden in den modernen Bau einbezogen).
> LITERATUR: Wilhelm Schwemmer: J.W. der Ältere und der Jüngere. In: Fränkische Lebensbilder. Bd. 3. Hrsg. v. Gerhard Pfeiffer. Würzburg 1969, S. 194-213.
>
> **Wolff, Jakob d.J., Baumeister, *1572 Bamberg, † 24.2.1620 Nürnberg**
> W. war Schüler seines Vaters Jakob -> W. d.Ä., erhielt 1605 in Nürnberg die Stelle eines Stadtwerkmeisters, hielt sich mit Erlaubnis des Rats u.a. in Bayreuth, Frauenaurach und Schwabach auf und begann, beeinflußt von der niederländischen und italienischen Renaissance, 1616 mit dem Neubau des Rathauses in Nürnberg, der 1622 von seinem Bruder Hans vollendet wurde.

A.1.2 English

Körner, Hans-Michael and Jahn, Bruno (2012, p.2128) [KJ12] translated from German by the author:

Wolff, Jakob d.Ä., master 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 Echtertor. 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., master builder, *1572 Bamberg, † 24.2.1620 Nuremberg
Wolff was the student of his father W. d.Ä., was given the job of a Stadtwerkmeister (Municipal Master of the Works) in 1605, had the permission from the council to stay in Bayreuth, Frauenaurach and Schwabach and started, influenced by the Dutch and Italian Renaissance, with the new build of the city hall in Nuremberg in 1616, which was finished by his brother Hans in 1622.

A.2 Software used

A.2.1 LaTeX

This paper was written in LaTeX. 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 LaTeXin 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 LaTeXbefore, various tutorials [Sha13; Vel15] on the internet have been a great help.

A.2.2 Faro SCENE LT

For preprocessing of the raw laser scanner point cloud.

A.2.3 Blender 3D

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

A.2.4 Meshlab

For converting binary test files to ASCII.

A.2.5 Visual SfM

For creating 3D models from images for free.

A.2.6 Agisoft Photoscan Professional

For creating 3D models from images with a 30-day test period. Mostly historic stereo pairs have been processed well.

A.3 Programming frameworks and libraries

A.3.1 Qt 5.4

Qt is an open source framework ...

A.3.2 OpenGL

The Open Graphics Library (OpenGL) is an abstraction layer for accessing graphics hardware on a high level. The current version supports the programmable function pipeline, where vertex and fragment shaders provide a rich set of ways to manipulate the final pixel on the output device, e.g. computer screens. ...

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