Cultural Heritage Documentation II

SYSTEM FOR ASSISTING IN THE RESTORATION OF STONE WALLS, USING 3D MODELING

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Abstract: In order to make it easy to have agreements with masons and managers of cultural relics, "three-dimensional model locating system" is developed to help the project, which enables the remodeling analyses and the visualization of the construction and to presume line type in three-dimensional when a stone wall constructed. The data of the stones was collected by conducting a three-dimensional-laser scans on individual stones General Instructions

1. Introduction

The Honmaru "Nakanomon Gate stone wall" inside the Kokyo Higashi Gyoen Garden (Imperial Palace East Garden) was suffering from deformation, loose joints, damaged and delaminating stones, and other defects – all symptoms of its age. To ensure the safety of the wall, restoration work was carried out and was completed in March 2007. This stone wall, which used some of the largest stones (around 35 tons) in Edo Castle, is of the “kiri-komi-hagi” type (where the stones are very carefully shaped to interlock perfectly). This type of construction requires immense precision, given that the joint gaps are small and very little "clearance" is permissible. For the "restoration" of such a stone wall, one of the important issues to consider in planning the restoration is how to place the stones appropriately to restore the wall to the shape it had when it was originally constructed. It is also important to reflect the traditional skills of the original masons in the restoration design and stonework. Thus, to facilitate the participation of masons in the project and gain a mutual understanding with those in charge of cultural properties, we developed a "3D model placement system" which uses a 3D laser and other technologies to measure the individual stones constituting a stone wall and then creates 3D models for visualization so that a "restoration study" can be made.

To further reduce the time required, improve the quality of the generated models, and increase the design efficiency, we considered the addition of the following typical functions.

- Function for enabling analysis with only the stone shape data for the surface of a stone wall, to simplify the work process.
- Function for enabling the automatic generation of drawings up to the repair design drawings by tracing the stone shapes in three dimensions beforehand.
- Function whereby the steps leading up to the outline placement study can be performed with user-friendly 2D CAD processing.
- Function whereby the system can accommodate kiri-komi-hagi (stones shaped to interlock precisely) and uchi-komi-hagi (where the joint surfaces are processed to increase the points of contact).

Figure 1:Before the restoratioon

Figure 2:After the restoratioon

2. Overall configuration of stone wall restration system

The "3D model placement system" is an interactive system intended to assist in design and construction management such that if, for example, the crest of a stone interferes with the bottom of another when individual stones are assembled sequentially to simulate the restored shape, the interference can be reflected in the restoration study in real-time.

3. Stone wall restoration

3.1. Stone model measurement

Measurement techniques in stone wall restoration work include physical measurements and digital photogrammetry, and cases have been reported whereby the stone wall surfaces are measured using 3D laser scanners. In the past, restoration studies used patterns for individual stones that were created from drawings made through surveys, which were then assembled in a plane so that the overall shape was free from any defects, to create a restoration design drawing. These patterns were, however, so simple that the joint gaps could not be determined accurately, with the result that re-assembly would be carried out whenever necessary. A restoration study of a stone wall of the "kiri-komi-hagi" type, with small gaps and high precision, like the stone wall discussed here, requires not only information about the surface of the stone wall but also accurate shape measurements of the individual stones to such a level that any interference between the individual stones can be verified. The stone model measurements for this stone wall restoration used 3D laser measurements on the five sides of each of the stones, except the bottom, before and during the disassembly of the stone wall. The bottoms of the stones were measured with digital photogrammetry while the stones were slung from a crane. By creating each stone model based on the

Figure 3:3D laser measurement(Front)

Figure 4:3D laser measurement(Back)

information thus collected, it is possible to perform stonework simulation.

Towards solutions to issues with generating stone models

When "stone models" are created from the point-group data obtained from 3D laser measurements only, the generated models can sometimes be smaller than they actually should be, because the peripheral edges of the stones are sometimes recognized as noise. Correction of this issue was extremely time consuming. Future improvements will include the ability to model stone shapes with high precision by complementing the laser measurements with photogrammetry.

Another improvement will be the capability to mark a stone wall with a grid beforehand to facilitate the checking of precision, thereby making it possible to reflect the check results on the work management during restoration.

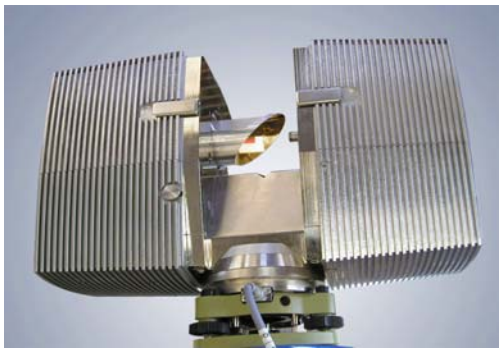


Figure 5:3D laser scanner (FARO)

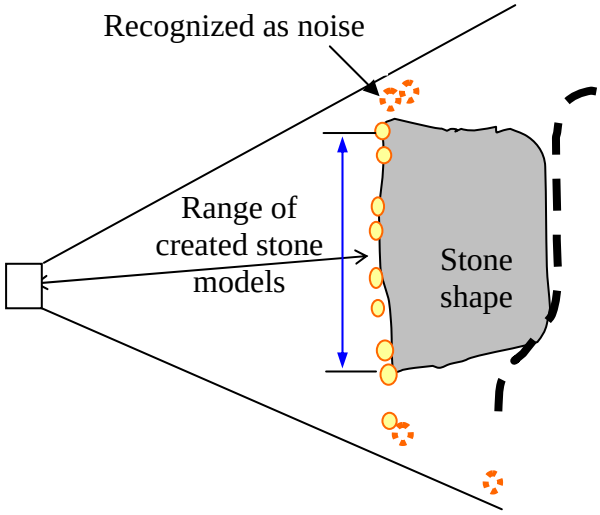


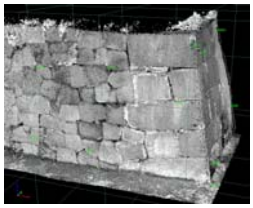
Figure 6:Issue of measurement

3.2. Interference assessment

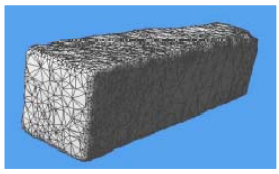
The "stone wall restoration assistance system" is used to assemble individual stone models sequentially to simulate the restored shape and assess the interference status at that time. To satisfy the on-site needs of a stone wall restoration, the system provides a function whereby, in the event of the interference of any of the crests, sides, or bottoms of a stone, that interference can be reflected on the restoration study in real-time. A function for automatically performing stone wall design simulation is also supported.

Prior preparation

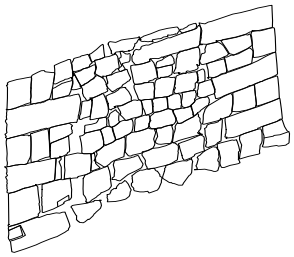
- measuring in 3D(3D laser scanner, photogrammetry)
- trace the stone shape



3D laser measurement



Create the 3D model



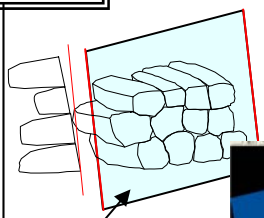
Tracing the stone shapes

Enabling the automatic generation of drawings up to the repair design drawings by tracing the stone shapes in three dimensions beforehand

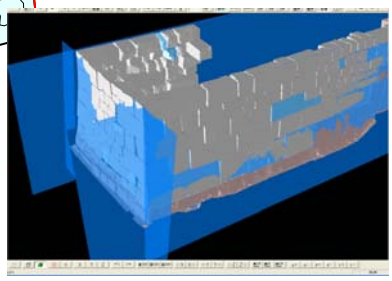
Input

- Stone model
- Restoration surface

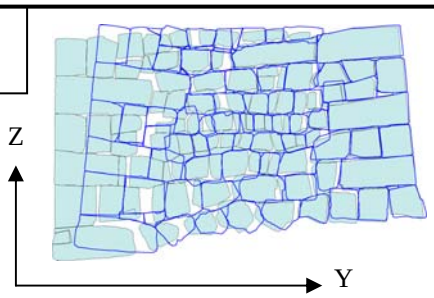
System for calculating the quantity of movement and rotation



Restoration surface



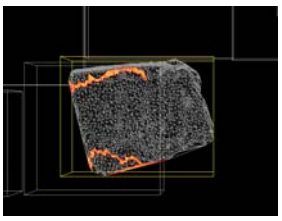
Place the stone model and restoration surface

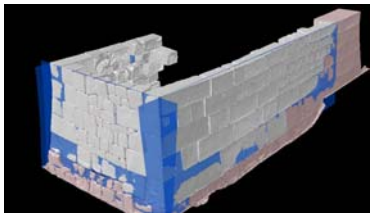


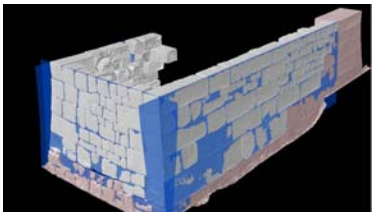
Reflect the quantity of movement and rotation for placement study in every stone

Process and Analysis

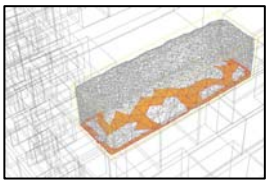
- Place the stone model in 3D
- Operate the placement of stone model

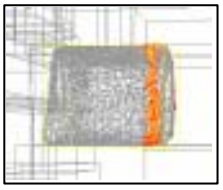




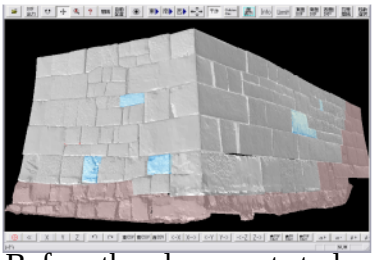


Matching to the restoration surface





Calculate the interference between the stones in real time (A yellow part interferes it.)



Before the placement study

After the placement study

Output

- Display the model
- Quantity of movement coordinate

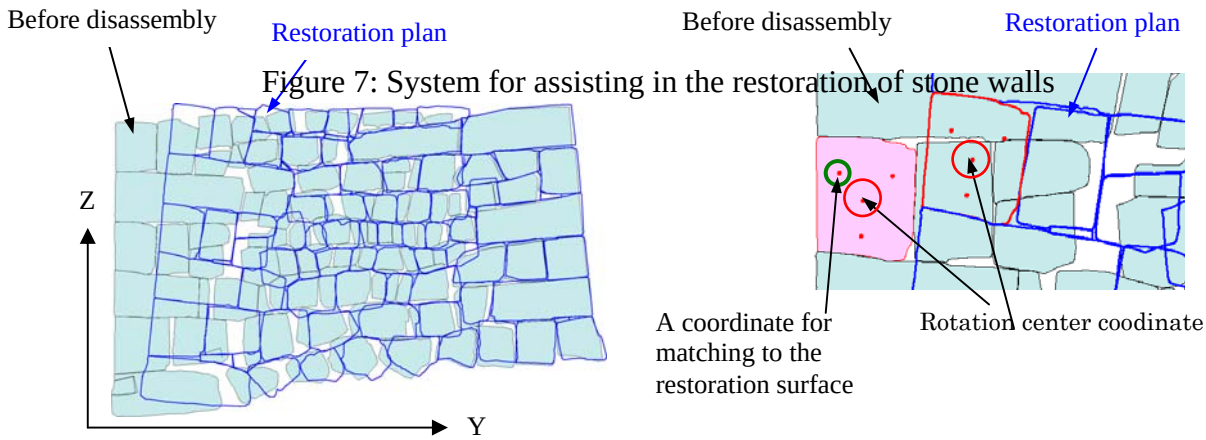


Figure 7: System for assisting in the restoration of stone walls

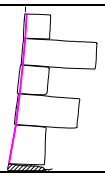
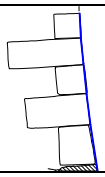
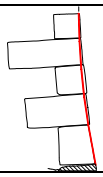
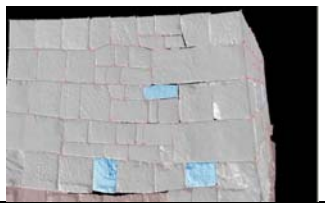
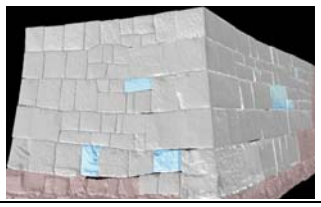
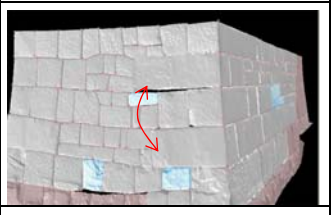
Figure 8: Prior study by 2D CAD

4. Restoration design-Study of the ridge line shapes of stone wall corners

In our study of restoration line shapes, we used the "3D model placement system" to study the placement of each stone in three dimensions by setting the gradients of the ridge lines of the corners of the stone wall while checking the planar shape, gradient, and warpage of the stone wall, as well as checking how the area to be restored would match the un-restored area from the viewpoint of appearance and how well it blends.

1. Plan to eliminate differences in level by keeping the current gradients intact
2. Plan to eliminate differences in level by partially modifying the gradients
3. Plan to calculate the gradients according to the "Ancestral Manuscripts of the Goto Family"

We studied the gradients of the ridge lines of these plans with 3D CG, and visualized and checked the resulting shapes, so that the gradient settings for plan 1 would make the stones fit well on each side, thus producing a stable shape.

	1	2	3
Stone wall corners and the ridge line			
Explanation	Keep the current gradients intact, and eliminate the difference	Modify the part of the gradients, and eliminate the difference	Calculate the gradients from the document of “Gotouke”
Diagrammatical view			
Assessment	At the top level of the stone wall, the corner stone leans inside, so the stone wall looks irregular	There are no interference between the stones, the stone wall don’t have any irregular	Stones at the 2nd level and 4th level are rotating, and there occurs interference.

5. Expansion into additional applications

3D laser measurement and the "3D model placement system" can be expanded into additional applications such as the visualization and display of construction processes and the central management of cultural property research results, because they offer innovative techniques for future stone wall restoration work.

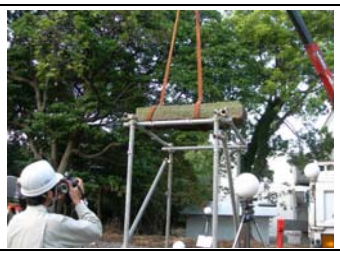
1. Assistance in construction process and safety management
Capability to place and set individual stone models created in accordance with restoration work processes and display them with 3D CG.

2. Function for centrally managing records of cultural property research
Function for enabling the display of photos, comments, etc. by selecting from among placed three-dimensional stone models, in conjunction with a separately configured "stone research report management system", etc.

6. Conclusions

By using the "3D model placement system", it is possible to improve the quality of restoration work and to reduce the work of re-assembling stones that have been assembled incorrectly due to poor restoration design, thereby reducing the risk of going beyond the scheduled term of work and projected cost.

Because it can represent stones in three dimensions, the system enables the study of the order in which stones are assembled, stone wall reinforcement work, etc. interactively by looking at 3D images on the screen, so that it is effective not only for design but also for work planning and work management. Besides, the system enables the creation of a restoration plan by exchanging opinions with experienced masons in the planning phase, making it possible to incorporate their traditional skills at an early stage. By combining the most advanced three-dimensional simulation techniques with the skills of masons, and thus handing down stonework techniques to the next generation, the system can make a meaningful contribution to society. In addition, it can be expanded as an effective tool for designing the landscaping around a stone wall and planning the restoration of turrets, gates, and so on.

	Physical measurement	Digital photogrammetry	3D laser scanner
Summary	-Set lines horizontally and vertically with constant distance, and Make a measured drawing with the lines as standard.	-Taking a stereo photogrammetry, from the image, acquire an ortho image.	-Enable to acquire much 3D information directly in short time.
Stone measure ment			
Validity	-It enable to make a drawing with touching the object directly while understanding the state of the object.	-Enable to utilize the texture information of the stone surface as ortho image	-Enable to create the 3D model, from acquiring 3D information. -It can measure the shape of each stones effectively
Problem	-It takes much time and cost to set a scaffold. -It is high place work, so it is necessary to be careful -It is impossible to modify the drawing.(it is difficult to measure again.) -It is hard to measure the angle. -There will be unevenness between the investigator	-It needs manual operation to acquire the specific point from the data and its matching. It takes long time to acquire the 3D data. -It needs to set a datum point and measure every aspect, for the measurement of each stones.	-It is important to choice the appropriate machine, the density of the data and the number of measurement, not to cause a lack of the data or a hidden part.

7. Acknowledgment

This system was jointly developed in August 2005 by Shimizu Corporation and Keisoku Research Consultant, Co., in response to Shimizu Corporation’s being assigned the "restoration work on the Honmaru Nakanomon Gate stone wall inside the Imperial Palace East Garden" from the Imperial Household Agency, for the purpose of assisting in work management.

During the development, we received tremendous cooperation from Mr. Koichi Tatsumi of the Imperial Household Agency and the chief on the site, Mr. Hiroyuki Yamauchi of Shimizu Corporation. We would like to express our sincere gratitude to them.

References:

[1] Syozo NISHIMURA:Utilization of Diital Information on Nishida Bridge Relocation and Restoration,

[2] Syozo NISHIMURA, Sunaryo SUMITORO: Digital Information Utilization on Preservation Management of Cultural Properties 、 International Society for Photogrammetry and Remote Sensing, Corfu, Greece, 2-6,September,2002 (2002)

GENERATING A PHOTO REALISTIC VIRTUAL MODEL FOR THE LARGE DOMITILLA-CATACOMB IN ROME

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Abstract: The Austrian START Project "The Domitilla-Catacomb in Rome" aims mainly to recover a complete 3D model for the Domitilla catacomb which is the largest catacomb in Rome. This model will allow archaeologists to virtually reach the catacomb and accordingly conduct their research without putting their feet underground. In this work, the documentation procedure using laser scanning technology and digital photogrammetry will be discussed. The automation is a challenge in such large sites therefore we focus here on a developed algorithm for automatic texture mapping with its corresponding software.

1. Introduction

The thorough documentation of the early catacombs including their mural paintings is an important step towards researching iconographic content, their allocation within the complex, the chronological development and the explanation of buildings. The referenced three-dimensional models within the architectural space make the catacombs accessible without the necessity of going there in person.

This paper aims to show the latest methods and automatic processes achieved for the documentation of the early Christian paintings, which are applied in the Austrian START Project "The Domitilla Catacombs in Rome: Archaeology, Architecture and History of Art of a Late Roman Cemetery". The 3D model geometry is captured here by a laser scanner with a mounted high resolution digital camera. The resulting images are not good enough to be used in texturing, therefore a digital camera mounted on a QTVR head is used under best possible lighting conditions in order to obtain reliable texture.

A large number of photos are captured from free positions, and then registered with the 3D model by using tie-points. A challenge in mapping these photos on the geometry is the automation which requires an effective occlusion detection algorithm based on the model geometry. The main characteristics of the used algorithm here are the ability to effectively detect all the occlusion types (ambient, self, and frustum) and to automatically choose the appropriate photo for each face from the 3D mesh.

The resulting photorealistic model is in the VRML format, which can be opened in any standard viewer. The individual paintings will then be used for the creation of a single model of the entire catacomb, which will allow a registration to the Roman GIS. Subsequently, the data will be available to all archaeologists and architectural historians for further research.

An overview on the project structure and the expected products is given in section 2. The data collection procedure is described in section 3, followed by the required post processing in section 4. The automation in texture mapping using the developed algorithm and software is presented afterwards in section 5.

2. Overview on the Domitilla project

In 2006, an archaeological START-project on the Roman catacomb of Domitilla has been installed by the second author, the "project head" at the Institute for Studies of Ancient Cultures of the Austrian Academy of Sciences[1]. The archaeological scientific work is done in a national cooperation with the Institute of History of Art, Building Archaeology and Restoration of the Technical University of Vienna. The interdisciplinary team consists of archaeologists and architects, supported by geodesists and mathematicians. The main goal of the project is to produce, for further archaeological studies, a high quality documentation of the architecture and the paintings of the catacomb, based on laser scanning techniques and digital photogrammetry.

The main problem to be considered is the complexity of the architectural structure of the Domitilla catacomb. It consists of a disordered grid of about 15 km of long underground galleries organized in up to four levels. Moreover, about eighty painted areas inside are of highest interest for archaeologists. These paintings are only partially known and not yet accessible to all scientists [Zimmermann and Eßer, 2008].

The expected products from the documentation are: a 3D model of the whole catacomb structure containing all relevant geometrical information, a textured 3D-model for simple visualization purposes (coloured point cloud), 2D maps, detailed floor plans, vertical sections, coloured orthophotos of wall elevations for archaeological exploration and accurate photo realistic 3D-models of all mural paintings. A workflow of data acquisition and innovative post processing has been developed that allows us to handle the entire catacomb in one point cloud. The most important models with wall paintings have now been full automatically textured using a developed occlusion detection algorithm, which is the main focus of the paper in hand.

3. Data Acquisition

The Domitilla catacomb consists of up to four levels which are connected by antique staircases. These staircases were dug irregularly into the Roman tuff and have grown together from different directions. Antique light wells, which connect the different stories vertically, are located in front of important cubicula. The catacomb includes primarily long galleries for community burials and cubicula, which are mostly provided with mural paintings, for richer people and professions.

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[1] http://www.oeaw.ac.at/antike/institut/arbeitsgruppen/christen/domitilla.html. The project is financed by the Austrian Ministry of Sciences, and administered by the Austrian science fund FWF.

The geometry of this complex structure is recovered by a terrestrial laser scanner, while its texture is captured by a high resolution digital camera. For the geo-referencing purpose, 3D points measured by a total station are employed. These points are necessary not only to connect the output with the local coordinate system but also to reduce the number of scan positions and to control the registration of all scans. A number of reflected targets are therefore distributed along the main corridors and staircases. The 3D coordinates of these points are then recovered using Leica TCRM 1103i total station.

The scans are achieved by a terrestrial laser scanner Riegl LMS Z420i surmounted by a digital camera. It permits a measurement range between 1 and 800 metres, a measurement accuracy of 10 mm standard deviation, and a measurement rate up to 12000 points per second. The scanner field of view is 80° x 360°, more information about scanner specifications can be found on the Riegl homepage (www.riegl.com).

In the course of eight measuring campaigns, nearly 2000 positions have been scanned, resulting in about two million points for each scan position. The scans are registered in the global coordinate system using the reflecting targets measured by a total station, which can be detected automatically in the point cloud. Some of the three thousand reflecting targets have been used as tie-points.

The camera mounted on the scanner delivers poor textures that cannot be used for high quality texture for the important mural paintings. That is why a Canon EOS 1Ds digital camera with a 14 mm objective is used to capture free hand photos from the best available positions. A professional lighting system with flexible light panels made by KINO FLO is also used to produce smooth underground lighting conditions.

4. Post Processing

Manual, semi automatic and automatic methods for point cloud registration are presented in detail in references such as [Zhang, 1994; Ripperda and Brenner, 2005; and Wendt, 2008]. In our project, the overlapping is crucial, as good registration requires large overlap. But at the same time the large overlap requires a larger number of scan positions. In case of a small overlap, large errors are expected, which have to be controlled using total station measurements.

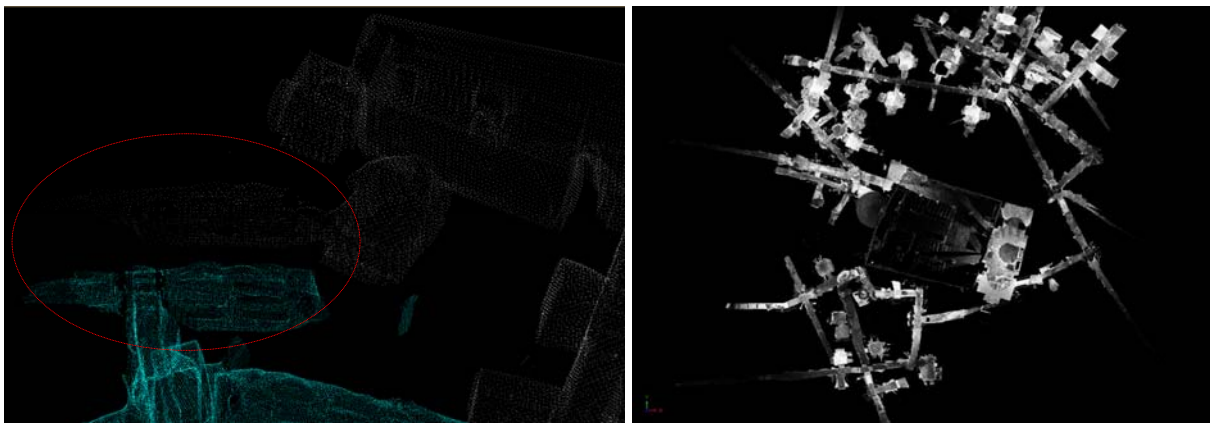

Figure 1: Domitilla point cloud registration error without considering the measured total station tie-points, final registered point cloud.

While figure 1 left shows the large error which resulted in the registration of the Domitilla with a small overlap between the scans without using the measured total station tie-points, the

same figure right shows the final and correct registered point cloud after using the total station tie-points.

Digital images are registered here by using photogrammetric software (3DM CalibCam) by Adam Technology. For a short post processing time in image matching, it is important to consider sufficient overlapping of the employed images and optimum ratio between the base line and the distance to the object, see figure 2 for an example of a set of photos captured for a cubiculum. The existence of at least three tie-points measured by a total station allows registering the photogrammetric model onto the local coordinate system. Self calibration for the used camera is also achieved during the photogrammetric solution in case a sufficient number of photos are available. The point cloud resulted from the laser scanning or from the photogrammetric solution can be then meshed into a 3D model as shown on the right of figure 2.

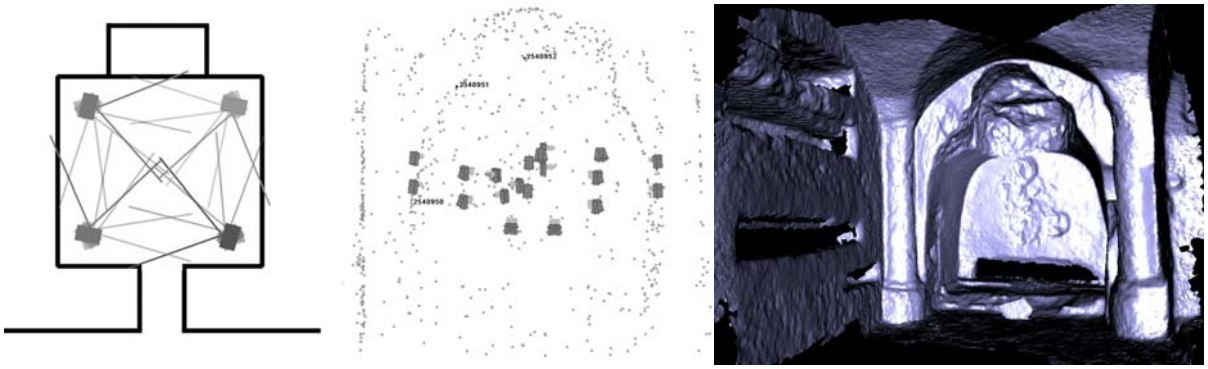

Figure 2: Scheme for camera positions in a painted room; calculated camera positions by 3DM CalibCam; mesh model

5. Texture mapping

Texture mapping procedure needs several manual processes which require too much time. Several days and sometimes several weeks for more complex objects are necessary in order to achieve good results. This is with no doubt time consuming and consequently cost consuming. Therefore, the automation presents a challenge in executing this process. The texture mapping process can be divided into three main steps which are: projecting triangles on photos, occlusion detection, and the assigning of appropriate texture.

Where collinearity equations are commonly used to project triangles on the oriented photos and the appropriate texture is assigned through a certain comparison process between the available textures, the real obstacle to employ the automation in texture mapping is the occlusion detection step.

Occlusion detection algorithms like the z-buffer algorithm [Catmull 1975] and the painter algorithm already exist. While the z-buffer algorithm requires large RAM, the painter algorithm [Goodrich, 1992] is computationally expensive. [Grammatikopulos et al., 2004] has speeded up the searching process of the z-buffer algorithm by tessellating the textured image area into a rectangular grid with cells larger than those of the original image in order to create digital ortho-photos.

[Alshawabake and Halla, 2005] have detected the occlusions by employing an object space threshold and an image space threshold. Although using such thresholds detects simply the visibility status, the algorithm shows low sensitivity as selecting small thresholds values may

wrongly classify visible parts as occluded and selecting large thresholds values may classify occluded parts as visible. [Abdelhafiz 2009] has also detected the occlusions effectively by classifying mesh vertexes into visible and non-visible layers without any misclassification.

Employing multiple photos commonly results in multiple textures for the same triangle. The image with the best texture quality is then selected and employed. Another approach to deal with the available multiple textures is to blend all textures together [Grammatik et al., 2004; Visnovcova et al., 2001]. The textures of the images are blended according to the weight which is proportional to the area of the projected triangle on each image. Blurring in the textured model is experienced as a result of the blending process.

In this work, the Multi Layer 3DImage algorithm [Abdelhafiz 2009] is in principle employed. In order to fulfil our project needs some modifications are required. The modified algorithm is integrated in the 3DImage software. All these points together with some results of real paintings from the Domittila catacomb are presented in the following subsections.

5.1. The original ML3DImage algorithm

The main function of the original ML3DImage algorithm [Abdelhafiz, 2009] is to employ multiple photos captured from different points of view in order to texture a given mesh automatically. Registering photos with the mesh model is a step before starting the algorithm. The object geometry is then investigated in order to assign all the occluded parts on each photo.

Considering a number of photos (N) registered in the same coordinate system of the object model, two main tasks are executed in order to texture the model employing N photos which are: detecting occluded parts in the mesh and assigning the appropriate photo for each triangle of the mesh. Details of these two tasks will be given in the following sub sections.

5.1.1. Occlusion detection

The following three steps are executed for each photo of the available images:

1) Constructing 3DImage for the concerning photo (P_i)

Having the camera interior orientations parameters (from a calibration process) and the photo exterior orientations, the mesh can be projected on the concerned photo using collinearity equations. Each triangle vertex is then attached to its corresponding image pixel; see [Abdelhafiz at al, 2005] for more details of the construction of the 3DImage. All the attached vertexes are labeled as visible by default and then classified into visible and non visible in the following step.

2) Classifying mesh vertexes into visible and non visible

The vertexes visibility is assigned by a visibility indicator (1/0) according to the vertex visibility status. In this step, occluded vertexes are sent to one of the back layers and labeled as non visible (0). Two types of points are considered. Points like (A) and points like (B) as shown in figure 3. Vertexes like (A) are occluded by other points (A1). This means that these two vertexes are corresponding to one image pixel. According to the fact that the point near to the camera is visible and the far one is invisible, the visibility status for the two points can be defined.

For points like (B) which are occluded by the object surface itself, all light rays connecting the vertexes with the exposure station are checked if they intersect with the object surface or

not. If yes, this means that the checked vertex lies behind the object surface i.e. occluded. So this vertex will be sent to the back layer, otherwise it will remain on the visible one.

3) Detecting and labelling occluded parts

Whereas vertexes on the visible layer are assigned with visibility indicator (1), vertexes on back layers are assigned with visibility indicator (0). The visibility indicators of the three vertexes of any triangle are then used to decide the visibility status for that triangle from the point of view of the concerning photo (P_i), see figure 5 left side. If the visibility indicators of the three vertexes of the triangle are (1) then the triangle is completely visible (e.g. triangle M from station_1 or station_3). If the visibility indicators of the three vertexes of the triangle are (0) then the triangle is not visible (e.g. triangle M from station_2). In case of one or two of the triangle vertexes have (0) visibility indicator, so the triangle is partially occluded and the texture from that photo will not be considered (e.g. the edge triangle E from station_1 or station_2).

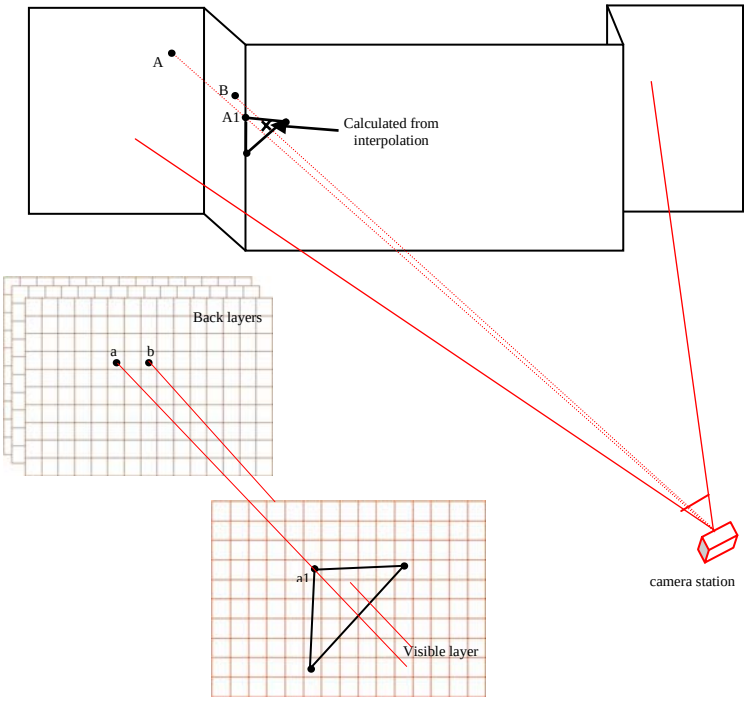

Figure 3: The classification of vertexes into visible and non-visible layers

5.1.2. Assigning the appropriate texture

By repeating the occlusion detection step with all the available photos, occluded parts on each photo are assigned as non visible. For triangles which appear in just one photo, this photo will be directly assigned to texture such triangles. On the other hand, triangles appeared in more than one photo are the concerned triangles in this step, see figure 5 left side. Due to the fact that rich texture is obtained from the photo with the largest triangle projection, this criteria is used in this algorithm as a control condition in case of multiple photos are available for texturing a certain part of the object.

5.2. Applying the ML3DImage algorithm on one of the Domatilla paintings

In this section, one mesh model of a painting with 400,000 triangles is presented. Eleven photos are selected from the available photos for texturing purpose. The original mesh model is shown in figure 2 and the resulted textured model is shown in figure 4. The variation in the radiometric characteristics between the used images can be easily noticed in the photo realistic model (red circles). This occurs as the used algorithm searches for the richest texture between the photos and consequently uses more than one photo to texture one wall painting. Therefore, it will be more convenient to texture each wall painting from one photo. In order to let the algorithm understand and accordingly fulfil our requirements automatically, some modifications for the algorithm are made as will be described in the following section.

Figure 4: A mesh model of one painting from the Domitilla catacomb including artifacts

5.3. Modified ML3DImage algorithm and the corresponding 3DImage software

The algorithm modification aims to push the algorithm to texture a certain part from the mesh model from a certain photo. The idea behind this is to mask this part in the remaining photos with a specific colour. Accordingly, the algorithm will detect this colour and consider it as occluded areas. In that case, the only choice for the algorithm is to use the photo without masking to texture this part.

For instance in figure 5 on the right side, please focus on the left part (L). If the algorithm is applied normally (as in the left side), (L) will be textured from station 3. Here it is required for any reason to push the algorithm to use station 2 in texturing this part. Therefore (L) part is masked with black colour as shown in the figure. Looking for the interpretation of part (L) under the figure, the only available choice for the algorithm is to use station 2 to texture (L) part.

Another useful modification is the ability to give priority to certain photos, for example to texture a complete wall painting from one photo, the painting can be selected in that photo and then the remaining part of the photo can be masked. With giving the masked photo priority, the modified algorithm will use this photo first to texture the entire painting and then use the other photos to complete the rest of the model. These two modifications are used to better texture the mesh model under investigation without any artefacts, see figure 6 for a textured model without the pre-mentioned artefacts.

The modifications are integrated in the 3DImage software which is developed and modified by the first author. The software is originally designed to texture laser scanner mesh models full automatically employing the ML3DImage algorithm. The software input is a mesh model together with all the available photos. A data file with the interior and the exterior orientations for all the employed photos is also required. All the required data is then organized in a batch file which can be created using an interactive procedure employing the same software.

Afterwards the software starts the processing which ends with a photo realistic model in the VRML format.

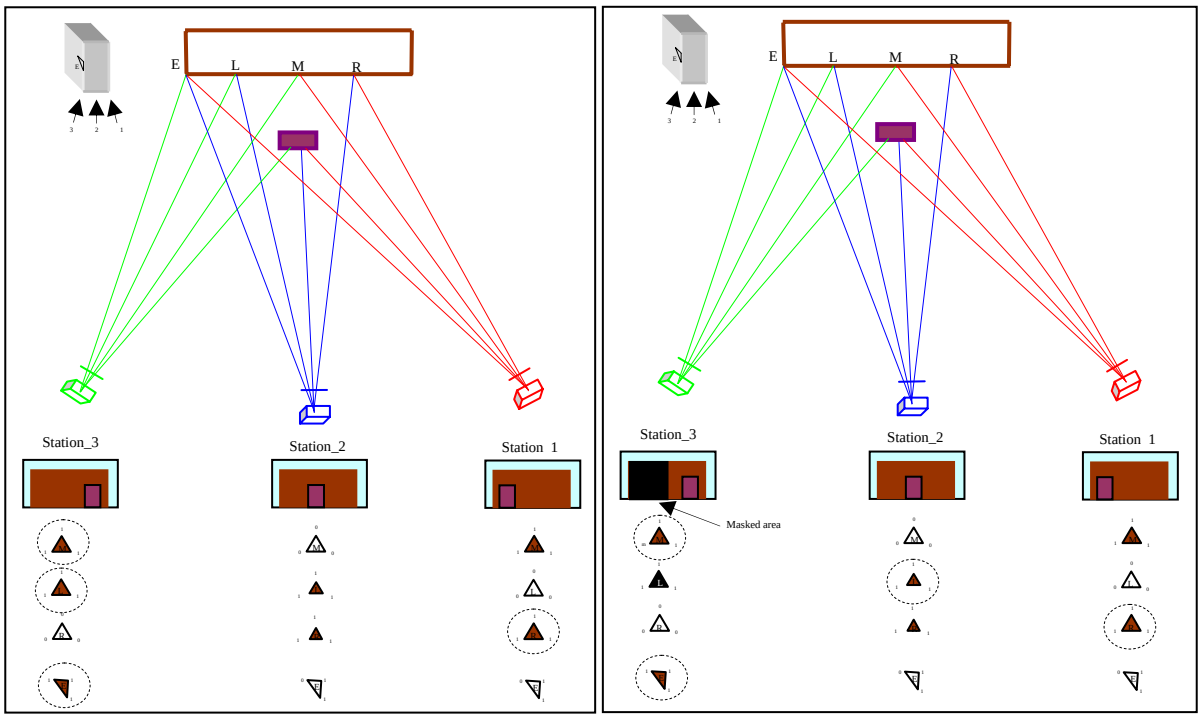

Figure 5: The principle of executing the original ML3DImage algorithm and the execution in case of existence of masked part

6. Conclusions

While the entire Domitilla catacomb in Rome is already recovered as a point cloud, its mural paintings are on their way to be modeled and textured. Through this work, the ML3DImage algorithm is further developed and modified to texture such paintings. The modified algorithm with its corresponding 3DImage software shows the reliability and the efficiency to texture the project paintings full automatically.

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Figure 6: A photo realistic model of one painting from the Domitilla catacomb textured with the modified ML3DImage algorithm

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