<u>İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY</u>

MODELING STONE WALLS USING LASER SCANNER DATA

MSc. Thesis by

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JANUARY 2008

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TAŞ DUVARLARIN LAZER TARAYICI VERİLERİYLE MODELLENMESİ

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PREFACE

I would like to thank my supervisor Assoc. Prof. Dr. Rahmi Nurhan ÇELİK for all the help and support he gave me not only for this thesis but all through my college life. I would like to thank Kaletakimi for all the hard work at the field and in the office. For giving the technical support during the project, I also would like to thank Sistem A.Ş. and most importantly to Bora SAYIN, 3D and GIS manager of Sistem A.Ş., who has the most two important roles in my life. I'm so thankful for the time he spent for the project, without him we wouldn't be able to use laser scanner, and also I'm so thankful for his patience and belief and all the help he gave me as my husband.

January 2008 Banu YÜKSEL

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ABBREVIATIONS

3D	: 3 dimensional
TOF	: Time of flight
LED	: Light emitted diot
CAD	: Computer aided drawing
GIS	: Geographical information systems
CCD	: Charged coupled device
LFM	: Light form modeler
DLL	: Dynamic link library
RGB	: Red, Gren, Blue

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X, Y, Z	: Cartesian coordinates of the points
r, θ, φ	: Spherical coordinates of the points
c	: Speed of light
τ	: Elapsed time

TAŞ DUVARLARIN LAZER TARAYICI VERİLERİYLE MODELLENMESİ

ÖZET

Lazer tarama teknolojisi mimarlık, arkeoloji, ölçme, otomotiv, olay yeri inceleme, halihazır, jeoloji, inşaat …vb. de kullanılan bir ölçme tekniğidir. Geniş bir kullanım alanı vardır. Bu tezde kültürel miras dökümantasyonunda kullanımı ve mimarı değerlendirilmesi ele alınmıştır. Türkiye'de ilk defa lazer tarama teknolojisi Seddülbahir projesi kapsamında büyük ölçekli mimari bir alanın dökümantasyonunda kullanılmıştır. Tüm alan 5 mm hassasiyette Leica HDS 3000 lazer tarayıcı ile ve Leica TCR407 reflektörsüz total station eşliğinde taranmıştır. Bu projenin değerlendirme safhasında, mimarlar lazer tarayıcı verilerinin değerlendirilmesinde bazı zorluklarla karşılaşmışlardır. Bu yüzden bazı değerlendirme aşamalarını otomatik olarak yapabilmek yönünde çalışıldı. Ancak piyasadaki mevcut yazılımlardan hiçbiri bunu yapamıyordu. Duvardan taşları çıkartabilmek için, noktalardaki derinlik farkını analiz eden bir araç -SWT geliştirildi. Nokta bulutundan taşları çıkartabilmek için bir matematiksel model oluşturuldu. SWT her bir noktanın tanımlanmış bir düzleme olan uzaklıklarını analiz ediyor. Eğer bu noktanın uzaklığı kendinden bir önceki ve bir sonraki noktanın uzaklıklarından daha az ise bu noktaya ait bilgiler tutulur. Bu noktalar taşların çevresini oluşturmaktadır. SWT, eğer taşlar arasındaki derinlik farkları mantıklı ise ve de taş yüzeyleri çok deforme olmamış ise iyi bir performans sergiler. Eğer taşların yüzeyleri çok hasar görmüşse, SWT taşların sınırlarını yakalayamaz yada bazılarını atlayabilir. Diğer bir durumda tanımlanan düzlemin taşlara mümkün olduğunca paralel olmasıdır.

MODELING STONE WALLS USING LASER SCANNER DATA

SUMMARY

Laser scanning technology is a measurement technique used in architecture, archeology, surveying, automotive, forensic and accident, as-built, geology, construction …etc. It has a wide variety of use. Here in this thesis its use in cultural heritage documentation and architectural evaluation is discussed. For the first time in Turkey laser scanning technology was utilized for the documentation of a large-scale architectural heritage site in the Seddülbahir Project. The entire site was scanned with 5 mm accuracy using a Leica HDS 3000 laser scanner accompanied with a Leica TCR407 Power reflectorless Total Station. During the post processing of this project, architects came across with some difficulties in evaluation of the laser scanner data. So some thought went into doing some stages automatically. But none of the commercial software was able to do that. A tool for the extraction of stones is developed analyzing the depth differences of each point, called SWT. For being able to extract stones from the point cloud data, a mathematical model is created. SWT analyzes each points distance to a specified plane. Then it stores the point's information if that points' distance is smaller than the one before and the one after itself. These points make up the area of the stones. SWT works best if the depth differences among the stones are reasonable, and if the stones are in good conditions. If the surfaces of the stones are damaged a lot so that they also have depth differences on the surface, then SWT cannot recognize the outlines or may loose some of them. Another condition that SWT needs is that the referenced plane defined is as much parallel to the stones as possible.

1. INTRODUCTION

Modeling reality has always been one of the most complicated and desirable topic of engineering. All of the engineering professions model the reality by all means, chemists, geodesists, mathematicians, biologists, computer scientists, aeronautics engineers etc., and architects. But no matter how close we can get, it would never be the same as original. For example mathematicians try to find some models like taking the derivates to solve for some problems. The model would be perfect if you could reach infinity but it is not possible. A geodesist tries to find the best model to represent geographic features. Physicians try to understand the “big-bang” by creating a small model of it nowadays. But even if they could do everything the same, the time would be different. So when we’re modeling something, we start the job knowing that there must be some tolerances. Why is that? Because if we want to model something we have to make some measurements and as we all know a measurement is a coincidental variable. If we repeat the measurements infinite times and take the mean value that would be the actual value of our measurement. But again it is not possible. So we do a sampling. We measure a couple of times, take the mean value and we assume that the result represents the actual measurement value. If none of the measurements are “true” than we can say any model that we make out of our measurements would not be perfect. But why not try to make it as good as it gets?

To do this, newly technologies are being developed – one of them being the laser scanning. Laser scanning technology is a measurement technique used in many fields including architecture, archeology, surveying, automotive, forensic and accident, as-built, geology, construction. It has a wide variety of applications. Here in this thesis its use in cultural heritage documentation and architectural evaluation will be discussed.

2. 3D LASER SCANNERS

A 3D laser scanner is a device that analyzes a real world object or environment to collect data on its shape and possibly color. The collected data can then be used to construct digital, 3D models that are used in a wide variety of applications. These devices are used extensively by industry in the production of such entities as movies and video games. Other applications include industrial design and prototyping, computer vision and documentation of cultural artifacts. [1]

3D laser scanners record the 3D coordinates of numerous points on the surface of an object. Thousands of points are recorded per second, at milimetric/centimetric grid intervals, across a scanned object to build up a dence 3D point cloud representation of the object containing typically millions of points and requiring specialist software to process. The 3D points are in a common coordinated system that represents the spatial distribution of an object or site. The combination of digital photo modeling and laser scanning can enhance the point cloud data, allowing for the recognition of better definition in the texture and geometry of the scanned objects.

The purpose of a 3D scanner is usually to create a point cloud of geometric samples on the surface of the object. These points can then be used to extrapolate the shape of the object (a process called reconstruction). If color information is collected at each point, then the colors on the surface of the object can also be determined.

3D scanners are very analogous to cameras. Like cameras, they have a cone like field of view, and they can only collect information about surfaces that are not obscured. While a camera collects color information about surfaces within its field of view, a 3D scanner collects distance information about surfaces within its field of view. The “picture” produced by a 3D scanner describes the distance to a surface at each point in the picture. If a spherical coordinate system is defined in which the scanner is origin and the vector out from the front of the scanner is $\varphi=0$ and $\theta=0$, then each point in the picture is associated with a φ and θ. Together with distance, which corresponds to the r component, these spherical coordinates fully describe the 3D position of each point in the picture, in a local coordinate system relative to the scanner. [1]

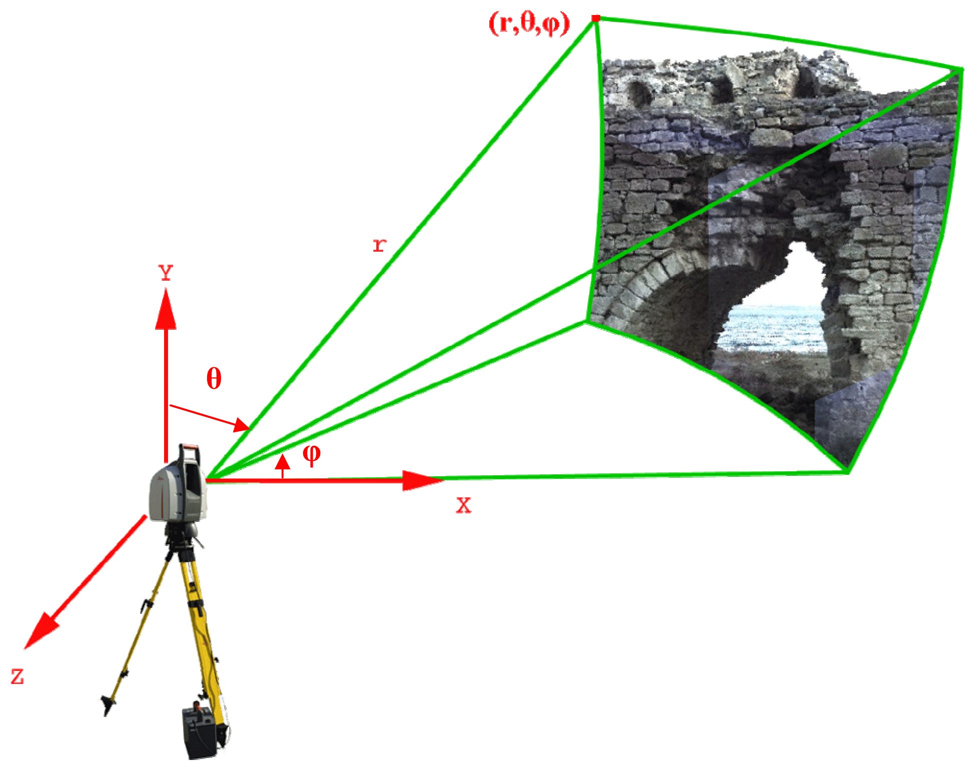

Figure 2.1: Coordinate systems of the laser scanner and the picture

2.1 Laser Scanning Methodology

Traditional scanning methodology uses measurements to capture a number of common targets, either flat or spherical, to relate multiple scans to one another or to relate measurements to an existing control network. This workflow involves placing the scanner and measuring a number of targets and objects, such as buildings. The scanner is then moved to a second location and at least three common targets, as taken from the first scanner location, are measured. This is necessary to relate the scans in a manner very similar to GPS calibration. The process is typically done in the office after completion of field data collection. While traditional scanning methodology is suitable for many applications, it does have limitations:

- measurements have to be done to multiple targets from each scan location, which requires careful survey planning and time to measure each target
- multiple scans require field post-processing to relate the data into a single homogeneous set, and to a control network.

Older 3D scanners were large, not easily manoeuvrable and required a ground power supply and a PC or laptop for operation. To support the survey workflow, a modified approach is required to 3D scanning hardware, software and methodology: one that resolves the above listed limitations. Basically, this can be achieved by using a traditional total-station survey workflow whereby the scanner is set up over known points to provide a direct relationship to control points. Measurements between stations (traverse measurements) provide an instant relationship between multiple stations and allow the user to view homogenous data in the field without post-processing. In order to support a survey workflow, 3D laser scanners must provide:

- tribrach with laser or optical plummet to ensure that the scanner is precisely positioned on a known point
- mark for accurately measuring the instrument height and field software that corrects instrument height measurement for the slope to obtain a true vertical measurement
- dual-axis compensator for levelling the instrument over a known point and which is able to actively correct the horizontal and vertical angles for mis-levelling
- centric-standard 5/8” thread mount in the top of the scanner for placing a prism or GPS receiver on top of it as part of an integrated survey solution, even during scanner operation.

In addition, 3D scanners should be equipped with advanced laser technology to provide accurate focused measurements and enhanced long-range operation. This technology ensures that the scanner can be used for a variety of survey applications and environments. Further, to enhance field portability 3D scanners should be equipped with a rugged field controller[3].

2.2 Laser Scanning Types

In the last years, terrestrial laser scanner technology was proposed as useful and competitive approach for documentation of cultural heritage. It is commonly accepted that precise documentation of the status quo is essential for the protection of a building for scientific studies, during restoration and refurbishment, but also for the presentation to the general public. Laser scanner technology allows to model objects in 3D with a density of measurements that cannot be acquired within a possible time frame with traditional technologies. Laser scanner can be defined both as imaging and non-imaging system due to the capability to acquire 3D measurement (non imaging characteristics) with a resolution comparable to a digital picture (imaging characteristics). Completeness, accuracy and fastness are the peculiar characteristics for which laser scanner is generally accepted by survey community as a valid support for documentation and conservation of historic buildings, monuments or archaeological sites. Beside the most popular measurement system based on the time of flight principle, the phase measurement principle represents the other technique for medium ranges. Phase-based scanners, existing on the market since more than10 years, were initially proposed as system for industrial applications. These systems are characterized by high speed of acquisition and very high data density and resolution. These characteristics can be considered peculiar for cultural heritage applications, but pose challenging problems with regard to efficient data processing and 3D modeling.

Several instrument configuration of the measuring head and of the internal mirrors are available for both the measuring technologies; the geometry of the laser field of acquisition can vary from a fixed window – like a digital camera – to approximately 360° field of view [3].

Table 2.1: Main differences of time of flight based and phase-shift based systems.

Measuring System	Range(m)	Accuracy (mm)	Scan Rate (point/sec)
Time of flight	<1500	<20	Up to 12.000
Phase shift	<100	<10	Up to 625.000

2.2.1 Time of Flight

Most of laser scanner application, also in cultural heritage applications, presented in last years makes use of time of flight scanning systems. 3D coordinates of an object are derived measuring the time the laser signal spent from the laser head to the object and back. Generally time of flight systems allow unambiguous measurements of distances up to several hundred of meters and are generally characterized by middle speed of acquisition.[3]

Time-of-flight technology works by sending out a laser pulse and measuring time taken to reflect it from an object back to the instrument. Combining the range with angle-encoder measurements provides the 3D location.

Time of flight technology is similar to the Direct Reflex (DR) or reflector less technology used in advanced total stations. However, the difference between 3D scanners and DR technology is the speed of measurement. Total stations can measure around four distances per second in DR mode. In contrast, time of flight laser scanners can measure up to five thousand distances per second; that is over a thousand times the speed of a total station. This allows a 3D scanner to quickly produce large amounts of survey data. The resulting point cloud can provide a 3D shape, or visualization, of the object being measured.

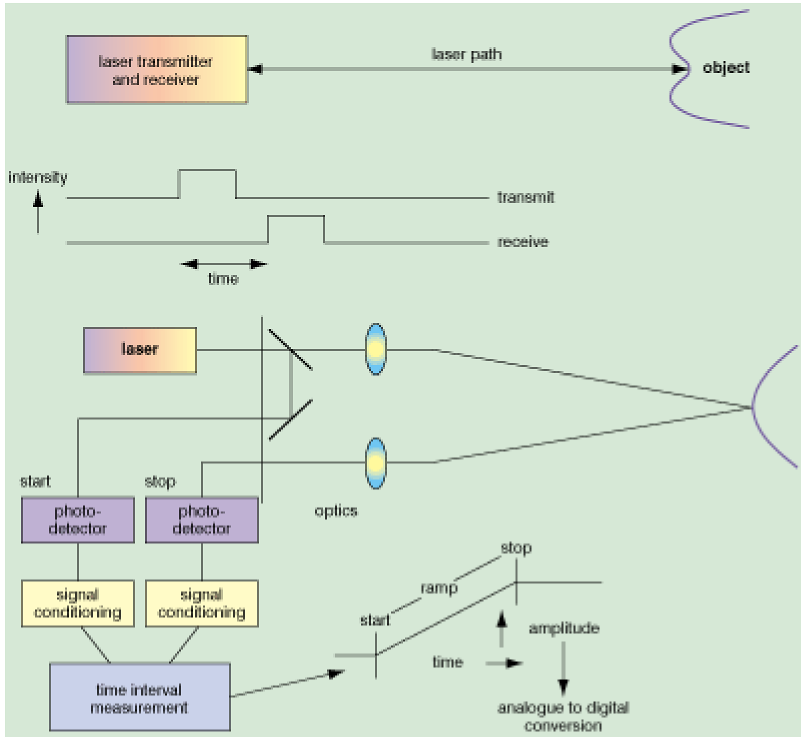

Figure 2.2 : Schematic diagram of a pulsed time of flight system.[4]

The basic principle of a pulsed TOF system; a laser signal is projected towards the object surface and the reflection is acquired by a receiving optical system. As the speed of light in the transmitting medium (usually air) is known then the distance to the surface can be measured accurately as ½cτ where c is the speed of light and τ the elapsed time.

Laser time of flight instruments offer very long range distance measurement, with a trade-off between accuracy and speed. They can measure the distance to a single, small point without requiring a special target, or measure several kilometers with a retro-reflecting target. Instruments can be compact, and are often combined with a sighting device, such as a theodolite or binoculars.

There are essentially two methods for determining distance in time of flight instruments: a short pulse of light is emitted and the delay until it returns is timed or a phase difference between emitted and reflected waves is measured. Each method has advantages and disadvantages, which initially lead to them being used in very different applications. Continued development has improved both technologies and they are used in a wide range of surveying and engineering products.

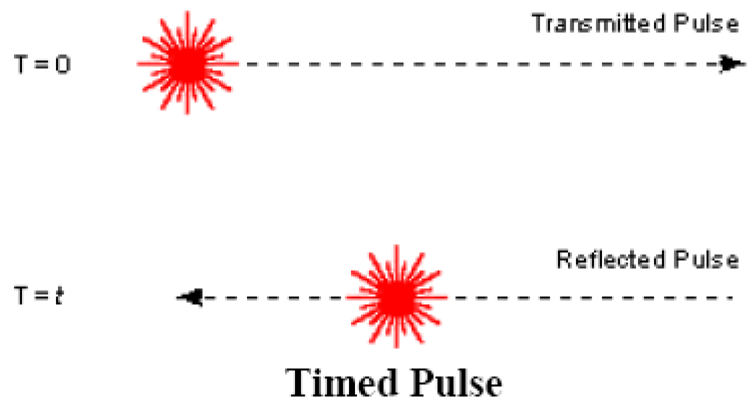

Figure 2.3: Timed pulse – showing the time of flight principle

A short pulse of laser light is emitted, and the delay until its reflection returns is timed very accurately. If the speed of light is known, the distance to the reflecting object can be calculated. A single timed pulse is not very accurate, so a large number of pulses are used and averaged to give a more accurate distance. Hence there is a trade off between the accuracy and speed of measurement.

2.2.2 Phase Shift

Beside the time of flight principle, the phase measurement principle is the other technique for medium ranges. High acquisition rate and high density of 3D point's acquisition are the peculiar characteristics of phase-shift systems. [3]

Phase-shift technology works by sending a laser beam with a sinusoidal wave to the centre of a rotating mirror, which deflects the beam around the site. After reflection from an object, 'phase shift' is measured by the instrument, giving the distance. Using encoders to measure mirror rotation and horizontal rotation of the laser scanner, the 3D coordinates of each point can be recorded.

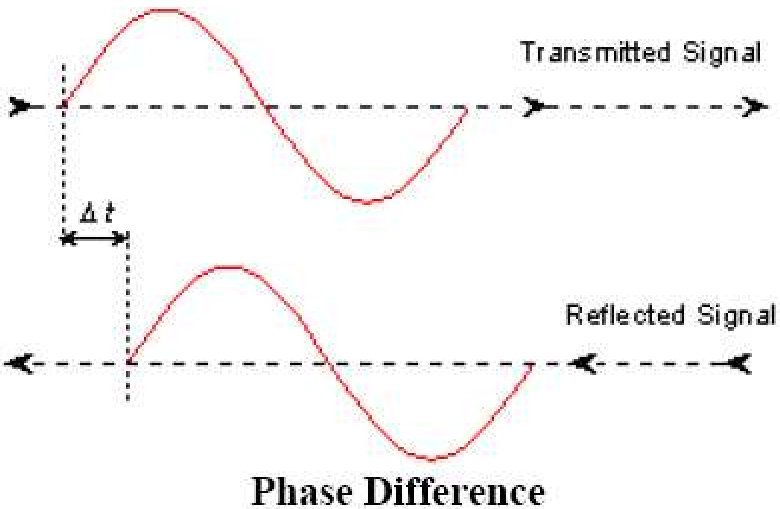

Figure 2.4: Phase difference– showing the phase shift principle

The laser of LED beam is modulated with a wavelength of 20 to 30m, and the phase of the emitted and reflected waves is compared. This phase difference, which is obtained by timing the delay between an emitted and a reflected wave-front, can be expressed as a fraction of the modulated wavelength. However, the distance to the object is ambiguous, since it could be any integer number of wavelengths away. By using several different wavelengths, and solving a simultaneous equation, the distance to an object can be calculated uniquely.

2.3 Laser Scanner Data – properties – data format

All types of laser scanners produce a very dense data composes from 3D points which is called a point cloud. A point cloud is a set of 3D points describing the outlines or surface features of an object. In some scanners you can even get color attributes for these points of the point cloud. Some scanners have internal digital cameras or they have an external utility to gather the images of the scene. The points that intersect with the pixels of the photographs get the value of the pixel as an attribute so you have a colored point cloud. So basically point cloud data composes of X, Y, Z coordinates and R, G, B values.

There are a bunch of file formats developed by different companies in laser scanning technology. Leica products produce files with the extensions of .pts and .ptx. IQvolution products produce files with the extensions of .iQscan, .iQmod and .iQwsp. Riegl products produce files with the extension of .3dd. MENSI products produce files with the extension of .soi. Z+F products produce files with the extension of .zfc and .zfs. Visi Image products also produce files with the extensions of .pts and .ptx.

PTS : is a graphic file format for 3D points

PTX: Pentax raw bitmap graphic

3DD: Graphic Animation File

SOI: MENSI 3D Laser Enhanced 3D Scanner File (Trimble Navigation Limited)

.pts and .ptx are also text files. Additional to these file formats you can export your point clouds into bunch of text and image formats.

The point clouds that are used in this thesis are collected by Leica laser scanner HDS3000. Leica also gathers all data in an internal database format called .imp. This format stores all data in control spaces, model spaces, scans and images.

Control spaces keep point clouds and the targets that are measured at the field and there you can do all the registration works.

Model spaces keep the point clouds that are registered.

Scans keep the images of each scan and also the target scans.

Images keep all the images that are taken during the measurement.

Laser scanners either horizontal or vertical – scan line by line. Since you can set the horizontal and vertical spacing, the data actually can be characterized as in a matrix form.

Figure 2.5: Point cloud data showing the matrix form of the data

As shown in figure 2.5 points make up a matrix form of data and each are in a 3D format having the color attribute. This figure is from a point cloud which is collected by a Leica laser scanner. This scanner collects data by vertical lines. So the points are stored as shown below.

1	7	13	19	25	31	37	43	49
2	8	14	20	26	32	38	44	50
3	9	15	21	27	33	39	45	51
4	10	16	22	28	34	40	46	52
5	11	17	23	29	35	41	47	53
6	12	18	24	30	36	42	48	54

Figure 2.6: Graphic representation of a point cloud of a vertical point gathering system

If a laser scanner gathers data in a horizontal line strips then the point cloud would look like figure 4.2.

1	2	3	4	5	6	7	8	9
10	11	12	13	14	15	16	17	18
19	20	21	22	23	24	25	26	27
28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45
46	47	48	49	50	51	52	53	54

Figure 2.7: Graphic representation of a point cloud of a horizontal point gathering system

2.4 Applications of Laser Scanning

3D laser scanning is used in numerous applications: industrial, civil, surveying, topography, mining, quality, archaeology, dentistry, reverse engineering, and mechanical dimensional inspection are just a few of the versatile applications.

3D laser scanning technology allows for high resolution and dramatically faster 3D digitizing over other conventional metrology technologies and techniques. Some very exciting applications are animation and virtual reality applications. A virtual reality application may be employed to create a 3D virtual space from an existing architecture.

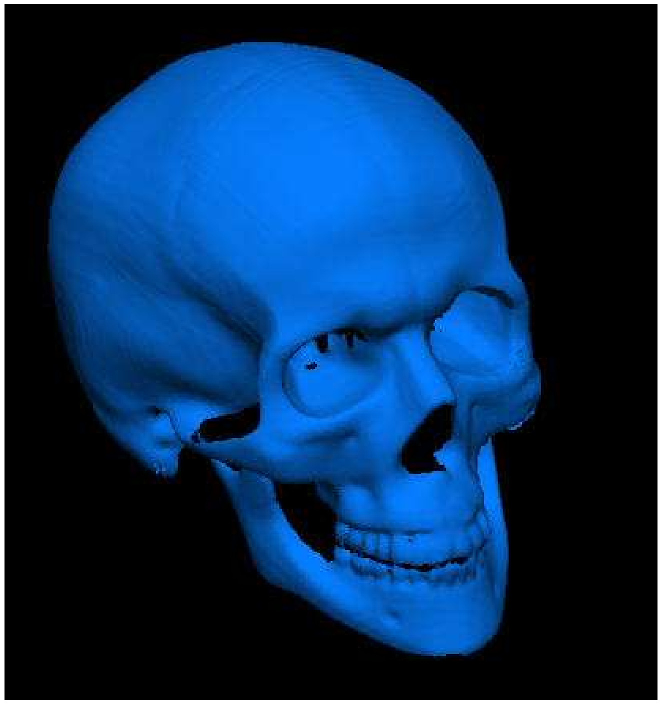

Figure 2.8: 3D mesh model of a skull that is measured using laser scanner.

The virtual reality space may then be used in computer simulations of various desired activities. Such activities could include a workflow or manufacturing line simulation. The 3D virtual space may be used for entertainment, such as animation or a movie action scene simulation, keeping even the stunt professions safe from harm.

Transportation applications may include an accident investigation. The scene of the accident could be 3D laser digitized, and a simulation of an actual accident event or "what if" scenarios explored.

A practical mechanical and civil engineering application would be to assist in the production of "as built" data and documentation. Currently, many manufacturing or construction activities are documented after the actual assembly of a machine or civil project by a designer or engineering professional. 3D laser scanners could expedite this activity to reduce man hours required to fully document an installation for legacy.

Laser scanning can also be an excellent method to document a rebar installation for inspection requirements. Other civil activities could be for a roadway periodic inspection. The digitized roadway data could be contrasted to previous roadway 3D scans to predict rate of deterioration. This data could be very helpful in estimating roadway repair or replacement costing information.

Laser scanning is also very useful in cultural heritage, you can evaluate the data in classical architectural means and also you can get a 3D model of the site without architectural subjective ness. And as long as you can store the data, many decades to come, people would be able to witness that heritage.

When personnel accessibility and/or safety concerns prevent a standard survey, 3D laser scanning could provide an excellent alternative. 3D laser scanning has been used to perform accurate and efficient as-built surveys and before and after construction and leveling surveys.

2.4.1 Laser Scanning in Cultural Heritage

Cultural Heritage can be defined as monuments, buildings, or landscapes of “outstanding universal value from the point of view of history, art or science.” These sites are often under threat from environmental conditions, structural instability, increased tourism and development, and they are most likely under funded, and hence, inadequately documented and maintained. Laser scanning, in combination with other digital documentation techniques and traditional survey, provides an extremely useful way to document the spatial characteristics of these sites. This spatial information forms not only an accurate record of these rapidly deteriorating sites, which can be saved for posterity, but also provides a comprehensive base dataset by which site managers, archaeologists, and conservators can monitor sites and perform necessary restoration work to ensure their physical integrity. [5]

When presenting the history of a heritage site or an artifact using multimedia technology, the proper use of technology to acquire and represent spatial information is crucial in order to facilitate the understanding of that particular site and the relationship between the elements constituting that site. In many cases, one has to model complex environments that have a rich historical content. These are composed of several objects with various characteristics and it is essential to combine data from different sensors and information from different sources. There is no single approach that works for all types of environment and at the same time is fully automated and satisfies the requirements of every application. A general approach combines information from historical material, multiple images, single images, laser scanner data, known shapes, CAD drawings, existing maps, survey data, and GPS data. [6]

3D laser scanner technology, joining precision and versatility, assures survey's high quality and working time's optimization. Nowadays, this is the most advanced methodology to document, monitor and diagnose buildings which are difficult to survey for their articulated formal-geometric shape, unfavorable logistic and environment conditions. Thanks to its peculiarities, this methodology has great potentialities in archaeological survey, not yet explored; whereas traditional systems have more difficulties and limits. [7]

The documentation and monitoring of cultural heritage assets is a challenging application of laser scanning. For these applications it is necessary to have a precise surface model and thus high point densities. While it is possible to achieve the required precision with close-range scanners, this quickly becomes economically infeasible. The goal is thus to work with medium-range laser scanners at high point densities and improve the quality of the surface model in the post-processing. If the sampling is very dense, techniques to reduce the measurement noise becomes essential.

2.4.2 3D Scan for the Digital Preservation of a Historical Temple in Taiwan

In 2005, "3D Scan for the Digital Preservation of a Historical Temple in Taiwan", a promising application of a long range scanner in heritage documentation was undertaken. The main hall of Pao-An temple in Taiwan was scanned, a digital recording of the temple was undertaken as an extension of a project to record Chinese architecture. The first temple at the site of PaO-An Temple was a small one, made of wood which was constructed between AD 1775 and 1760. The existing structure was constructed between AD 1805 and 1830. The Cyrax 2500, a 3D long range laser scanner (50-150m) was employed to retrieve the data.[13]

The creation of the final 3D model was a different approach than conventional documentation where the transition from the 2D drawings to the 3D is fundamental. In this project the initial 3D model was used to create more 2D drawings and necessary measurements. The cloud model was exported to CAD software and by tracing the edges; the team obtained the 2D elevations, sections, etc. This method was very significant because regarding the prolific amount of 3D decorations on the temple, the drawing sequence from 3D to 2D provided errorless final products compared to the conventional method of tracing on the photos. [13]

2.4.3 Digital Statue of Liberty Project

The Statue of Liberty located in New York Harbor is one of the distinguished historic structures in the American history being a symbol of the ideals of freedom and liberty. She was designed by French sculptor Bartholdi in recognition of the friendship established between France and United States during the American Revolution. In 1886, the statue was erected on top of a granite pedestal which was built inside the courtyard of star shaped Fort Walls. [13]

In 2001, NPS contracted Texas Tech University College of Architecture to demonstrate the feasibility of using a laser scanner to provide highly accurate documentation of the skin of the Statue, to monitor the patina and thus supply a plan for the maintenance and operation of the Statue. The Digital Statue of Liberty Project was initiated by scholars from Texas Tech University and on the subject of investigating the utilization of scanning technologies for nonlinear colossal structures and examining the data conversion requirements. [13]

The team utilized a Cyrax 2500 laser scanner accompanied by a reflectorless Leica TCR702 total station. The scanned data was used to create a polymesh. The polymesh was smoothed and the holes were filled, and then the final polymesh was converted to NURBS. [13]

The TTU team encountered drawbacks as well while working with the point cloud data such as the tardiness of the computer in processing the large amount of data such as the data set for Fort Walls, the pedestal and the statue. Therefore the team subdivided the work areas throughout the processing and worked on the issued drawings one by one. The team especially encountered difficulty when dealing with the stones of the Fort Walls. The Fort Wall elevations were full of individual stones and this slowed down the manipulation of the data significantly, so the team preferred to subdivide the individual

Fort Wood elevations and trace the stones locally, similar to the method used by the Seddülbahir team. [13]

3. Evaluation of Laser Scanner Data

The laser scanner collects a large range of data representing 3D coordinates, called “point cloud data”; proprietary software is then required to manipulate massive amounts of 3D data. While laser scanners take a few minutes to scan millions of accurate 3D points, there is enormous work in transporting this data into a 3D model containing usable information. Dedicated software programs such as polyworks, leica cloudworks for AutoCAD and RiScanpro have greatly improved the processing, manipulation and analysis of vector and image data from the point cloud.

3.1 Software used for Laser Scanner Data

There are lots of software used for laser scanner data but only the most popular ones are mentioned here.

3.1.1 Cyclone

The cyclone software is developed from Leica since many years and is able to connect both, phase based scanners and pulsed systems as well as other GIS data measured by airborne scanners and other data capturing systems. Furthermore, the point clouds can be superimposed with color data from standard CCD cameras and therefore it is a kind of universal software tool. Different modules are available. [8]

Cyclone Server is a standalone server module that enables individual members of workgroups to simultaneously access 3D point clouds, embedded images, and geometric surface models. This provides a powerful environment for collaborative design on large, complex projects and can significantly reduce project execution time. [8]

Each module of the Cyclone 3D point cloud processing software product line is based on a Client/Server Object Database foundation. Cyclone- SERVER supports the concurrent connection of up to ten (10) 'client' users to the same data server in a network environment. These clients can be licensees of Cyclone-SERVER, MODEL, SURVEY, VIEWER, or Cyclone CloudWorx™ for AutoCAD and MicroStation CloudWorx (distributed by Bentley Systems, Inc). [8]

Cyclone-SERVER eliminates data redundancy and related synchronisation issues, frees disk space on workstations, and provides more reliable access in network environments. A dedicated server, administered remotely by authorised users,can serve databases to Cyclone clients on the same network. Workstations with licenses of Cyclone software can also contain Cyclone-SERVER licenses, distributing the server load. Cyclone’s PC-based server products are effective tools for computers with single or multiple processors. [8]

Cyclone is composed of individual software modules, allowing customization for the individual client. Cyclone-REGISTER quickly and accurately aligns point clouds captured from different scanning positions to a common co-ordinate system. Cyclone-MODEL is the complete, full featured tool set of Cyclone software for information extraction and 3D modelling. Cyclone-MODEL enables solutions in many applications including plant, survey, and civil engineering. Cyclone-SURVEY is a subset of the Cyclone-MODEL product and is an ideal module for surveyors. Cyclone-VIEWER is a free, view only version of the Cyclone software. [8]

3.1.2 3D Ipsos

3Dipsos from Mensi is a 3D modelling system used to reconstruct 3D models from large sets of point cloud data. 3Dipsos is a solution for as-built data capture and reverse engineering of large industrial sites including process, power, and oil/gas related plants. The software can also be sed to reconstruct triangulated meshes directly from clouds of points, in order to model nonmathematical shapes like statues, bas-relief, historical monuments, natural scenes, and other irregular objects. [8]

The core module allows for the manipulation point cloud data, the smoothing and the segmentation of the cloud of points. Segmentation allows for the cloud of points be separated into a unlimited number of groupings, which make up logical subsets. The lists of points are organized into a hierarchic table which create a universe using a tree with an unlimited number of levels. [8]

The points of view are used to scan the hidden-parts of the object. The corresponding clouds of points are in their own and unknown referential. To consolidate means to put them in the same referential (which could be given by the application). This consolidation is interactively realized with the help of the common parts between several points of view. The common parts may belong to scanned objects or magnetic spheres installed in the scene by the user. The presence of spheres increase the speed of consolidation, but are not essential. [8]

The operator interactively groups the 3D points (of the input cloud) into sub-clouds describing elementary parts of the environment. Then, there are a lot of methods to match these clouds to 3Dipsos primitives: 3D point, line, circle, ellipse, plane, sphere, ellipsoid, cylinder, cone, eccentred cone, torus.Further modules like the engineering module for treatment of piping applications, the image module which applies 2D imagesinto 3D space. [8]

3.1.3 Light Form Modeler

LFM from Zoller + Fröchlich has been developed specifically to convert 3D point clouds into 3D CAD models. It is one of the most advanced packages for laser scanner data treatment and various modules for modelling, but also to export point clouds directly into CAD software packages. Conversion from point data to CAD objects is achieved by the application of analysis algorithms which have been developed to facilitate swift points-to-primitives translation. Various modules are available. [8]

LFM register enables users of LFM to be able to register or join together neighbouring scans in order to form a point cloud. It also enables export data from the IMAGER 5003 or HDS 4500 scanners via DLL to a number of complimentary CAD packages (Microstation, AutoCAD, PDS, PDMS, etc.). [8]

LFM generator generates a database of points from the registered scan data. This database of points can then be viewed directly in LFM SERVER or through LFM

SERVER in a CAD package such as Microstation or AutoCAD. It is possible to generate a database of points comprising of up to 256 scans, or 13 million data points. This capability far surpasses other software on the market and enables the user to be able to hold all these scans in view and then zoom into the area of interest and then increase the resolution of the scan to view in normal mode. [8]

Phase-based scanners such as the Z+F IMAGER 5003 produce extremely large amounts of 3-D data (typically 50 Million pixels per scan). This means that loading individual scans can be a time consuming process. It is not desirable to have a work process which continually involves the opening and closing of individual scans. The user of high resolution laserscanned data wishes to access the area of interest within the point cloud quickly and be able to view high resolution data. Projects can reach 1000 scans or more, which can mean clouds of points containing 50 billion points or more. LFM SERVER is highly efficient at navigating these very large point clouds and serving the points data to view in high resolution. [8]

Where a user is using a CAD package not linked to LFM SERVER then they may wish to compare an existing CAD model with the real world by reading the CAD model into the cloud of points. Where this function is required then LFM VIEWER can be used as it is CAD engine based. In this instance the number of scans that can be viewed simultaneously will be limited to a handful by the processing power and RAM of the computer but it will be possible to compare the real world with the design model by working around the model in this fashion. [8]

Where accurate and semi-automatic fitting of the point cloud data is required then LFM MODELLER is used. An example of this work is tie-in and work package modelling in the Process Industry or modelling of equipment detail close to the car-line in automotive plant. Modelling using the LFM SERVER with the CAD package can be used more for infrastructure where accuracy is not quite as crucial e.g. HVAC, Walls, ceilings etc.[8]

3.2 Laser Scanner Data Processing

In order to turn scan data into a useful product the scans must first be registered, generally with the use of external survey measurements to provide some control. [9]

A typical processing workflow is shown in figure 3.1

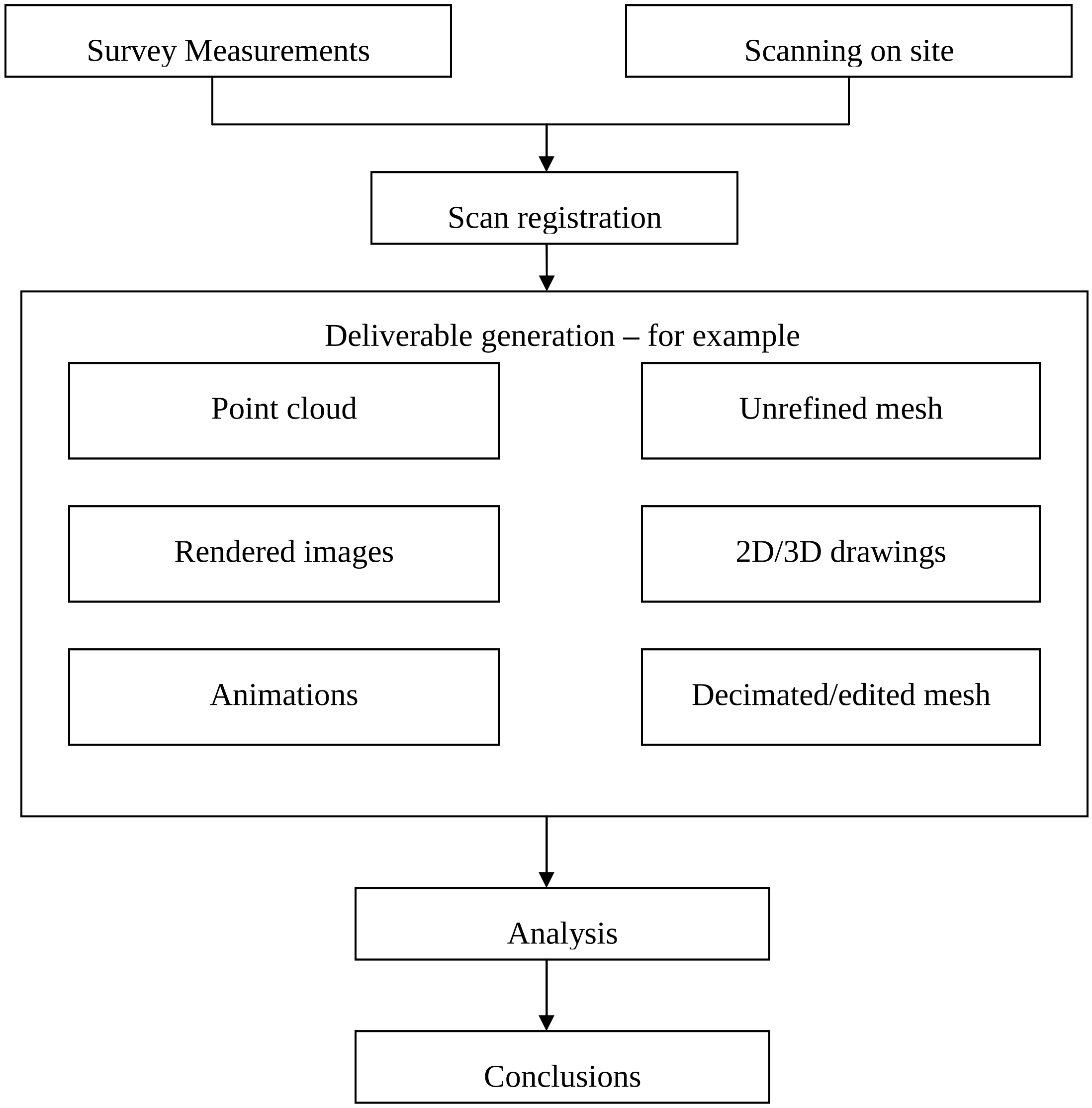

Figure 3.1: Laser Scanning workflow[9]

3.2.1 Cloud alignment/registration

For anything other than the simplest object, a number of separate scans from different locations are usually required to ensure full coverage of the object, structure or site. When collected, scans are based on an arbitrary coordinate system, so to use several scans together their position and orientation must be changed so that each scan uses a common coordinate system. This process is known as cloud alignment or registration. If the collected data needs to be referenced to a real world coordinate system it will be necessary to provide external survey measurements. [9]

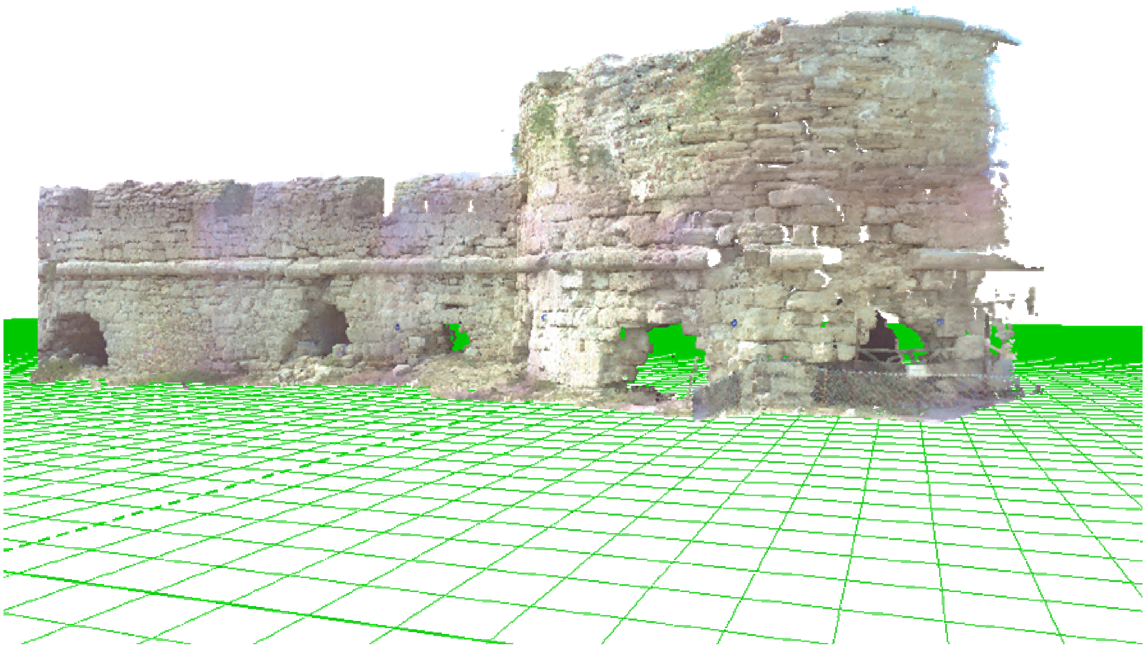

Figure 3.2: A point cloud from one setup

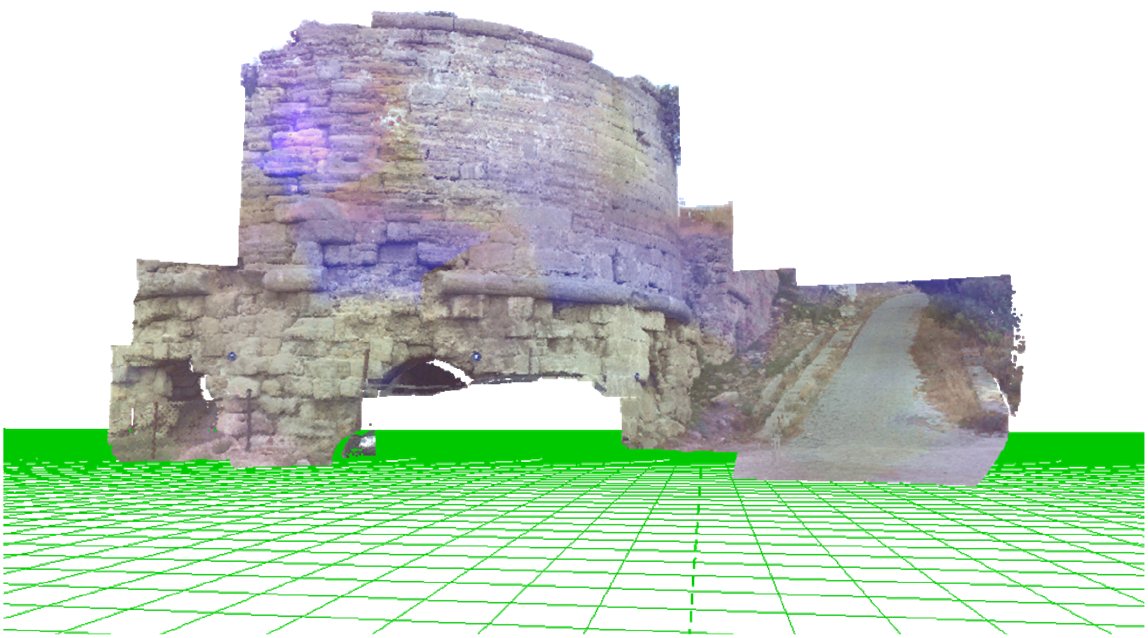

Figure 3.3: A point cloud from a different setup

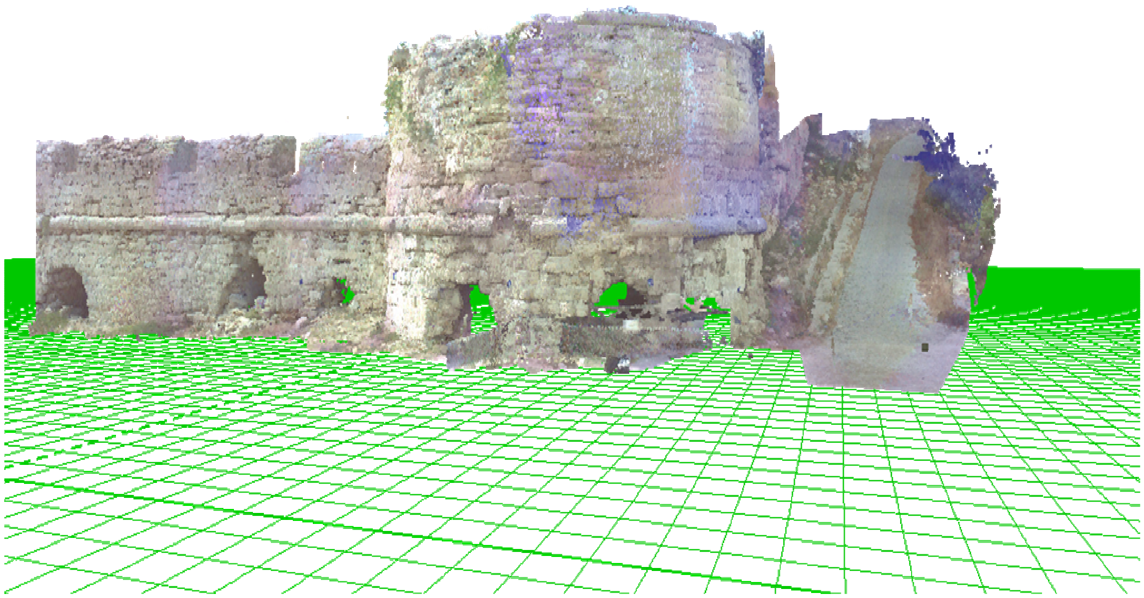

Figure 3.4: Registered point cloud from two different setups

3.2.2 Modeling

The general term for the process required to turn the collected point cloud information into a more useful product is modeling, or more descriptively, surface or geometric modeling. There are a number of approaches that could be used to turn the point cloud into useful information. [9]

For a small artifact or any object scanned with a high accuracy triangulation scanner the most typical product would be a digital model of the object's geometry, probably in the form of a meshed model, such as a triangular irregular network (TIN). In order to generate a complete model of the subject it is likely that some editing of the TIN will be required to fill holes where no data was collected. The resulting TIN is then suitable for use in several types of analysis. [9]

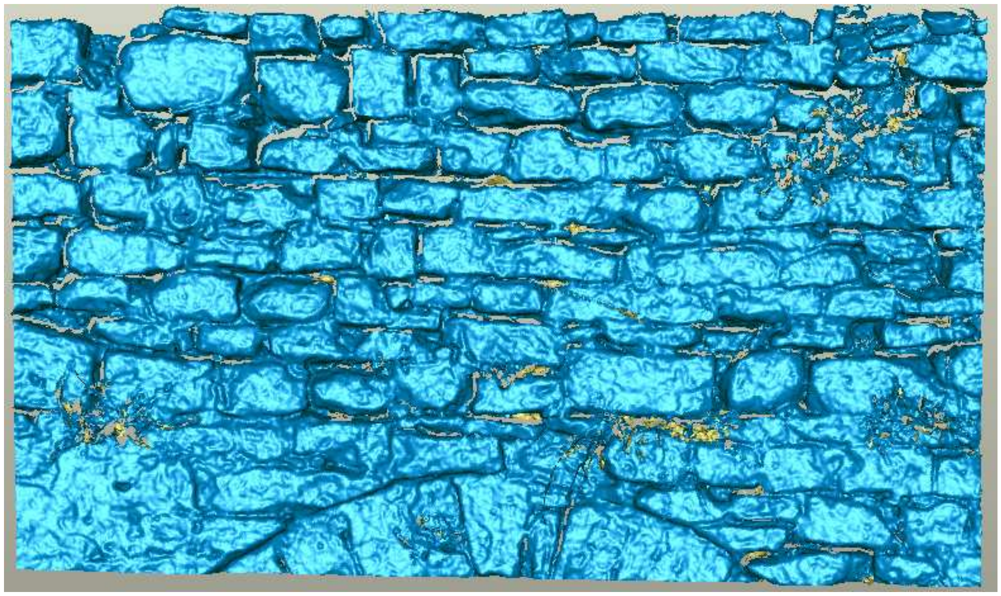

Figure 3.5: An automatically generated mesh model of the stone wall

While a meshed model might be required, plans, profiles and sections (line drawings) could be generated by using the point cloud as a base from which features are traced based on the edges in the geometry and intensity data. [9]

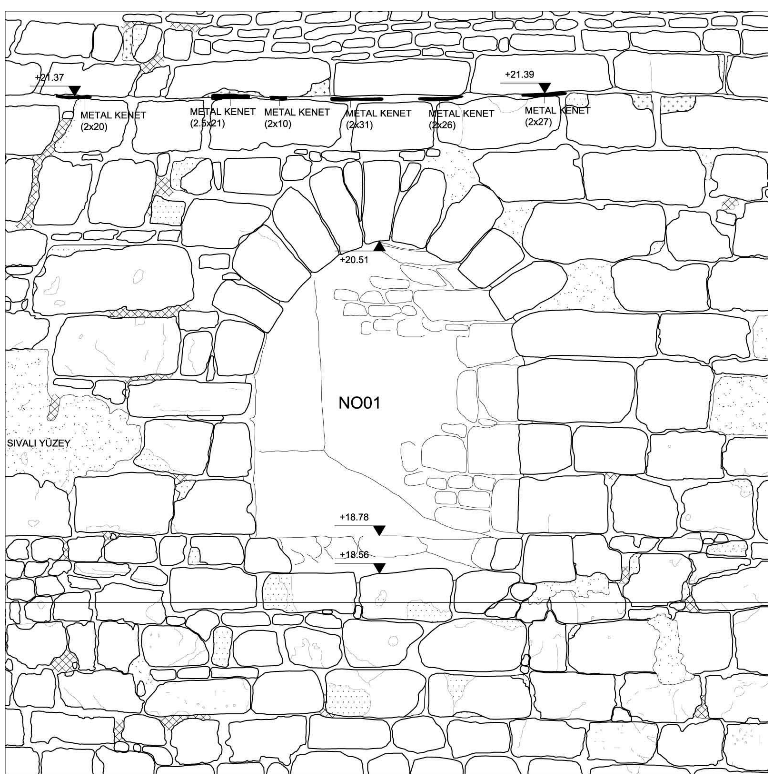

Figure 3.6 Drawing of the interior of a tower in Seddülbahir Project

3.2.3 Analysis

The delivery of a product derived from laser scanning data is only the start of the process of answering your original research questions. Some form of analysis is likely to be required using the final product. In fact some of this analysis may be best done during the processing stage itself. Analysis, during or after the deliverable generation should always include some supplementary data to support any conclusions made. One should consider supplementary datasets like historic mapping, photos, etc… [9]

As laser scanning provides three-dimensional data it lends itself very well to three-dimensional queries. Line of sight analysis allows a user to quantify if a particular part of the model can be viewed from another. [9]

Another useful technique in analyzing a surface is to use artificial raking light to illuminate a scene from directions not possible by relying on sunlight alone. Neither of these analysis techniques would be possible without detailed 3D information, to which laser scanning has greatly improved access. [9]

While laser scanning explicitly provides geometry, most time of flight laser scanners also provide a value that indicates the strength of the returning laser signal. This intensity data may be useful as an additional information source during analysis. As most scanners operate outside of the spectrum visible to the human eye the intensity information collected is often slightly different to that which is seen in reality. This can be useful, in some cases, in differentiating between slight changes in surface/material type.

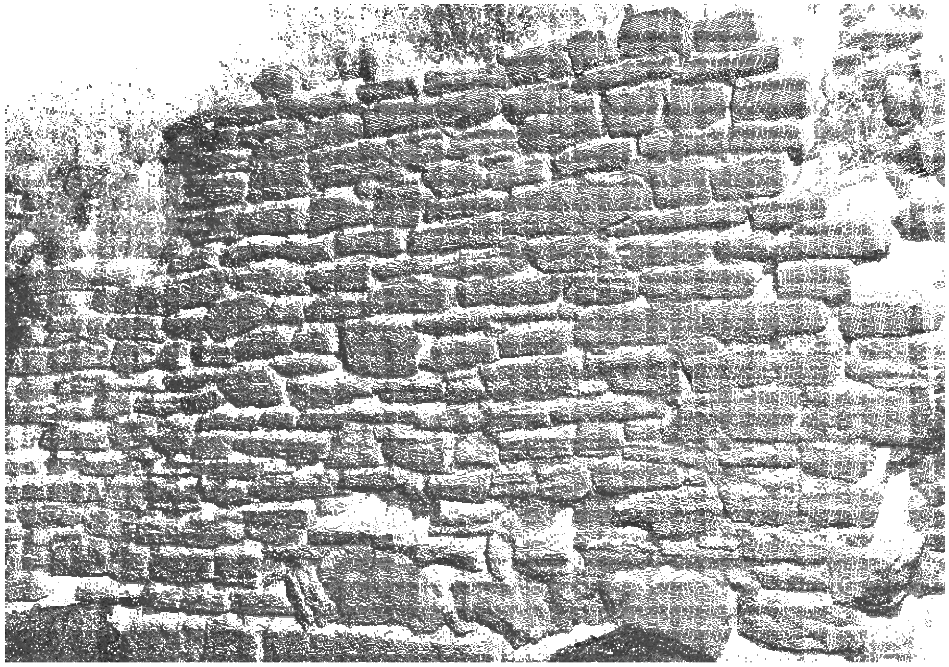

Figure 3.7 Part of a fortress' walls shown in intensity mapping.

Three-dimensional geometric models may also be used to generate high quality still or moving rendered scenes. Movies have been successfully used to present what would otherwise be very large data quantities requiring specialist viewing software and hardware. While such presentation does not provide an environment through which a user can freely navigate, they do serve a useful purpose in presenting an object, site or landscape to a non-specialist group. Such models generally include the use of image textures. Textural information can often help to replicate geometric detail, and reduce the need for some vertices.

4. Case Study – Seddülbahir Fortress Site Documentation and Restoration Project

4.1 About the Project

The fortress of Seddülbahir, the "Dam of the Sea", was built in the mid 17th century at the entrance to the Dardanelles, on the European side by Hadice Turhan Sultan, the mother of the Ottoman Sultan, Mehmet IV. The fortress was constructed as a part of the Ottoman defense against Venetian naval incursions into the Dardanelles during the long war over Crete and the eastern Aegean. Since that time Seddülbahir has protected the Ottoman, and later Turkish lands, against threats to the Dardanelles, the strategic waterway which leads to the capital of Istanbul on the Bosphorus. Located on the shore above Cape Hellas, the Ottoman fortress of Seddülbahir was instrumental in the Ottoman defense during the famed Gallipoli campaign of World War I. It was also severely damaged by Allied artillery fire during this campaign. After World War I and the withdrawal of British troops from the Gallipoli region, the fortress was returned to the Ottoman government. The fortress and the site served as a Turkish naval outpost until 1997 when our team, the Kaletakımı, began a preliminary survey of the site immediately after demilitarization. [10]

Figure 4.1 Seddülbahir fortress

The Kaletakımı research project began in 1997 and a vast array of data such as repair records from the Ottoman archives, European and Ottoman historical chronicles, engravings and archival photographs from various libraries' collections were collected for over a decade. A precise geodetic and architectural survey of the fortress and the site was conducted also initiated in 1997 and until 2003 preliminary post-processing of all collected data was maintained. In 2005 in response to a request from the Turkish Forest Ministry and with the financial support from the Vehbi Koç Foundation a project schedule was created which outlined the anticipated phases of the project and established a detailed program for the physical survey. First, it was essential to gather and check all the data from the work that had been conducted from 1997 and to establish an appropriate database. [10]

In the later phase of the project survey process which began in 2005, a team of 30 people from four different disciplines conducted 550 hours of field work. For the first time in Turkey laser scanning technology was utilized for the documentation of a large-scale architectural heritage site. Due to the high cost of using a laser scanner the organization of the survey focused on how to utilize this technology and equipment most efficiently. After reestablishing the measurement points from the earlier surveying work, the geodesy and architectural teams , working closely with the team of art historians, historians and archaeologists conducted a highly coordinated survey of the entire fortress.[10]

Figure 4.2 Kaletakımı working on the site using both the laser scanner and the total station

4.2 Scanning the Site and Objects

The entire site was scanned with 5 mm accuracy using a Leica HDS 3000 laser scanner accompanied with a Leica TCR407 Power reflectorless Total Station. During the survey process a total of 20.000 points were recorded with the total station and GPS. With the 360° horizontal and 270° vertical field-of-view of the Leica HDS 3000 laser scanner the survey was concluded with satisfactory results at a site comprising nearly 24.000 m^2 and a building mass of 4200 m^2. The total station points were used in conjunction with the laser scanning data to facilitate a cross-check of the point cloud data; the total station data also helped to detect missing data and sections of the scans. The scans were then processed and the point cloud was formatted in Cyclone Register. The post-processing of the point cloud data was transferred into AutoCAD in combination with CloudWorx. [10]

Figure 4.3 Seddulbahir Fortress' point cloud with DTM

4.3 2D Drawings of the 3D Surveyed Objects

For the drawing of building surveys laser scanner data, total station data, sketches and hand measurements were combined for more accurate processing.

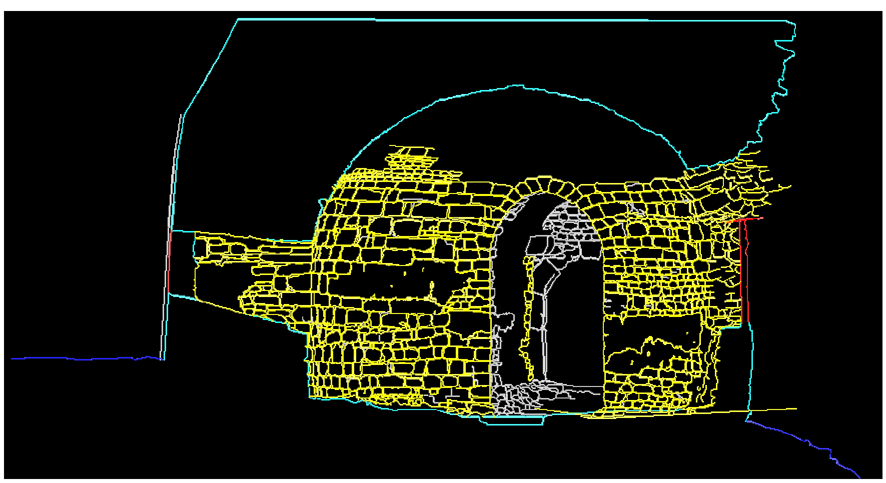

Figure 4.4 Drawing of the interior of a tower of Seddülbahir Fortress

Even though we had 3D data, architects had to generate 2D drawings out of them in 1/100 scale because the regulations in Turkey require that. Hopefully with the use and acceptance of this and newer technologies, the regulations would change, allowing us to be able to use all the information we gather from the site meaning to use as more accurate and more useful data as possible.

First the point data gathered from the total station and the hand sketches and measurements are used to draw the fortress. Then the laser scanner data evaluation process started. Since this project is the first one regarding technology used in such scale in Turkey, a drawing method had to be defined.

For evaluation of such dense points in 3D environment required a trial and error stage. To be able to draw all these stones one of the most important precautions to take is to figure out the snapping problem. In a very simple explanation snapping problem can be defined as deciding through which point to draw and to be able to catch these points. In such a dense point cloud one cannot easily choose which points to snap, or even it is chosen it is so easy to accidentally snap to another point which is at a different plane.

In the drawing for each object in different planes, an average plane is defined and the coordinate system set to this plane, so that in the CAD environment the drawing can no longer snap to another plane. Also pictures taken from the site are used in places where they are needed, to correlate the data.

Another tool used for drawing was the clipping tool of CloudWorx. It enabled to decrement the point cloud and just see the data that we need. Figure 4.5 shows the picture of the object, mesh model of the object, drawing with the point cloud and the final drawing of the same object.

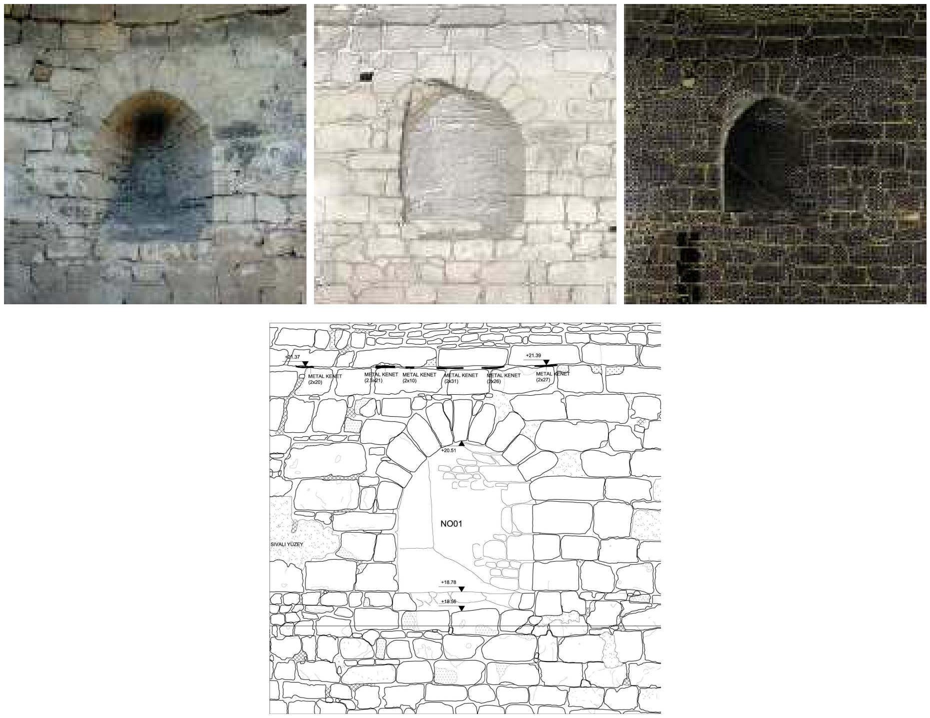

Figure 4.5 Drawing stages of an object from point cloud data.

4.4 Modeling 3D Surveyed Objects

There were no model creation in the scope of this project but couple of attempts was made. Cyclone software has a meshing tool used for this purposes. Other than that Rhinoceros, Geomagic and some other software were tried. If there is a gap in the data then in the meshing stage it has to be filled with triangles. So it needs a bit more editing. But regarding this fact an automatically created mesh model of a wall is in figure 4.6.

Figure 4.6 Automatic mesh model of a wall

5. Modeling Stone Walls Using 3D Laser Scanner Data

During the post processing of this project, architects came across with some difficulties in evaluation of the laser scanner data as mentioned above. So some thought went into doing some stages automatically. But none of the commercial software was able to do that. This thesis is inspired from those thoughts.

When one looks at a point cloud data he/she can easily recognize the objects with his/her eyes. So we have to somehow mimic the human eye and make the software do the same. For being able to do that we have to figure out how the eye recognizes objects. There are two parameters and one of them is by the change of color. If in a textured point cloud there is a change in the color, this shows that there is another object or the same object's part in a different dimension or a shadow. Another tool to recognize objects is by changes in the perception of depth. Again if there is a change in depth than that would mean there is another object or that part of the object is in another dimension.

A tool for the extraction of the outline of stones is developed analyzing the depth differences of each point, called Stone Walls Tool (SWT).

5.1 SWT Software Patch

SWT stands for Stone Wall Tool. It is a tool that is developed to be able to extract the outlines of the stones from the point cloud data. It is developed in C++ in Microsoft Visual Studio. A mathematical model has been developed to do this and uses the distance of a point to a plane equations.

5.2 Mathematical Model of the SWT

For being able to extract stones from the point cloud data, a mathematical model is created. SWT analyzes each points distance to a specified plane. Then it stores the point's information if that points' distance is smaller than the one before and the one after itself. These points make up the area of the stones. A basic representation of this model is shown in figure 5.1.

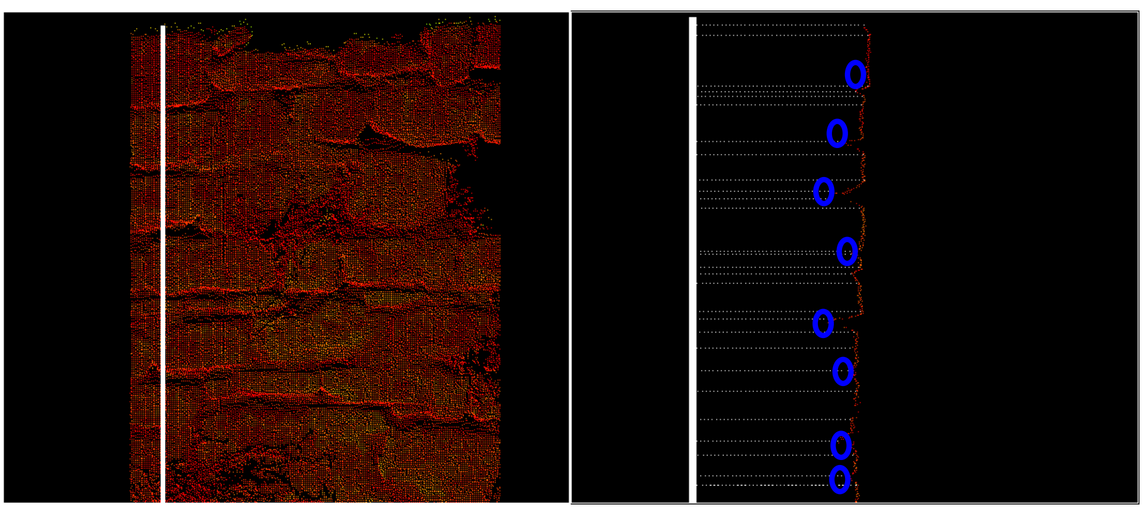

Figure 5.1 In this figure the distances (s) of each point to the specified reference plane is shown. After the analysis the points marked in blue are selected representing the outlines of the stones.

The algorithm for the tool is based on a distance of a point to a plane equation. For doing this first the plane equation in 3D has to be solved.

5.2.1 Equation of a plane in 3D

Let's assume that plane M is passing through point $P_0(x_0, y_0, z_0)$ and is perpendicular to the vector n which is not equal to zero.

$$n = A\mathbf{i}+B\mathbf{j}+C\mathbf{k} \qquad \textbf{(1)}$$

In this case M is the group of all P(x, y, z) points which makes $\overrightarrow{P_0P}$ orthogonal to n. Which means that P can only be in M if;

$$n \cdot \overrightarrow{P_0P} = 0 \qquad \textbf{(2)}$$

$$(A\mathbf{i}+B\mathbf{j}+C\mathbf{k}) \cdot [(x-x_0)\mathbf{i} + (y+y_0)\mathbf{j} + (z-z_0)\mathbf{k}] = 0 \qquad \textbf{(3)}$$

$$A(x-x_0) + B(y-y_0) + C(z-z_0) = 0 \qquad \textbf{(4)}$$

(2) equation is equivalent to (3) and (4). So in summary a plane passing from $P_0(x_0, y_0, z_0)$ and is normal to (1) has a vector equation of (2) and a component equation of (4)

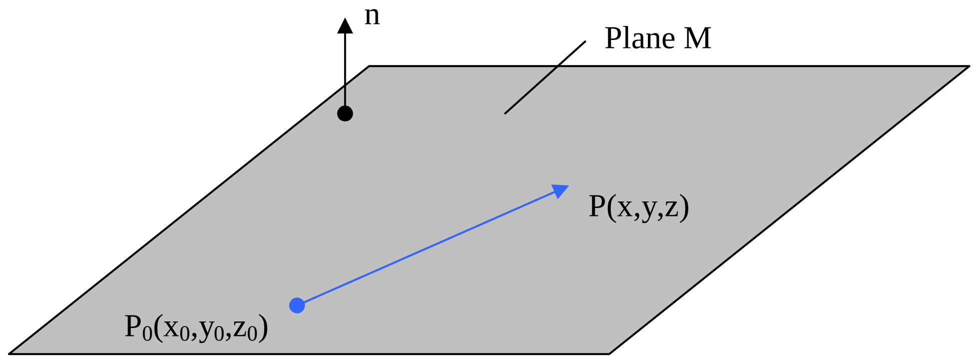

Figure 5.2 The standard equation for a plane in 3D is defined by a vector normal to the plane

5.2.2 Distance of a point to a plane in 3D

To find the distance from point S to the plane Ax+By+Cz=D, find a point (P) on the plane, calculate the vector $\overrightarrow{PS}$ and then find the direction **n**= A**i**+B**j**+C**k**. The distance would be;

$$d = \left| \overrightarrow{PS} \cdot \frac{n}{|n|} \right| \qquad \textbf{(5)}$$

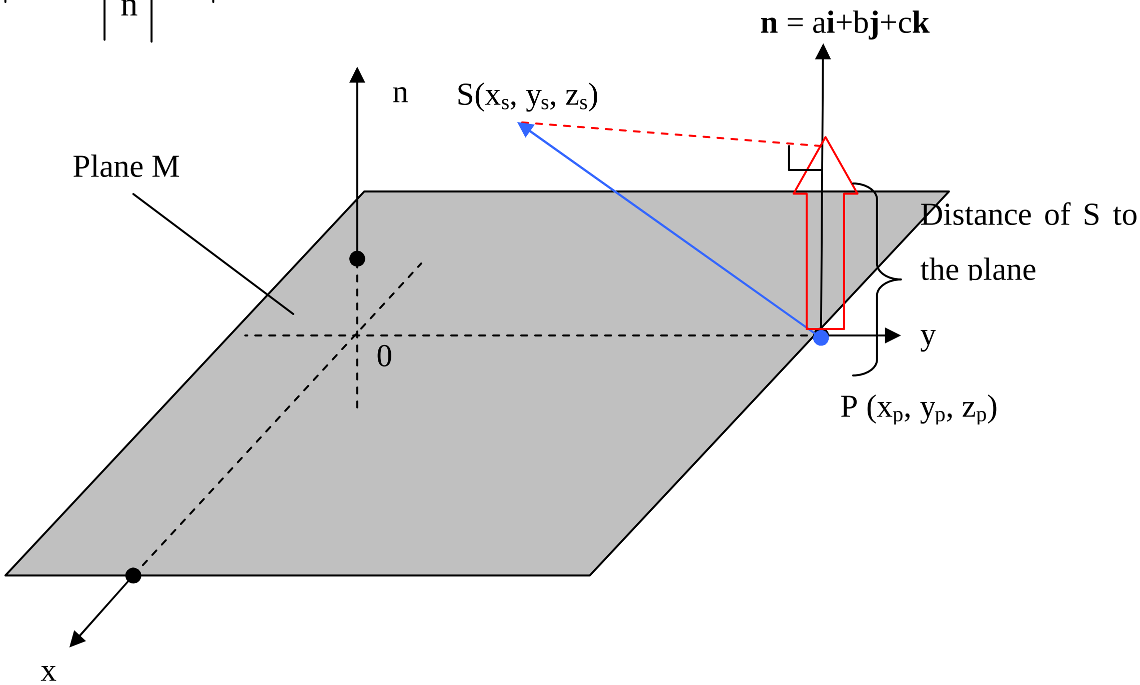

Figure 5.3 Diagram of the calculation of the distance from point S to the plane M

5.2.3 Setting up the data

First point cloud is grouped respect to the orientation using Cyclone software of Leica. Then for each group an average plane is defined. Three points representing the average plane are selected from the point cloud and then the coordinate system is set to a local coordinate system using these 3 points as shown in figure 5.4. Then the reference plane is set to YZ plane as shown in figure 5.5. So at the end an average reference plane parallel to the object is set.

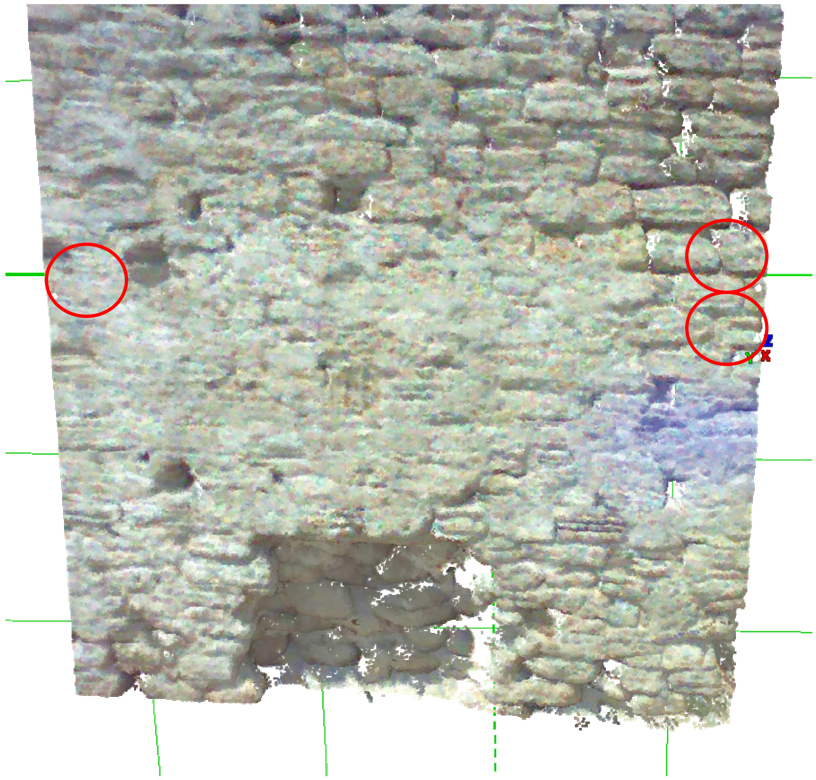

Figure 5.4 3 points selected from the point cloud to set up a coordinate system fairly parallel to the object.

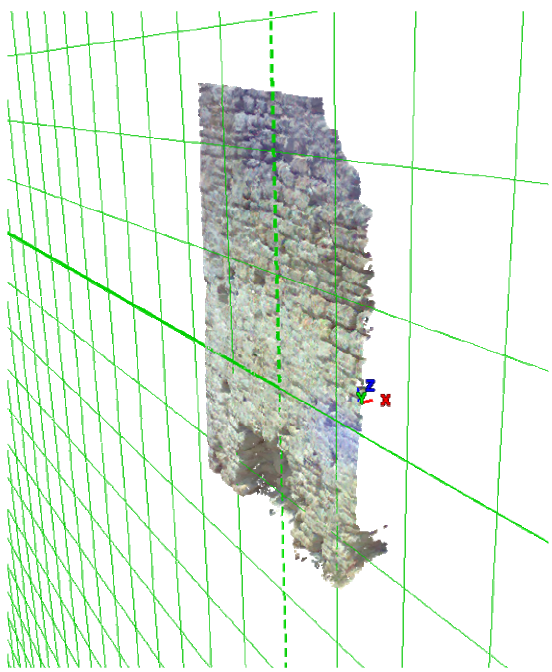

Figure 5.5 Reference plane set to the YZ plane of the local coordinate system.

Then the reference plane is lowered for easily analyzing the data. Figure 5.6 shows the lowered reference plane still fairly parallel to the object.

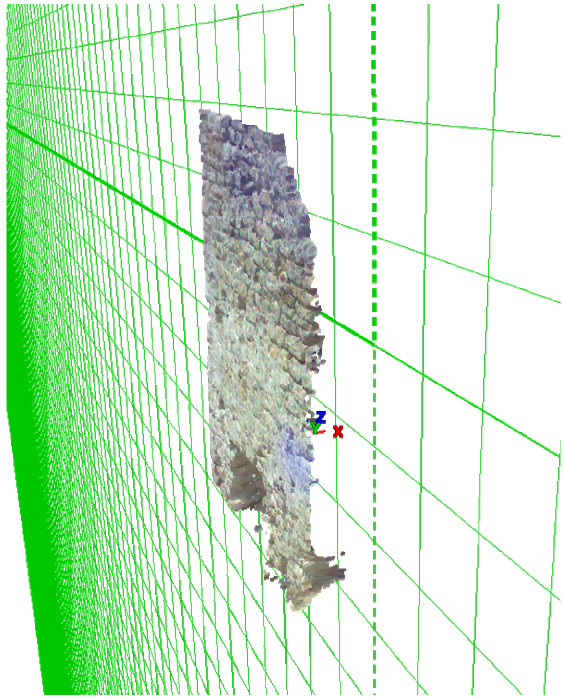

Figure 5.6 Lowered reference plane.

A plane can be defined by 3 collinear points. So 3 points have to be taken from the reference plane to be able to identify our plane. A drawing is made on the reference plane and coordinates of the vertices of the drawing taken. So now the reference plane is geometrically defined.

The points selected should be exported to .pts format or any text format.

5.3 SWT for Extracting the Points From the Cloud

SWT for extracting the outlines of the stones basically calculates each points distance to the specified plane. First it calculates parameters defining the plane from the specified 3 points on the plane.

double a,b,c,d,e,f; **(6)**

a= ((Yb-Ya)*(Zc-Za))-((Zb-Za)*(Yc-Ya))

b= (-((Xb-Xa)*(Zc-Za))-((Zb-Za)*(Xc-Xa)))

c= ((Xb-Xa)*(Yc-Ya))-((Yb-Ya)*(Xc-Xa))

Then calculates the distances from the points to the plane.

```
double Xi,Yi,Zi,ri,gi,bi,di,ei,fi;                                    (7)

double Si;

int ini;

di = Xi-Xc;

ei = Yi-Yc;

fi = Zi-Zc;

Si=(((di*a)+(ei*b)+(fi*c))/(sqrt((pow((a),2))+(pow((b),2))+(pow((c),2)))));
```

Now every point’s distance is defined and each point is stored as vector in the memory. The last thing is use an algorithm to select the points that are needed. This algorithm selects the points which have distance smaller than the point’s distance before itself and then the point’s distance after itself. This ensures to get the deepest point of the stone’s outline. And to also take the scanning density into account a Q variable is defined. In our project the scanning density was about 0.5 mm and after some trial and error period it is understood that the Q variable should be defined as 1 cm for this specific project.

```
double Q;                                                             (8)

Q = 0.01;

if ((abs (vect[i]< vect[i-1] - Q)) && (abs(vect[i]< vect[i+1] - Q)))
```

For using this SWT in other scanning projects a little bit of familiarity with the data is needed to determine the Q variable.

5.4 Workflow for Modeling the Stone Walls

The workflow for modeling the stone walls start with some evaluation of the data in the Cyclone software. Some verification and editing is done on the data. After the editing, the data goes into SWT. The output data from the SWT can be imported to Cyclone for verification of the data and it can later be used in CloudWorx, too.

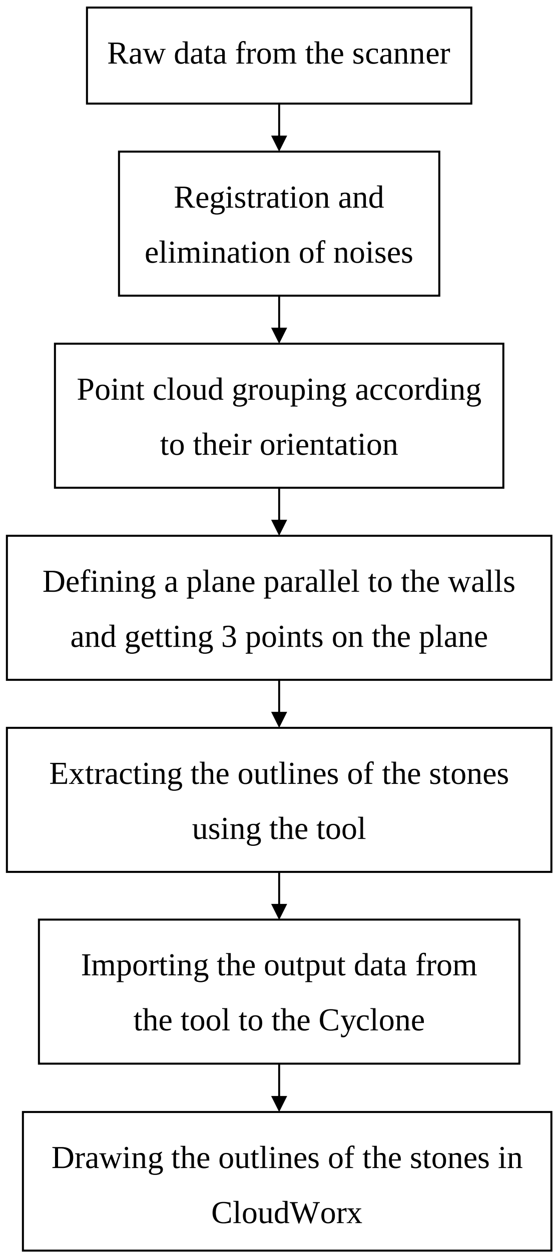

Figure 5.7: The workflow for modeling the the stone walls.

5.5 Results of SWT

After applying the workflow above, to the data, SWT outputs points showing the outlines of the stones. Figure 5.8, 5.9 and 5.10 analyzes the output data.

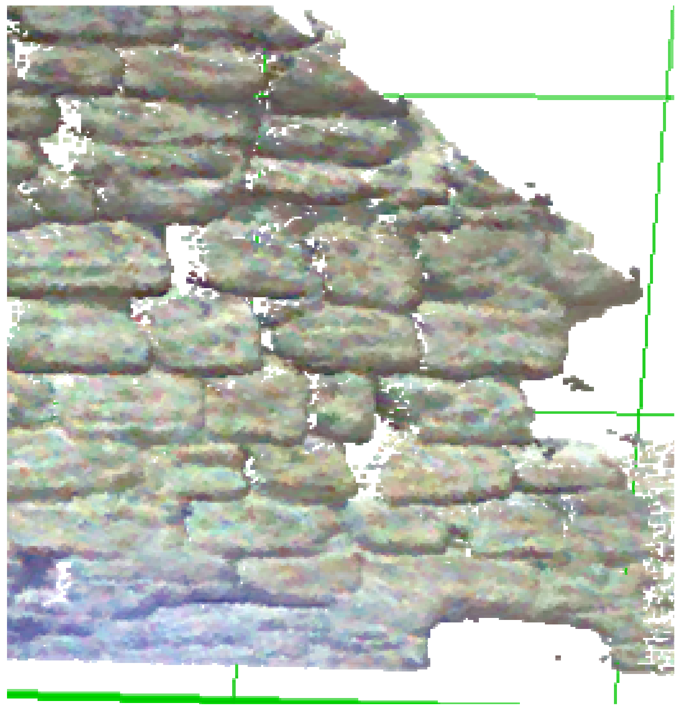

Figure 5.8: A part of the point cloud from the original data

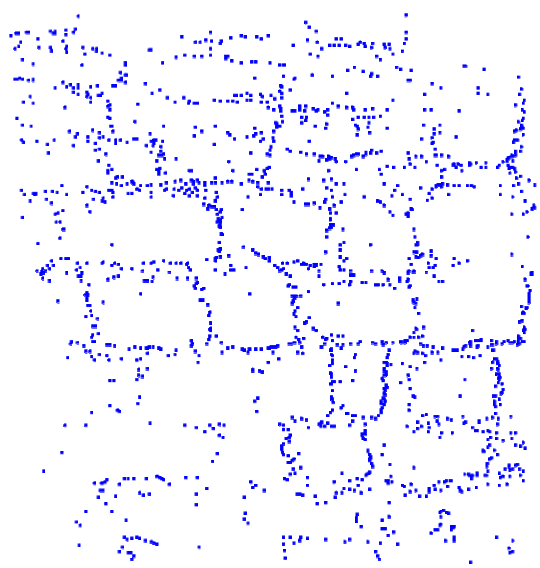

Figure 5.9: The output from the SWT of the data in figure 8.7

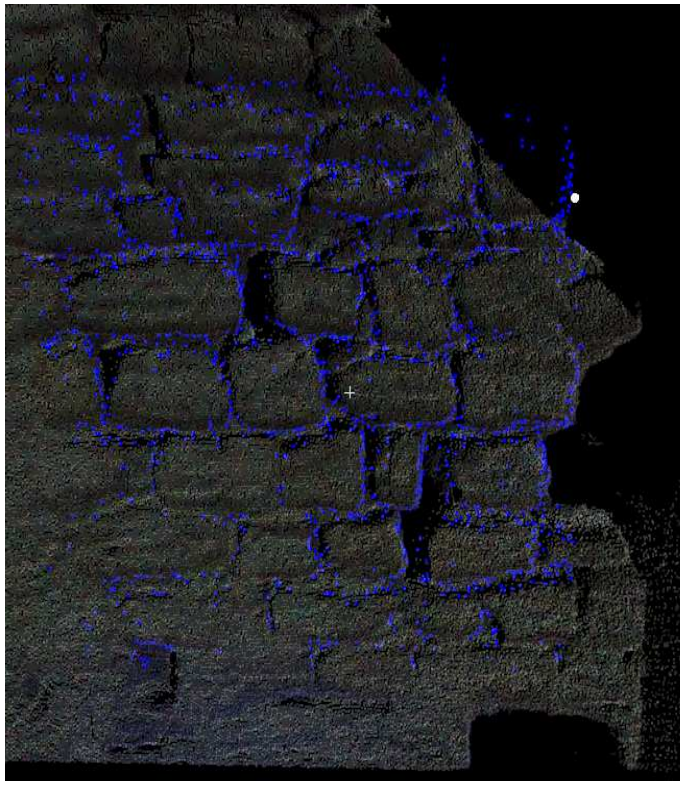

Figure 5.10: The input and the output data together

There are conditions where SWT works best and where it is not suitable. To be able to identify these conditions one should know the quality of the data, and the roughness of the stones.

The quality of the data means the point spacing in the scan. For example in the project of Seddulbahir the point spacing was 0.005 m. for most of the areas, and 0.007 m for some other areas. When using SWT, this knowledge is a must because SWT selects points within a tolerance value to avoid the errors as much as possible. After calculating the distances of each point to the specified plane, SWT would select the closest points to the plane. In order to do that it chooses points that are closer than the point before and after itself. But the tolerance value makes it sure that, the distance difference is not from the point spacing but actually because of the geometry. In the following figures it can be seen that, changing the tolerance value have a deep effect on the output data.

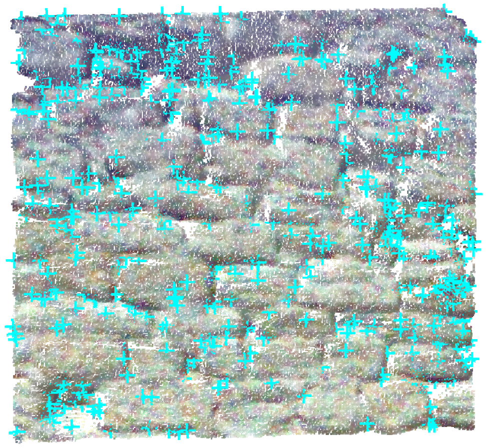

Figure 5.11: Point cloud data with an output with the tolerance value of 0.01m

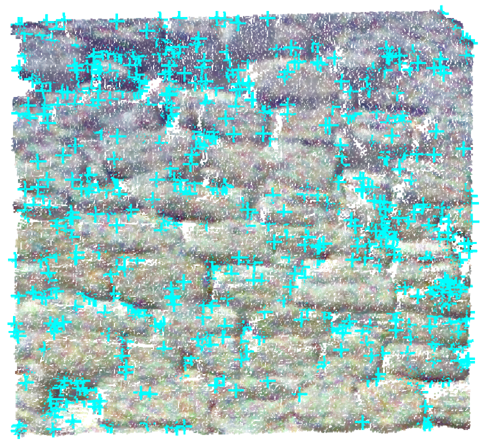

Figure 5.12: Point cloud data with an output with the tolerance value of 0.009m

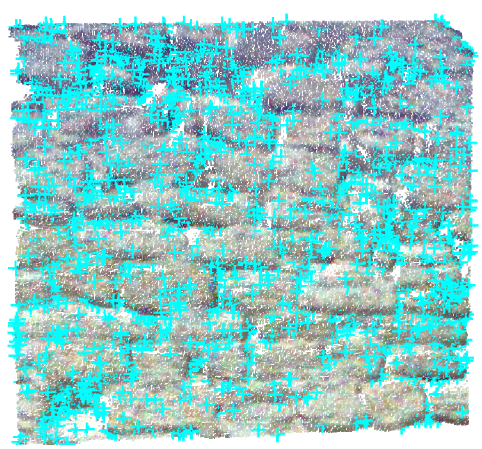

Figure 5.13: Point cloud data with an output with the tolerance value of 0.007m

In figures 5.11 to 5.12 the effect of the tolerance value is shown. This piece of scanned data has a really rough surface, that’s why the outcome wouldn’t be so good. In the 1cm output, most of the stones are missed. In the 7mm output stones are captured but there are lots of additional points on the surface of the stones. In the 9mm some of the stones are captured and a little bit extra points on the surfaces. To get the best output data, one should have experience with the use of tolerance value.

In the figures above the effect of the roughness of the surface can also be seen. Since the surfaces of the stones are really rough, the output data has some noises.

Figure 5.14: Point cloud data from a tower interior. Has a non-planar surface.

If the geometry of the objects in the point cloud are non-planar, SWT would work in some extents. Since the distances of the points to a plane are calculated, the comparison of the point distances wouldn’t be accurate so, the noises would be more. In such cases point cloud should be divided into reasonable parts so that the deviations from a planar surface are optimum. Then planes parallel to each of them should be defined. SWT should be used for each set of the data. This way the noises would be less.

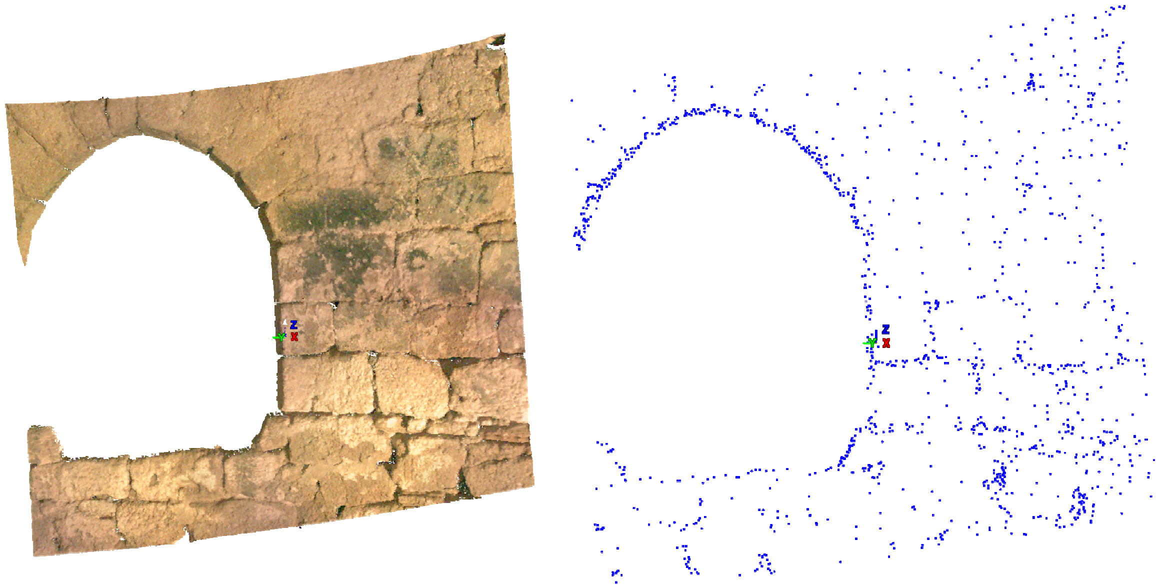

Figure 5.15: Point cloud data from an interior of a tower – nonplanar surface. And the output data from SWT.

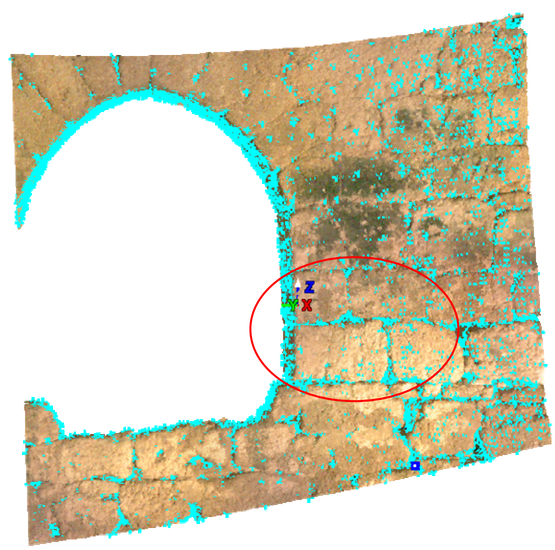

Figure 5.16: The point cloud data merged with the output data from SWT.

In figure 5.16 the plane defined is parallel to the stones marked in red. The deviation from the plane is bigger in the z direction so the points at the top can be seen as noises.

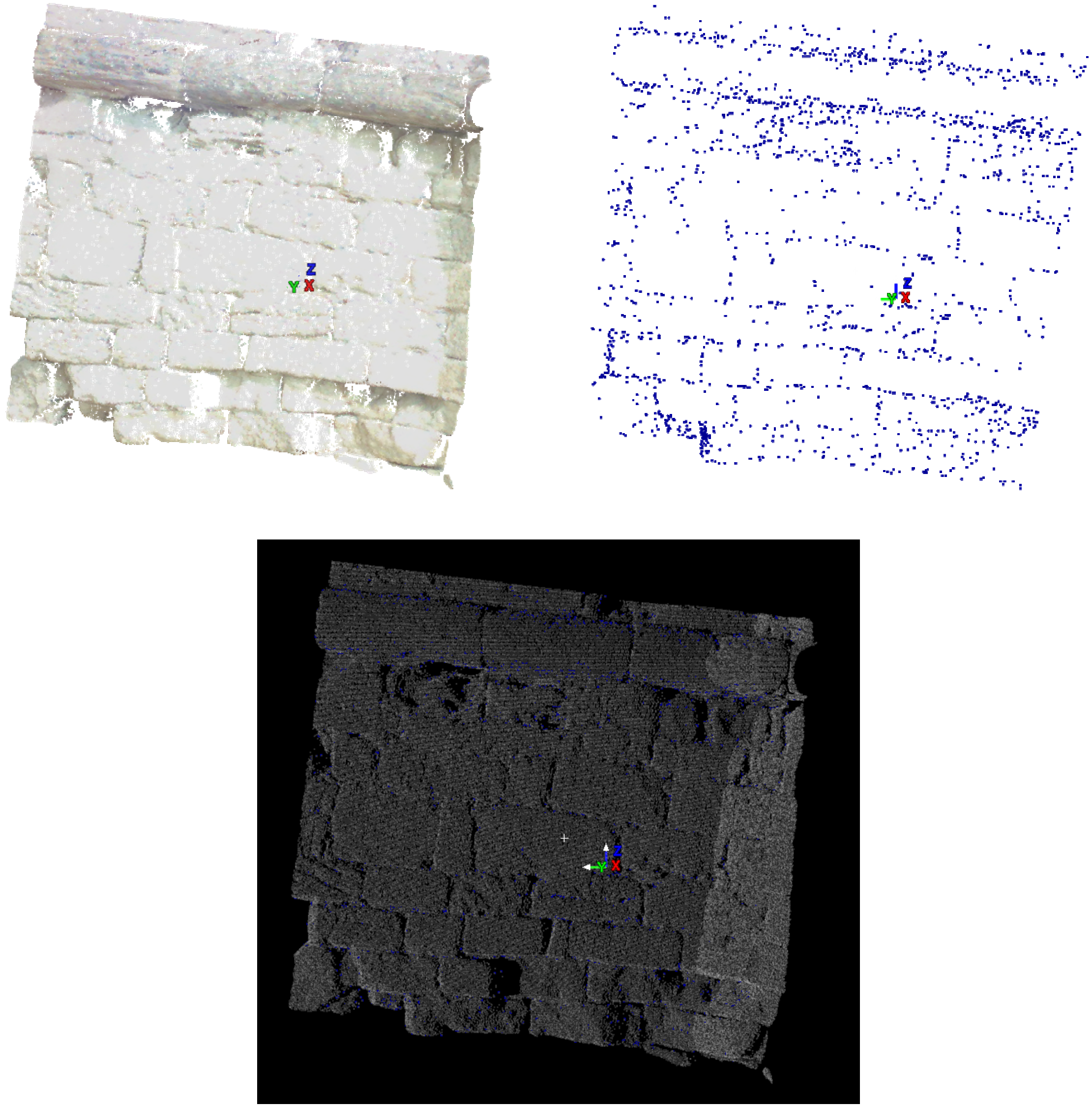

Figure 5.17: Point cloud data, output data and merged data are shown. This data has different depths among the stones and different shape of stones.

In figure 5.17, the output of from SWT is reasonable. It doesn't matter for SWT if there are different depths or different geometries of data, as long as they are parallel to the specified plane. There can be seen some noises in the output data, that is caused by the damaged stones – the roughness on their surface.

6. Results and Recommendations

Documentation on cultural heritage is a really important topic. Although technology improves the quality of the documentation process, still a lot of work and effort has to be sacrificed. Any attempt to reduce the work and increase the quality of the process should be assessed. SWT – stone wall tool proposed in this thesis helps to improve the quality of the documentation process and reduces the time.

SWT works best if the depth differences among the stones are reasonable – more than the specified tolerance value, and if the stones are in good conditions. If the surfaces of the stones are damaged a lot so that they also have depth differences on the surface, then SWT cannot recognize the outlines or may loose some of them.

Another condition that SWT needs is that the referenced plane defined is as much parallel to the stones as possible. If there is a non-planar surface than one, should divide the data to get semi-planar data sets. And evaluate each set separately.

So there are two ideal conditions for SWT to output the desired data. Planar surface and the depth differences among the stones are identifiable.

As mentioned among this thesis, there are other ways to automatically extract data from the laser scanner data, which one of them is by the color difference. A similar approach to SWT can be used for color differences. Since all points have RGB values, a comparison among the RGB values of the points can help to extract objects from a colorful point cloud.

Another work on this topic can be done to improve SWT, it can be used to draw polygons from the output data automatically. Some kind of logical relationship among the output points like using the matrix form or something else, can draw the stones automatically.

So there still is a long way to do all the work automatically but the suggestions that this thesis brings a new approach in the evaluation of the laser scanner data.

REFERENCES

[1] http://en.wikipedia.org/wiki/3D_scanner, 04.12.2007

[2] **Lemmon T., Biddiscombe P.**, September 2006, Adapting 3D Laser Scanning for the Surveyor Adapting 3D Laser Scanning for the Surveyor, *GIM*, Volume 20, Issue 9

[3] **M. Sgrenzaroli**, 2005 Cultural Heritage 3d Reconstruction Using High Resolution Laser Scanner: New Frontiers Data Processing, *Cipa 2005 Xx International Symposium*, 26 September – 01 October, Torino, Italy

[4] **Wallace A.M., Buller G.S., Walker A.C.,** 2002, 3D imaging and ranging by time correlated single photon counting 07 March

[5] **Ristevski J.,** Cultural Heritage Applications, http://www.profsurv.com/archive.php?issue=110&article=1555

[6] **Valzano, V., Bandiera, A., Beraldin, J.-A.**, 2005 Realistic Representations of Cultural Heritage Sites and Objects through Laser Scanner Information, *The 10th International Congress "Cultural Heritage and new Technologies"*. Vienna, Austria. November 7-10

[7] **Giuffrida, A., Liuzzo, M., Santagati, C., Andreozzi**, **L.,** 2005, The Laser Scanner For Archaeological Survey:"Le Terme Dell'indirizzo" In Catania, *CIPA 2005 XX International Symposium*, 26 September – 01 October, Torino, Italy

[8] **Fröhlich, C., Mettenleiter, M.,** Terrestrial Laser Scanning – New Perspectives In 3D Surveying, http://www.isprs.org/commission8/wg2/ workshop_laser_forest/ FROEHLICH.pdf

[9] *Advice and guidance to users on laser scanning in archaeology and architecture*, November 2006

[10] **Özsavaşçı A., Thys-Şenocak L**.,2006, New Survey Technologies In Multi-Disciplinary Architectural Heritage Documentation and the Project Process: The Role of the Architect and the Analysis of the Interdisciplinary Approach, *Forum Unesco - University And Heritage, 11th International Seminar, Documentation For Conservation And Development: New Heritage Strategies For The Future*, 11-26 September

[11] **Güney C., Yüksel B., Çelik R.N.,**2004, GIS Data Modelling of 17th Century Fortresses on Dardanelles *Proc. 12th Int. Conf.on Geoinformatics – Geospatial Information Research: Bridging the Pacific and Atlantic*, University of Gavle, Sweden, 7-9 June

[12] **Güney C., Yüksel B., Çelik R.N.,** 2003, Object Oriented Approach to 3D GIS *International Symposium on Modern Technologies Education and Professional Practice in the Globalizing World*, Sofia, Bulgaria, 6-7 September

[13] **Akboy S.** ,2007, *The Application of New Survey and Documentation Technologies for Cultural Heritage Sites: Case Study Analyses of the Digital Statue of Liberty, New York City andthe Ottoman Fortress of Seddülbahir, Gallipoli Peninsula*, Graduate School of Social Sciences & Humanities, Koç University

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