VIABILITY OF PHOTOGRAMMETRY FOR AS-BUILT SURVEYS WITHOUT CONTROL POINTS IN BUILDING RENOVATION PROJECTS

A Thesis

by

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ABSTRACT

In recent years, it is becoming more and more common to utilize 3D modeling technology to reconstruct cultural heritages. The most common way to deliver the 3D model of an existing object is based on hands-on surveys and CAD tools which could be impractical for large or complex structure in term of time consumption and cost. Recently, laser scanning technology and more automated photogrammetric modeling methods become available, and making the 3D reconstruction process of real world objects easier. Photogrammetry is one of the most cost-effective approaches we could use to gather the physical information of an object, such as size, location, and appearance. Also, the operation of the equipment of photogrammetry, which is a camera, is very easy and cost-effective. However, it also has its drawback, which is mainly caused the outcome's low accuracy level. Accurate drawings or models only have been achieved with other approaches, such as 3D laser scanning or total station.

The 3D model of the Francis Hall at Texas A&M University, which will be renovated soon, was created in order to investigate whether the image-based 3D model produced using photogrammetry technology would be acceptable or not for the use in renovation projects. For this investigation, the elapsed time for data acquisition and 3D modeling was measured. The accuracy level of the image-based 3D model and the deficiencies of this approach were also recorded. Then, the image-based 3D model of Francis Hall was presented in the BIM CAVE to four industry professionals and one graduate student.

The regular 3D model of the Francis Hall, which was created, using dimensions extracted from 2D drawings, was also presented to the interviewees in the BIM CAVE. After watching two different 3D models (image-based 3D model and regular 3D model) of the same Francis Hall, five interviewees were requested to describe the differences they noticed between image-based 3D model and regular 3D model presented in the BIM CAVE.

By reviewing and analyzing the data from interviews. Following conclusions could be made. First, the image-based 3D model of Francis Hall gave people more feeling of reality than the traditional CAD drawings or BIM models. Second, the image-based 3D model could be used for saving travels, showing details, improving coordination, improving design, facilities management tool, and marketing tool. Third, in order to make it practical for the industry, the time consumption and cost of generating the image-based 3D model should be at least equivalent to time consumption and cost for architects to conduct survey and generate CAD drawings or BIM model.

DEDICATION

To my mother Yang Yi and my father Liu Ziwen

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CHAPTER I

INTRODUCTION

Background

According to American Society for Photogrammetry and Remote Sensing (ASPRS), photogrammetry has been defined as "the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena".

The earliest photogrammetry can be traced to Renaissance painters, specifically Leonardo Da Vinci who wrote "perspective is nothing else than the seeing of an object behind a sheet of glass, smooth and quite transparent, on the surface of which all the things may be marked that are behind this glass. All things transmit their images to the eye by pyramidal lines, and these pyramids are cut by the glass. The nearer to the eye, the smaller the image of their cause will appear" (Doyle, 1964). From mid-1600s to mid-1700s, the development of projective geometry formed the mathematical basis of photogrammetry. Then, Daguerre invented photography in 1839 made photogrammetry became possible as one of the practical tool. A year after Daguerre's invention, the first photogrammetric experiment was conducted by Colonel Aime Laussedat from French Army for topographic mapping. Kites and balloons were employed for taking aerial photographs in the experiment (Kubik, 2003). The term photogrammetry was formed by the German geographer Otto Kersten in connection with the German civil-engineer Albrecht Meydenbauer. The term was firstly introduced in 1893 as title of an article from Meydenbauer which was published in Berlin Architectural Society (Grimm, 1980).

Nowadays, photogrammetry has many applications in different fields and is becoming more and more popular in the field of architecture and heritage preservation (Arias 2006), engineering application (Mills 2001, Dare 2002), industrial application (Przybilla 1988, Beyer 1995), forensics and accident reconstruction (Fenton 1999, Lynnerup 2005), medical applications (Burke 1979, Walton 1990). Furthermore, photogrammetry "still remains the most complete, economical, portable, flexible, and widely used approach" (Remondino, 2006).

At the same time, with the development of technology, 3D models are required for many different reasons which include "documentation in the case of loss or damage, virtual tourism and museum, education resources, interaction without risk of damage", and so forth. The requirements specified for many applications, including digital archiving and mapping, involve high geometric accuracy, photo-realism of the results and the modeling of the complete details, as well as the automation, low cost, portability and flexibility of the modeling technique (Remondino, 2006).

In recent years, it is becoming more and more common to utilize 3D modeling technology to reconstruct cultural heritages. The most common way to deliver the 3D model of an existing object is based on hands-on surveys and CAD tools which could be impractical for large or complex structure in term of time consumption and cost. Recently, laser scanning technology and more automated photogrammetric modeling methods become available, and making the 3D reconstruction process of real world objects easier (El-Hakim, 2004).

A large amount of experiments and researches have been done regarding the accuracy of photogrammetry. In most cases, it has been proved to be a very accurate approach to preform measurement (Randles, 2010) (Burt, 2000). However, its application in construction industry is rare.

Statement of Problem

It is not practical to use laser scanning as the only technique to record the entire building and details for complex or large architectural objects, because it requires large numbers of scans and produce a huge number of points even for a flat surface. On the other hand, it is hard for image-based modeling to deal with irregular and sculpted objects (El-Hakim et al., 2004). Thus, in many complex or large architectural objects, photogrammetry and laser scanning have been combined with each other to satisfy all the project requirements (Abdelhafiz, 2009). It is also agreed by most of researchers that no technique by itself can efficiently and quickly provide a complete and detailed model (Remondino, 2006).

In certain researches, image-based techniques and laser scanning techniques are combined in a way that using photogrammetric approach to determine the basic shapes, and using laser scanning to determine the fine details (El-Hakim et al., 2004). Two models, basic shape model and detail model, are generated from two or several different applications. Certain parts of both of the models could be matched and integrated into one model. Then common points (control points), usually 8 to 10 points, from two models will be measured and used to register in the same coordinate system. Then, points from the laser scanned model along its perimeter could be inserted into the image-based model automatically within certain applications (El-Hakim et al., 2004).

In some other cases, instead of using a laser scanner, a laser total station will be utilized to obtain control points which allow orientating, leveling, and scaling an image-based model. In this approach, control points are used to adjust the image-based model to the ground's co-ordinate system (Arias et al., 2005).

Even though combining the use of a total station or a laser scanner with photogrammetry will bring a very precise result, it will also cost additional money and time to obtain the data and generate the model.

In today's construction industry, there are lots of projects have already benefited from using 3D laser scanner for recording 3D as-built condition of existing structure. However, photogrammetry has never been used actively to achieve a 3D model in the construction industry although it has been regarded as the most cost-effective, flexible, and portable approach in terms of getting a 3D model. Nevertheless, it is widely accepted that photogrammetry maintains various potential usages (Bhatla et al., 2012):

1. "Measuring elements that are inaccessible from the line of sight;
2. Efficient dimension takeoffs for progress measurement purposes;
3. Serving as a digital storage of visualization and future dimension takeoffs, for decision-making and asset management purposes;
4. For visualization purposes and communication of construction progress".

Furthermore, a large amount of historic buildings do not have as-built drawings. Photogrammetry could be used to generate as-built drawings for a building renovation project, and it could be a very powerful tool for presentation in the pre-bid phase, as well as pre-construction phase.

Based on pervious discussion, following question is proposed: 1) Is it possible that a 3D image-based building model could be created without using laser scanner or a total station? 2) Is 3D building model created from photographs without utilizing other technology, such as laser scanning, acceptable for owners, architects, or construction professionals to use for their decision making in a building renovation project?

Objectives

The research objective is to test if a 3D model can be created using photogrammetric technology without using other technology, such as laser scanning, and if this model could be used by owners, architects, or construction professionals to make decisions for historic building renovation projects.

Expected Outcome

This investigation will let us know 1) whether we can create a 3D model using photos, 2) how we can create it without using any other technology such as laser scanning, and 3) if owners, architects, or construction professionals can use it for construction planning or project control.

CHAPTER II

LITERATURE REVIEW

In order to be more knowledgeable in the aspect of photogrammetry, and their current trends in the field of construction, some literatures have been reviewed.

Fundamentals

American Society for Photogrammetry and Remote Sensing (ASPRS) defined photogrammetry as "the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena."

Photogrammetry encompasses methods of image measurement and interpretation in order to derive the shape and location of an object from one or more photographs of that object. The primary purpose of a photogrammetric measurement is the 3D reconstruction of an object in digital form or graphical form. The photograph or image represents a store of information which can be re-accessed at any time. (Luhmann, 2006)

An overall workflow of using photogrammetry was described by Remondino (2006).

1. "Design and recovery of the network geometry: Designing a network includes deciding on a suitable sensor and image measurement scheme; which camera to use;

the imaging locations and orientations to achieve good imaging geometry; and many other considerations. The network configuration determines the quality of the calibration and defines the imaging geometry";

2. "Surface measurements: Once the images are oriented, the surface measurement step can be performed with manual or automated procedures. After the image measurements, the matched 2D coordinates are transformed into 3D object coordinates using the previously recovered camera parameters (forward intersection). In the case of multi-photo geometrically constrained matching the 3D object coordinates are simultaneously derived together with the image points";
3. "From 3D point clouds to surfaces: Polygons are usually the most flexible way to accurately represent the results of 3D measurements, providing an optimal surface description";
4. "Texturing and visualization".

People from industry and researcher without the domain knowledge of photogrammetry could utilize certain easy-to-use software to recreate 3D models of existing structure solving practical problems. Among a large amount of software, PhotoModeler (Eos Systems Inc.) and ImageModeler (Autodesk) are two of the most popular ones. (Dai, 2009)

Applications of Photogrammetry

Applications of close-range photogrammetry could be categorized as the following five groups (Dai, 2009):

- Architecture and heritage preservation:
- Engineering application
- Industrial application:
- Forensics and accident reconstruction:
- Medical applications:

Architecture and heritage preservation: Close-range photogrammetry techniques were employed by Arias et al. (2006), image and metric documentation were combined to conduct research on the traditional agro-industrial buildings which have significant value for heritage of Galica, Spain.

Engineering application: distortion of a pavement within the Newcastle University Rolling Load Facility was measured by Mills et al. (2001). By utilizing stereo-imagery taken with both analytical and digital photogrammetric instrumentation, the 3D measurements of the pavement have been obtained accurately. The advantages of employ a photogrammetric survey have been concluded. However, it is still ineffective to establish a permanent, automated photogrammetric system for rolling load facility at a reasonable cost.

Dare et al. (2002) illustrates the operational application of automated image processing techniques for accurate, multi-temporal concrete structure crack measurements. They provided an overview of automatic feature extraction, essential for automatic crack detection. They also described the methods developed for detecting and measuring cracks. Due to the long term nature of the application, operational results have yet to be finalized, although sample results are presented.

Industrial application: Phototriangulation was used to determine the shape of a fuel assembly in a research conducted by Przybilla et al. (1990). The fuel assembly is a crucial part of a nuclear power plant and can only be handled underwater. Phototriangulation was used to obtain orientation elements, taking into account light refracting surfaces. Analytical restitution and the shape parameters of the object were then set up based on the stereomodels. The project is a typical example of high precision underwater photogrammetry.

Fraser and Riedel (2000) monitored the deformation a series of super-hot steel beams by digital close-range photogrammetry. An on-line configuration of three CCD cameras was established to measure both stable reference points and targets subject to positional displacement. Measurements for each beam were conducted at 70–80 epochs over 2 hours as the steel cooled from 1100 ℃ to near room temperature. Special targeting was required to accommodate the changing color of the beams from white-hot to brown as they cooled and ensure target survival through a large temperature range. A computational approach was employed whereby the photogrammetric triangulation process for any given recording epoch utilized all images obtained up until that time. All aspects of the project in which seven beams were monitored to a dimensional tolerance of close to 1 mm (RMS 1-sigma) were discussed in their paper.

Forensics and accident reconstruction: Fenton and Ziernicki (1999) presented a method of determining a vehicle crush and equivalent barrier speed using digital photogrammetry. Close-range photogrammetry allows engineers and accident reconstructionists to create 3D computer models of damaged vehicles utilizing photographs. Utilizing photogrammetric software (PhotoModeler), engineers can digitize accident scene photographs to create accurate 3D computer models of the vehicles, which can be used to quantify structural damage sustained by the vehicles. Crush deformation can be quantified utilizing this process and the resulting crush dimensions can be input into engineering software to determine a vehicle's equivalent barrier speed. Knott Laboratory, Inc. has utilized these techniques on cases worldwide including Princess Diana accident in France.

Lynnerup and Vedel (2005) analyzed surveillance images from a bank robbery, and the images were compared with images of a suspect. Based on general bodily features, gait and anthropometric measurements, we were able to conclude that one of the perpetrators showed strong resemblance to the suspect. Both exhibited a gait characterized by hyperextension of the leg joints, and bodily measurements did not differ by more than 6 mm on average. The latter was quantified by photogrammetry: i.e., measuring by using images of the perpetrator as captured by surveillance cameras. Using the computer software PhotoModeler Pro, synchronous images from different cameras were compared and concurrent body features were identified. The program could then render the perpetrator as a three dimensional, high-precision, scalable and measurable object.

Medical applications: Burke and Beard (1979) monitored facial shape as it changed over an extended period of time through growth.

Walton (1990) involved photogrammetry in the therapy of various gait problems arising primarily from deformities or injuries.

Applications of Photogrammetry in Construction

Improve Managerial and Operational Capabilities

Abeid et al. (2003) integrated the site construction progress bar chart in MS Project with a database of digital site pictures showing the building process and building elements at particular points of time. The digital pictures taken from up to four cameras are placed on a website from where a remote computer(s) can capture and store the pictures in the database. The system enables management staff at the contractor's and owner representatives' headquarters to follow developments at the construction site in real time. Additionally, time-lapse films of activities at the construction site taken by multiple cameras can be played back in synchrony with dynamic graphs showing planned versus actual schedules. A new concept in time-lapse photography has been introduced. It enabled a reasonable playback time as well as the implementation of the technology for long-term construction projects using standard PCs.

Quantity Takeoff and Progress Control

Kim and Kano (2008) suggested a method for determination of the 3-dimensional viewpoint and the direction vector of a construction photograph to perform comparison of the construction photograph and the corresponding virtual reality (VR) image. In addition, through a case study in which acquisition of construction photographs and comparison of construction photographs and VR images according to the elapsed time have been carried out, the validity of proposed methods has been well prove. They developed photo images in 3D computer graphics showing the as-built site situation. The photo images were used to compare against the associated images from as-planned CAD models. It has been proved that the method is convenient and effective in checking actual site progress against designed models in terms of foundation excavation, refill, scaffolding and steel erection.

Memom et al. (2005) identified the techniques, which were used in the construction industry for monitoring and evaluating the actual physical progress, and discuss the Digitalizing Construction Monitoring (DCM) model. The DCM model, an interactive system which integrates 3D CAD drawings (is being used increasingly as a design tool for construction projects) and digital images (is being used to provide accurate information needed to document as-built construction schedule). The authors made a practical attempt to automate the process of producing as-built construction schedule by applying modern photogrammetry techniques to photographs and integrating with CAD drawings. The applications of the DCM model in monitoring the progress enables project management team to better track and control the productivity and quality of construction projects.

Quinones-Rozo et al. (2008) explored the use of two image based techniques – Close-Range Photogrammetry and Image Reasoning – to perform semi-automated tracking of excavation activities. A new image reasoning algorithm, Enhanced Pattern Detection and Comparison (EPDC), is introduced to quickly identify changes in poor contrast excavation surfaces. EPDC is illustrated using laboratory and field trials. The proposed image reasoning algorithm paves the way for new uses of large numbers of digital camera and webcam images now available at many construction sites to acquire detailed construction staging information.

Measuring the Differences on Building Products between Two Temporal States

Kamat and El-Tawil (2007) discusses the feasibility of using augmented reality (AR) to evaluate earthquake-induced building damage. In the proposed approach, previously stored building information is superimposed onto a real structure in AR. Structural damage can then be quantified by measuring and interpreting key differences between the real and augmented views of the facility. Proof-of-concept experiments were performed in conjunction with large-scale cyclic shear wall tests. They measured and interpreted the drifts between the original walls in 3D CAD images and the actual wall specimens in order to assess the earthquake-induced building damages. CAD images of the walls were superimposed onto the wall specimens. Then, as the wall specimens were deformed under applied loading, the horizontal drifts between the walls and the augmented images were computed using two different techniques and compared with actual wall drifts. The obtained results highlight the potential of using AR for rapid damage detection and indicate that the accuracy of structural displacements measured using AR is a direct function of the accuracy with which augmented images can be registered with the real world.

Accuracy of Photogrammetry

Burt (2000) conducted research on factors that could affect the accuracy of close range digital photogrammetry for measurement. He used historic adobe wall ruins located at Fort Davis, TX as his case study. He used a 35-mm single-lens reflex camera and a digital photogrammetry program call PhotoModeler by Eos Systems to form his image-based system. An origin point and the location of the X-axis were established on the wall. After establishing the origin and X-axis with the digitizer each target and control point on the wall was measured approximately 20 times. In order to avoid the possibility of using an erroneous coordinate measurement, the standard deviation of the 20 coordinate measurement of the target was calculated.

After the entire measurement process and statistical calculation process, a conclusion has been made that photogrammetry is a suitable method for obtaining measurements of adobe erosion. The factors which influence the accuracy and precision of measurement were due either to the three-dimensional relationship between the cameras taking the images and the object, or decisions made during the digital photogrammetry process. The following Table 1shows which independent variables had an effect on the accuracy and precision of digital photogrammetry measurement.

Table 1 Independent variables used in multiple regression models

Independent Variables	Dependent variables					
	MEAN X	MEAN Y	MEAN Z	STDEV X	STDEV Y	STDEV Z
VECTOR	YES	YES	NO	YES	YES	NO
MAX XY	YES	YES	NO	YES	YES	YES
MAX XZ	YES	YES	YES	YES	YES	YES
MAX YZ	YES	YES	YES	NO	NO	YES
CONTROL	NO	YES	YES	YES	YES	YES
PRECIS	YES	YES	YES	YES	YES	YES
DIST	NO	YES	YES	YES	YES	YES
DPI	YES	YES	YES	YES	YES	NO
PIXEL	NO	YES	YES	YES	YES	NO

Randles et al. (2010) compared traditional technique of hands-on measurement with the use of photogrammetry for measurement of targeted damaged vehicle. Figure1 shows one of the targeted damaged vehicles. The points on each vehicle were measured using both techniques, and compare to baseline reference measurements obtained via a prismless imaging total station. PhotoModeler was employed as photogrammetry technique, and photographs of the post-impact vehicles were obtained using several different cameras and photographers. Hands-on measurements were obtained via two groups of qualified professionals in the field of accident reconstruction.

The hands-on measurements for all participants were grouped for each of the four damaged vehicle measurement areas. Mean and standard deviations were calculated for each measurement point, and compared to those obtained from the total station. Similar, photogrammetry measurement point means and standard deviations were also calculated for each of the four damaged vehicle areas.

After all the calculation and comparison, they got a result that both methods effectively measured the vehicle points, with a mean difference between the baseline and hands-on measurements of 0.6 ± 1.4cm, and a mean difference between the baseline and photogrammetry measurements of 0.1 ± 1.0cm. The accuracy of the photogrammetry method was found to be slightly greater than that for hands-on physical measurement.

Another research has been conducted by Bhatla et al. (2012). In their research an under-construction bridge, which is about 2000 ft., located in southern United States was used as the test project to assess the accuracy of the photogrammetry for use in modeling in highway infrastructure projects. The bridge deck consists mostly of planar members like beams and box girders. While the central and exterior box girders are vertical with respect to the ground, the other members of the bridge deck, including the beams, are inclined due to a cross slope along the width of the bridge.

For data collection purposes, the bridge was divided into 5 sections along the length, and a total of 351 photos have been shot. Then, utilizing the software which is called Photofly from Autodesk to generated 3D model, some photos have been automatically stitched and generated 3D model. However, due to the lack of texture and contrast of a bridge structure, large amount of photos of some sections cannot be automatically assembled. They manually located those photos and stitched, and run the software again to generate the 3D model. The 3D models then have been exported to a CAD modeling software to model the bridge beams, exterior box girder, and the holes for electrical fixtures.

Comparison has been made between the models generated using photos and 3D model developed using the 2D drawings. The average height of exterior box girders, average distances between the holes for electrical fixtures, and the average length and width of the floor beams were used for the comparison. The deviations were calculated by subtracting the 2D drawing based 3D model dimensions from the dimensions extracted from the photo based model. Then, they performed statistical analysis.

After all, they made a conclusion that significant differences to the order of about 2%+/-5% were observed for the length of beams, height of exterior box girder and distance between the holes for electrical fixtures. Thus, they concluded that photogrammetry in its present state is not suitable for modeling infrastructure projects.

CHAPTER III

EXPERIMENTAL APPARATUS

Francis Hall

Francis Hall (1913) was designed by Rolland Adelsperger, college architect and professor of architecture and architectural engineering, in a highly distinctive Romanesque style for the School of Veterinary Medicine. The proposed design exceeded the budget. The architectural firm of Endress and Watkin reduced the size and changed the exterior design to match other buildings. Completed in 1918, it is a classically proportioned three-story reinforced concrete building with brick and cast stone exterior. The façade has brick pilasters with Doric and Ionic capitals and projecting balconies. The third floor is marked by cast stone quoins. The entire building is capped by a brick parapet wall. Named after Mark Francis Hall, the father of veterinary medicine at Texas A&M (College of Architecture, Texas A&M University). Figure 1 shows the Southwest façade of Francis Hall.

Texas A&M Construction Science Department, with over 650 students and 30 faculty members, is one of the largest and best programs of construction higher education in the world. However, the department currently has 8,501 sq. ft. of assigned space, 45% less than its current needs, with no room for growth for the development of state of the art laboratories and classrooms to prepare students for a constantly changing field. Francis

Hall as the 8th oldest building on campus has been awarded to Construction Science Department to use as its headquarters (Construction Science Department).

Figure 1 Southwest façade of Francis Hall

Interior of first floor of Francis Hall will be used in this research to investigate the acceptability of a 3D photogrammetric model for construction professionals to use for their decision making. This project was chosen because it has characteristics that are typical of a higher education building renovation project.

In order to keep the data collection process and data well organized, the first floor of the building is divided into several sections. They are hallways, stairwells, and rooms. Two hallways are divided into 5 sections—HW 1 to HW 4, and Major HW; one stairwell; and every room will be treated as one section. Figure 2 shows the floor plan and section plan of hallways and stairwell of Francis Hall.

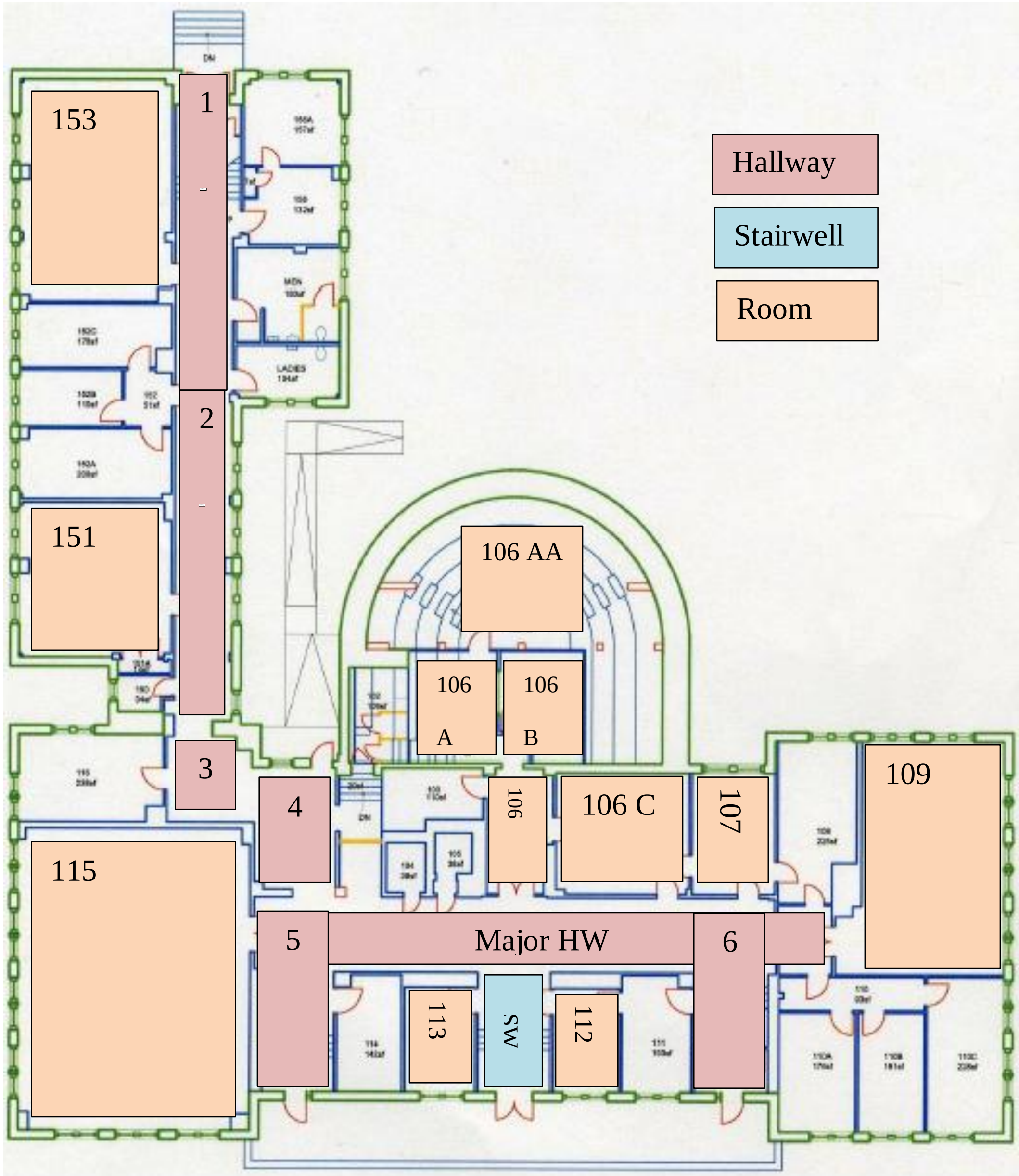


Figure 2 Floor plan & section plan

3D Data Acquisition

The dimensional data is acquired in two ways: an existing drawing from Department of Construction Science, Texas A&M University and image-based photogrammetry.

Image-Based Systems

The image-based modeling process begins with taking photos for 3D modeling with a DSLP camera, and some measurement with a sonic laser tape measure. Then, photos will be processed into panoramas with Autodesk Stitcher. The panoramas will be used to generate 3D models with Autodesk ImageModeler, and the textured 3D models were checked and transferred into NWC file within Autodesk 3ds Max. Finally, the sectional models will be combined into one single model within Autodesk Navisworks.

Camera

A Canon EOS Rebel T3i Digital Single-Lens Reflex camera with EF-S 18-55mm lens was used. The effective focal length equals to the focal length times 1.6. Thus, the effective focal length of the lens is range from 28.8mm to 88mm. The interior space is relatively narrow, in order to reduce the amount of photos, 28.8mm effective focal length has been used to achieve photos with wider zoom.

Sonic Laser Tape Measure

A Strait-Line 50 ft. Sonic Laser Tape Measure was used to quickly gain certain dimensions for future use.

Autodesk Stitcher Unlimited 2009

Autodesk Stitcher Unlimited 2009 is the way to build high-quality panoramas for the Web, film, print, and 3D. With advanced features, Autodesk Stitcher Unlimited 2009 gives photographers and artists the power to deliver the most impressive panoramas in the formats they need. Autodesk Stitcher creates wide-angle, high-resolution 360° * 180° panoramic images in seconds from horizontally and vertically overlapping photos. You can create new image sets from the panorama using a virtual camera with zoom, pan, and roll motion. Results can be rendered as a cube, plane, cylinder, sphere projection, and as a QuickTime movie (Cylindrical QTVR and Cubic QTVR), and in VRML format for creating high-impact Web pages, definition matters, environment maps, and 3D models (Autodesk Inc., 2008).

Autodesk ImageModeler 2009

ImageModeler 2009 offers architects, designers and entertainment content creators a new approach to 3D modeling; by generating 3D models from 2D digital images or panoramas. Using advanced technology, ImageModeler 2009 extracts 3D information from still images to construct accurate 3D models and scenes with highly realistic textures automatically applied. The software also delivers a number of productivity-enhancing features including a rules toolset that enables you to make point-to-point measurements, and a mapping feature that allows you to define how each texture will be created. Additionally, ImageModeler 2009 offers support for Autodesk 3ds Max, Autodesk Maya and AutoCAD software (Autodesk Inc., 2009).

Autodesk Navisworks 2013

Autodesk® Navisworks® project review software helps architecture, engineering, and construction professionals holistically review integrated models and data with stakeholders to gain better control over project outcomes. Integration, analysis, and communication tools help teams coordinate disciplines, resolve conflicts, and plan projects before construction or renovation begins (Autodesk Inc., 2013).

Existing Drawing

Existing drawings are acquired from Department of Construction Science, Texas A&M University. The drawings are developed by the project architect, BRW Architects, and previous students work.

CHAPTER IV

IMAGE-BASED SYSTEM DATA ACQUISITION

Image-based system data acquisition means taking photos in this thesis. The photos will be used for generating panoramas for interior sections.

Equipment

According to the User Guide of Autodesk Stitcher Unlimited 2009, either a high-resolution digital camera or a traditional camera could be used in this step. If a traditional one is used, the photos have to be either scanned or have a photo lab digitize images to transfer them to a computer. The author chooses a Canon EOS Rebel T3i Digital Single-Lens Reflex camera with EF-S 18-55mm lens to simplify the data acquisition process and shorten data process time. The camera was set up on a tripod with a panoramic pan head. A panoramic pan head could not only prevents parallax, but also ensures sufficient overlap between images.

Shots Planning

In order to capture a full 360° × 180° view of the scene, images have to be captured in rows. That is, in addition to capturing images in a 360° circle as you normally would to make a panorama, you also need to capture rows of images with the camera tilted up and down. Figure 3 (top view) shows 12 images per row captured at 30° increments and Figure 4 (side view) shows three rows of images captured at –45°, 0°, +45° pitch.

However, the number of images, rows, and spacing needed to capture a panorama depends on the field of view of the lens being used. Stitcher requires an overlap of about 30% between adjacent images. Wide-angle lenses are preferred for capturing spherical panoramas because they reduce the total number of images required. The approximate field of views (FOV) for some common lenses and the number of images needed to capture a full 360 °* 180 °view are shown in Appendix I. Furthermore, all the images of one section must be the same size in pixels (height and depth), and they have to be shot with the same focus length (Autodesk Inc., 2008).

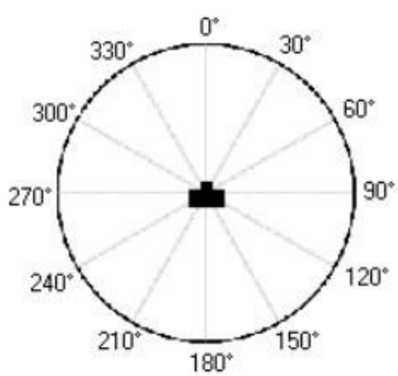


Figure 3 Top view of 12 photos in a row

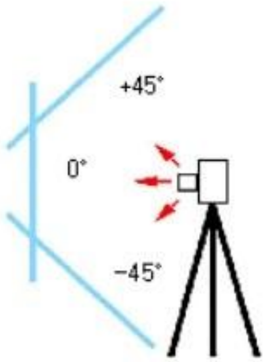


Figure 4 Side view of 3 rows

Problem Met and Solutions

It was the first time that the author uses this process to generate 3D model, and all the material and instructions the author could obtain is the user guide of certain applications, very few videos on Youtube, and some discussion on forums. Thus, in the process of learning a large amount of problems have been encountered.

Number of Photos

Canon EOS Rebel T3i Digital Single-Lens Reflex camera has a sub-frame sensor on it meaning that it has a smaller angle of view (by a factor of 1/1.6) than a full frame camera with any given lens. Any lens used on the Canon T3i will have the same field of view as one with a 1.6* greater focal length would when attached to a 35m camera. For example, a 100mm lens on the T3i will show the same field of view as a 160mm lens on a full frame camera. This means that the 18-55mm kit lens for the T3i has coverage roughly equivalent to that of a 29-88mm lens on a full frame camera (Imaging Resource, 2013). The author kept use the focal lens as 18mm which is roughly equivalent to 29 mm lens on a full frame camera to achieve wider field of views and reduce the amount of photos.

According to the table in Appendix I, a 28mm lens needs approximately 32 photos to generate a panorama. Because of the focus length the author uses, 29mm, is close to 28mm, the author firstly took 32 photos for the major hallway (shown in Figure 6) to run a test in the order shown in Appendix I. However, because of the width of major hallway section is very small, 4.9 feet approximately, which makes the camera is very close to the wall, and 32 photos cannot cover all the surface of the hallway. Thus, more photos have to be shot. Figure 5 is a top view showing the relationship between the camera and the walls of the major hallway. Figure 6 is a front view showing the result if the camera is too close to its target.

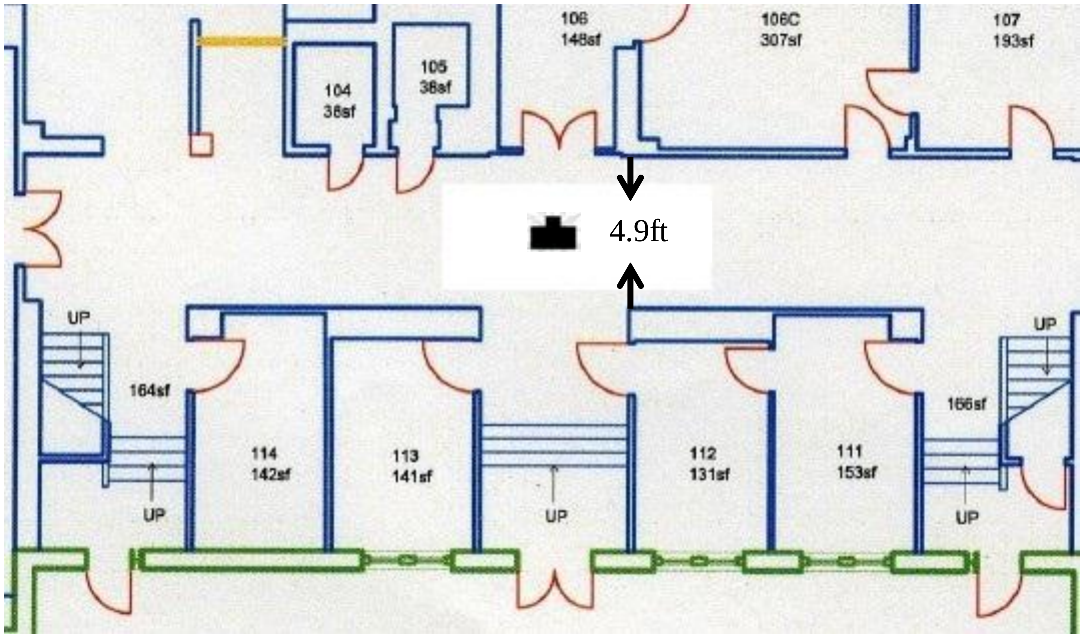


Figure 5 Relationship between camera and target wall

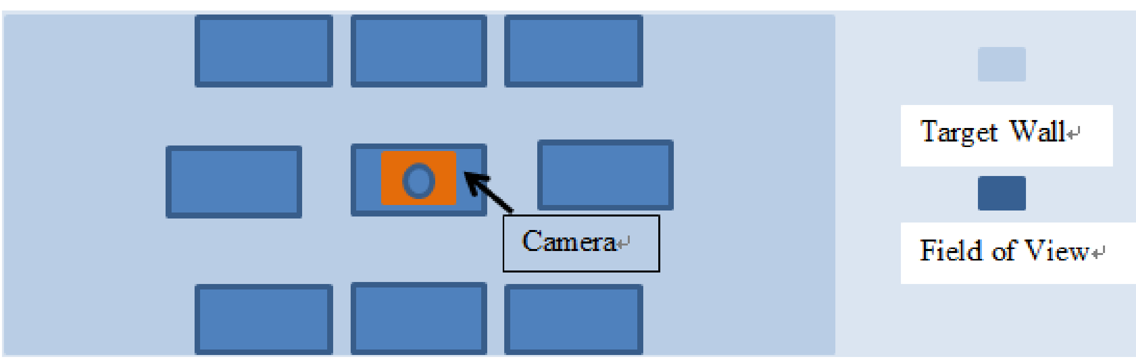


Figure 6 Front view of field of view

In order to cover the entire surface and achieve enough overlaps between photos of the target walls even they are close to the camera, the only way is to take photos of more rows instead of just three rows. Through multiple times of tries, the author took 4 rows of photos, and rotate the camera every 20 °within each row. Finally, instead of taking 32 photos, 72 photos have been shot.

In order to make sure the camera was neither tilted too much which could not cover the entire object, nor tilted too less which will lead to more pictures, the author used sticky notes which is very easy to be posted on the wall as a mark. Photos were shot from the top row. After taking the first row of images, a sticky note will be posted on the wall and close to the bottom of the field of view of the camera (Figure 7). Then the camera will be tilted down for certain degree. The sticky note will be near the top of the field of view after the camera was tilted down (Figure 8). The rest of photos and marks can be done in the same manner. For different size of different sections, the number of photos may change from time to time.

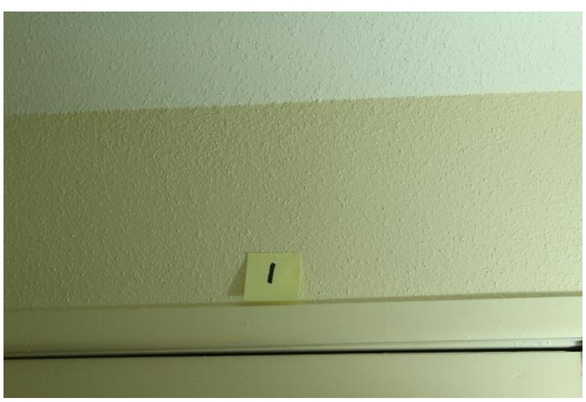


Figure 7 Sticky note marks on the wall before tilt camera

Figure 8 Sticky note marks on the wall after tilt camera

Targets Lack of Texture

Since the Department of Recreation, Park & Tourism Science moved out from Francis Hall, most stuff in its rooms has been moved out left only less-textured walls. However, the software, Autodesk Stitcher which will be used in the following step, requires texture of targets to generate panoramas. The software cannot automatically find the relationship between photos of target with no texture, thus these photos cannot be assembled to generate panoramas.

There were two ways that the author used to give some texture to those plain walls. One of them is to hang some paintings or posters which were left in the building to the wall, see Figure 9. Another way is to use sticky notes stick a regular pattern on the wall, see Figure 10. After taking photos and modeling for about 20 sections, the author consider using sticky notes is a better solution. Instead of using paintings and posters which could be hard to find a nail to be hung and heavy to be moved, a sticky note could be posted anywhere, and they are very light to be brought with.

Figure 9 Using painting and poster mark the wall

Figure 10 Using sticky notes mark the wall

Time Consumption

The time used for taking photos for each section has been recorded in the following table, Table 2. The time recorded includes time for tripod and camera setup, mark on the wall, take photos; problems met and solve, and use sonic laser tape measure get dimensions (width and length) of each section.

Table 2 Time consumption table for image-based system data acquisition

Section	Time Consumption (Minutes)	Number of Photos
Room 106	48	90
Room 106 A	18	108
Room 106 AA	20	90
Room 106 B	26	72
Room 106 C	7	77
Room 107	9	77
Room 109	14	54
Room 112	27	56
Room 113	18	108
Room 115	6	57
Room 153	5	57
Room 151	6	57
Stairwell	7	58
Hallway 1	8	77
Hallway 2	11	79
Hallway 3	8	59
Hallway 4	11	76
Hallway 5	9	90
Hallway 6	14	90
Major Hallway	6	77
Total	**278**	**1329**

The time consumption for taking photos of certain sections, such as Room 106 and Room 112, took much more time than other rooms. The reason for this relatively long time consumption is because of they are the first two rooms the author took photos. In order to make sure the set of photos could be used in the following step which is generating panoramas; several sets of photos have been shot to figure out the best way to give plain walls texture, and the number of photo needed. After finding out the best way to take pictures, the time consumption for taking photo of other sections is significantly shortened.

CHAPTER V

IMAGE PROCESSING

In this step, software called Stitcher produced by Autodesk is used to generate panoramas for each individual section using photos taken in the previous step.

In most cases, the software could successfully generate panoramas. However, due to the lack of texture and contrast of some of the walls, some photos cannot be stitched automatically. In order to overcome such situation, the author either manually stitched some of the photos or left the problem for this step and fixed it in the modeling step.

Five Phases to Generate Panoramas

There are five phases to generate panoramas in this particular application. They are loading images, stitch images, align the viewing horizon, equalizing images, and render and export panorama.

Loading Images

By clicking the Load Image button in the application, you could load one or multiple images into the application. After loading the images, the application will automatically read the EXIF information in the images and asks whether you want to keep the settings. In most cases the automatically calculated EXIF data, for example camera lens type and focus length, are correct. The author always used the automatically calculated data.

However, any operator should keep in mind to verify the EXIF information every time after a set of photo has been loaded. EXIF is short for Exchangeable Image File, a format that is a standard for storing interchange information in digital photography image files using JPEG compression. Almost all new digital cameras use the EXIF annotation, storing information on the image such as shutter speed, exposure compensation, F number, what metering system was used, if a flash was used, ISO number, date and time the image was taken, white balance, auxiliary lenses that were used and resolution. Some images may even store GPS information so you can easily see where the images were taken (Exifdata, 2013). An example showing some of EXIF data of Figure 13 is shown in Table 3. Figure 11 is one of the photos used to generate panorama for section Room 115. The reason for us to use the EXIF data is because of in order to successfully generate a panorama, some of the EXIF data of a set of images have to be the same and known, for example, the size in pixel, and focal length.

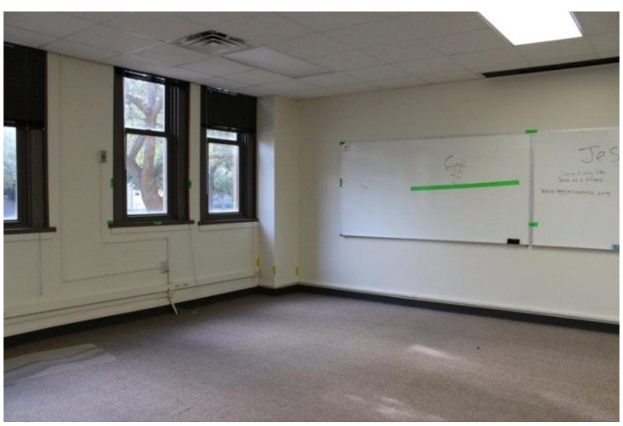


Figure 11 EXIF data example

Table 3 EXIF data table

Make	Canon
Model	Canon EOS REBEL T3i
Aperture	5.6
Exposure Time	1/125 (0.008 sec)
Lens ID	Canon EF-S18-55mm f/3.5-5.6 IS II
Focal Length	18 mm
Flash	Off, did not fire
File size	1200KB
File type	JPEG
Image width	1920
Image height	1280
Encoding process	Baseline DCT, Huffman coding
Bits per sample	8
Color components	3
Exposure mode	Manual
Exposure program	Manual
Saturation	Normal
Contrast	Normal
F number	5.6
Quality	Fine

Images Stitching

After loading images, next step which is the most important step is stitch all of the images together to generate a panorama. There are several four ways to stitch images together. They are automatic stitching, semi-automatic stitching, manual stitching, and force stitching.

Automatic stitching means Stitcher allows automatic stitching of all or a selection of images.

Semi-automatic stitching means that each individual image needs to be moved and rotated by the operator to overlap and align with each other. 15% overlapping of each image also needs to be ensured. The third image could start to be stitched, only after the previous two images are successfully aligned (Figure 12).

Manually stitching needs the operator put at least three corresponding points in the two images, Figure 13.

Force stitching is another option for images which cannot be automatically or semi-automatic stitched. You can move and rotate image to the satisfy position and select force stitching option without using corresponding points (Figure 14).

This will stitch the images precisely as you have placed them and do not require any matching points to be set.

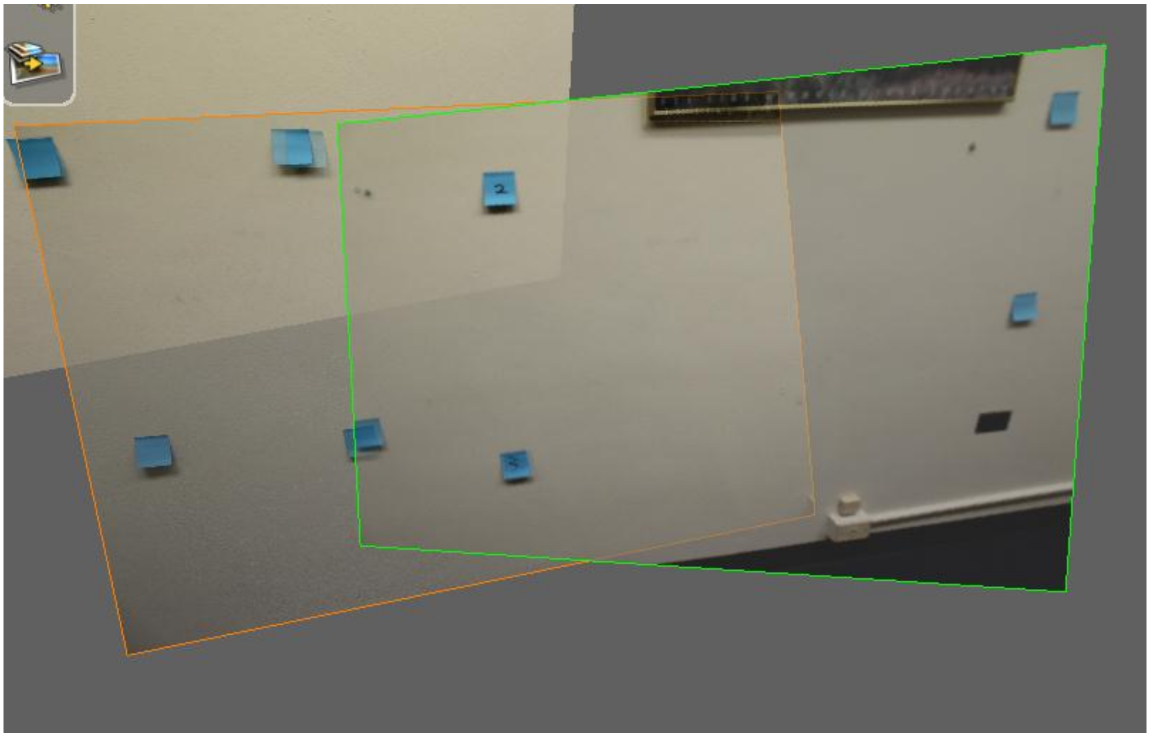


Figure 12 Image has been semi-automatic stitched

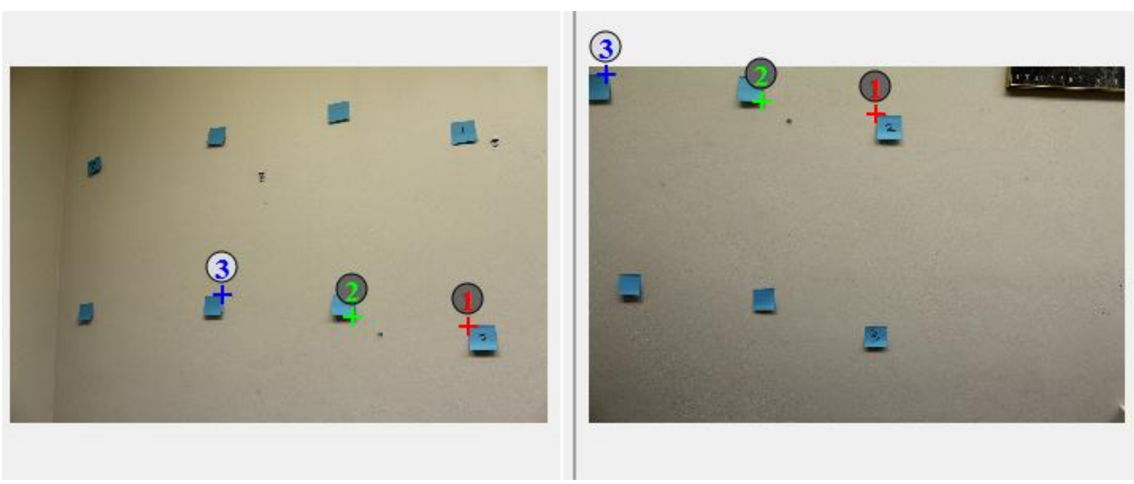


Figure 13 Place corresponding points in two images for manually stitching

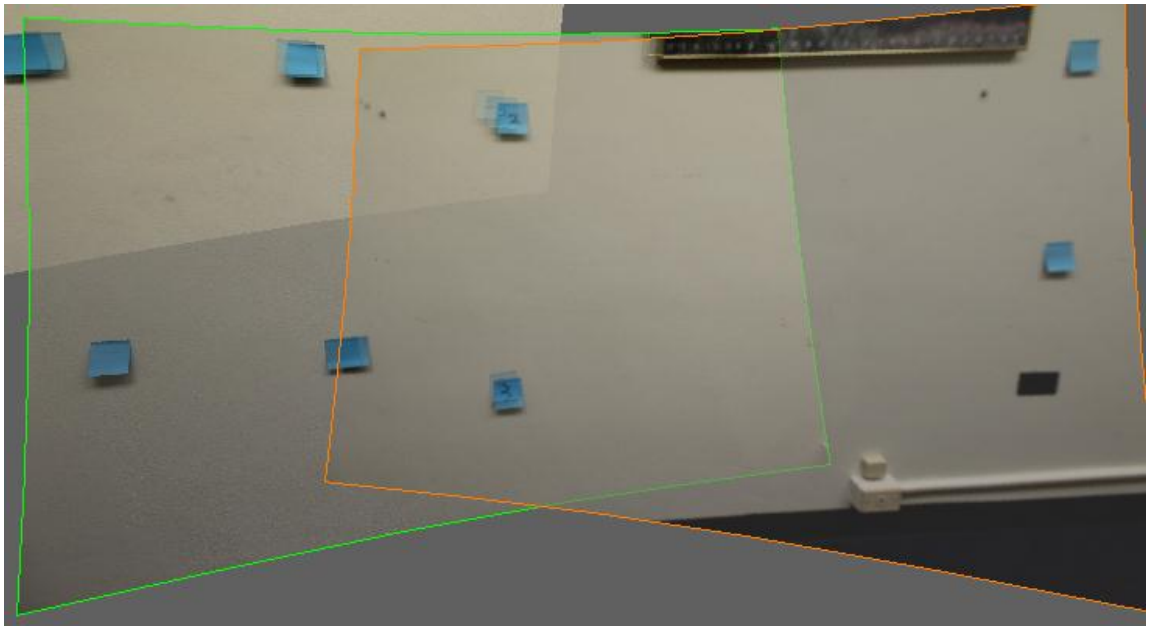


Figure 14 Force stitching an image

Aligning the Panorama

After stitching the images together, a panorama is already generated. Aligning the panorama could determine what could be seen in the final panorama. Stitcher aligns the panorama based on what is visible in the Stitching Window at the time the panorama is rendered (Autodesk Inc., 2008).

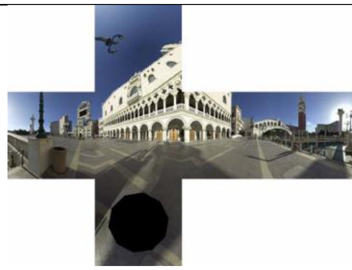
Lighting Equalization

Equalization is an optional phase during the generation of the panorama. It could make the image lighting more uniform for the panorama, if the images vary in their brightness or contrast (Autodesk Inc., 2008).

Rendering and Exporting

Rendering and exporting is the last phase to obtain a panorama. The type of projection to render the panorama should be chose depends on how it will be used (for example, the Web, film production, or product packaging) and whether or not you will edit the stitched images in an external graphics application. Table 4 shows a list of projection types, what are they look like, theirs features, and the use of each of them (Autodesk Inc., 2008). According the user guide of ImageModeler, it supports 4 types of panorama which are spherical images, cylindrical images, cubical images, spherical/cylindrical/cubical QTVR panoramas. The cubical QTVR panorama type was chose by the author, and the file type is .mov.

Table 4 Table of projection types

Projection type	Look	Feature	Use
Snapshot		Flat map; Maximum of 4 to 5 images	Creating images for the Web and for print
Cubical		Six images that correspond to the six sides of a cube	Good for rendering backgrounds in 3D scenes and for producing Cubic QTVR movies
Spherical		Single image	Printed panoramas, environmental maps for 3D packages, Java spherical viewer on the Web, cubic QTVR movies
Cylindrical/ Cubic QTVR		Cylindrical and cubical movies which can be viewed in QuickTime	Publishing panoramas on the Web or inclusion on a CD-ROM
Cylindrical		A row panorama w/o distorting top and bottom	Ideal for print or for creating Internet banners

Problem Met and Solutions

Automatic stitching is the most efficient way to stitch images in terms of time consumption and operation. However, the panorama could be generated with a hole, Figure 15, or closed imperfectly, Figure 16, if the automatic option is used.

Figure 15 Automatic stitched panorama with hole

Figure 16 Automatic stitched panorama closed imperfectly

The best solution for the situation above is to conduct the automatic stitching process again and see whether the result is better or not. If the result still cannot achieve the operator's expectation, semi-automatic stitching turns to be the best solution. The pro of this approach is that the operator could keep moving and rotating the images until he or she is satisfied.

In some cases, the automatically or semi-automatically stitching methods could fail and manually stitching is needed. The differences between semi-automatically stitching and manually stitching is that manually stitching needs the operator put at least three corresponding points in the two images. In most cases, the image that cannot be automatic stitched is because the images are lack of shared feature. Sometime it is also hard to find three corresponding points in two photos, and it takes time to locate three corresponding points accurately in two photos. Thus, in the author's point of view it is impractical when there are more than five images need to be manually stitched.

Another option for the images which cannot be automatic or semi-automatic stitched is force stitching. It is similar to semi-automatic process, and it is time-saving comparing with manually stitching.

There is no single approach that could bring the best result in terms of precise and time consumption. Automatic stitching will be conducted firstly. By reviewing the automatic result, the author then stitched the unstitched images semi-automatically or conducted force stitching. However, sometimes some images still cannot be stitched perfectly after these approaches. By evaluating the best result achieved, the operator could either go back and retake more images for the section, or leave the deficiency and try to fix it in the future steps or make logical assumption while making 3D model.

Time Consumption

The time used for stitching images for each section has been recorded in the following table, Table 5.

Table 5 Time consumption table for image processing

Section	Time Consumption (Minutes)	Number of Photos
Room 106	53	90
Room 106 A	32	108
Room 106 AA	85	90
Room 106 B	32	72
Room 106 C	16	77
Room 107	18	77
Room 109	27	54
Room 112	9	56
Room 113	67	108
Room 153	8	57
Room 151	25	57
Room 115	15	57
Stairwell	10	58
Hallway 1	17	77
Hallway 2	16	79
Hallway 3	18	59
Hallway 4	17	76
Hallway 5	66	90
Hallway 6	47	90
Major Hallway	19	77
Total	**597**	**1329**

After run several tests with section Room 106, the author found out that most deficiencies of the panorama could be eliminated during the modeling process. Thus, the time consumption for all the other sections is relatively less than the time consumption for section Room 106. The way that the author used will be introduced in the next chapter.

CHAPTER VI

3D IMAGE-BASED MODELING

3D image-based modeling is the most comprehensive step in this modeling process. It not only includes sectional modeling, but the assembly of sectional models as well. Multiple software is used in the step. They are Autodesk ImageModeler 2009 for sectional modeling, Autodesk 3Ds Max for changing the file type, and Autodesk Navisworks for sectional models assembly.

Sectional Modeling

Five phases are needed to deliver a textured 3D sectional model within this modeling process. They are loading image, image calibration, modeling, texturing, and export.

Loading Image

The first step to create a new project is loading images. Either a single image or a set of images could be loaded into the software. A single image could be either a 360° panorama, or a normal shot. A set of images could be either normal shots, or a mix of normal shots and panoramas (Autodesk, Inc., 2009). In this specific research only single panoramas are used.

Cameras Calibration

After a panorama is loaded into the 3D workspace, the project is needed to be calibrated. The reason for the step of calibration is to define a 3D space. The 3D model will be created, evaluated, and modified in that defined 3D space. In order to define a 3D space, a Calibration Triedron, at least one Helper Axis (Figure 17), and the length of X Axis are needed. The Triedron is composed of three orthogonal axes, and it is used for defining a world coordinate system. Three Calibration Helpers are available in ImageModeler to help define the 3D space. They are Calibration Helpers for X Axis, Y Axis, and Z Axis (Autodesk, Inc., 2009). The length of X Axis is used for scaling the world space to right size.

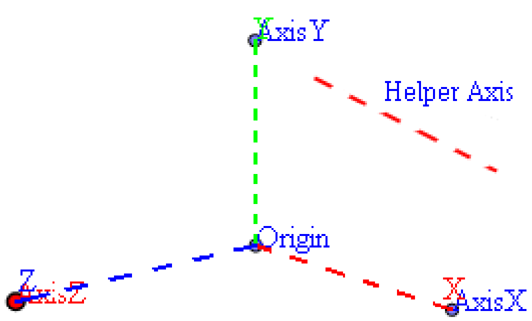


Figure 17 Calibration triedron and helper axis

To calibrate a panorama, the first step is to select an origin point of your coordination system. The origin point should be placed at an easy-defined and clear corner where the three axis meet at, and it would be good to choose the edges of walls as axis (Figure 18).

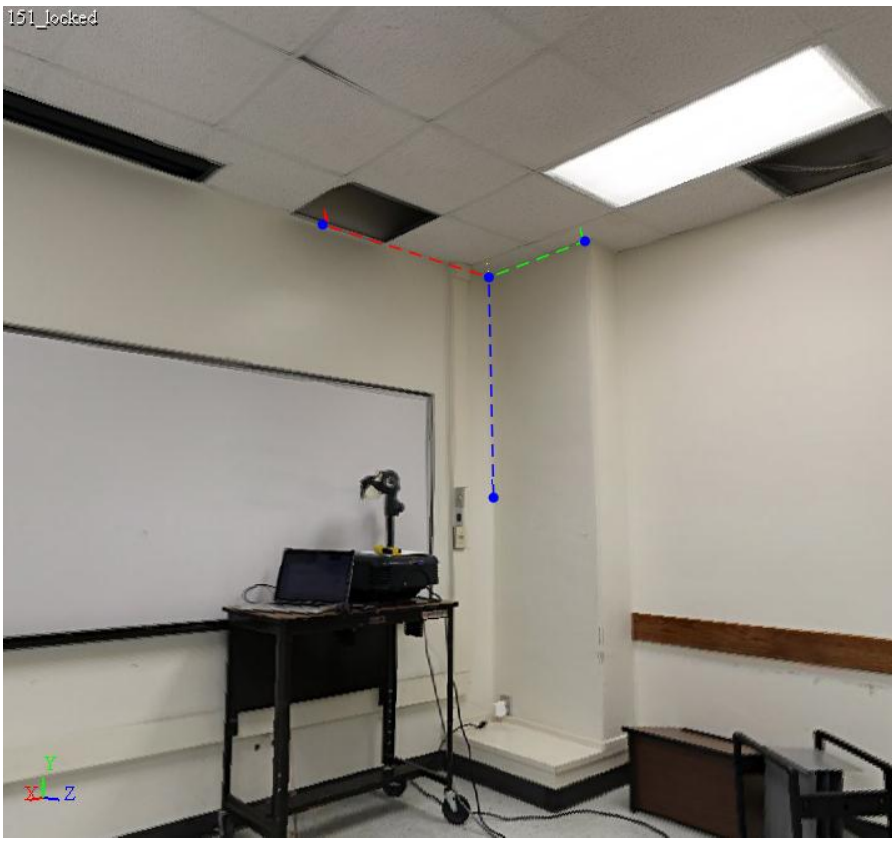


Figure 18 Origin point selection

After selecting the origin point and put the three axis, at least one Axis Helper is needed to achieve an accurate coordination system, and the helper should be placed parallel to its associate axis (Figure 19). The first helper axis that the software will ask the operator to add is Calibration Helpers for X Axis. Thus, choosing the clearest edge as the X axis never fails to be a good idea.

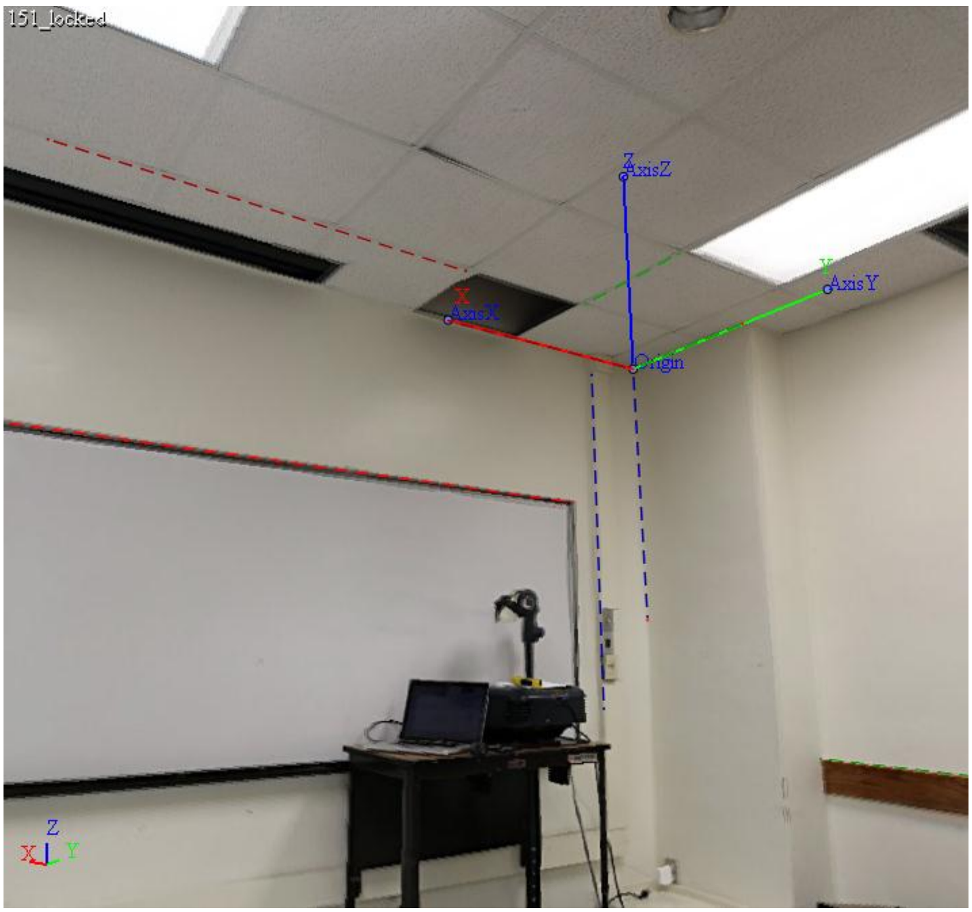


Figure 19 Adding axis helpers

The software will also ask to input the X Axis length. The length should be measured while taking photos, or you have to go back to the site to get the dimension, except you have a good set of drawings, and dimensions could be retrieved from it. The operator needs to remember which dimension he or she recorded and set it as Axis X. However, if you already have an as-built drawing of your object, this step (inputting length of X Axis) could be eliminated, and your image-based model could be scaled to right size in other software, such as Navisworks.

Modeling

In ImageModeler, creating 3D model is the process of creating shapes and forms on screen using one or more types of geometry which is called polygon mesh. A polygon mesh is comprised by connected polygons. A polygon consists of three or more points connected by lines that create a shape. A polygon can be three-sided, four-sided, or many sided.

In this research, the author usually starts creating the model from the origin point of the 3D space (Figure 20). The author uses the function of Create Face for model of walls (Figure 21), roof, and floor; uses Primitive for model of column (Figure 22); uses Split Face to cutting a hole for doors (Figure 23); and uses Extrude Face to model the door frames (Figure 24).

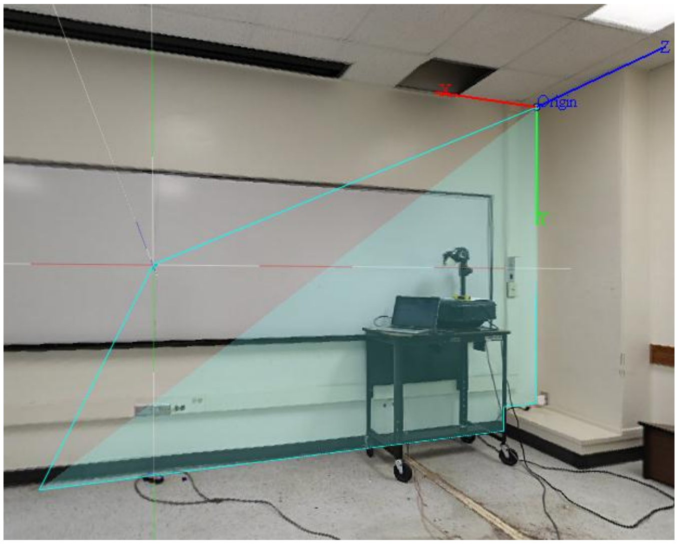


Figure 20 Create face

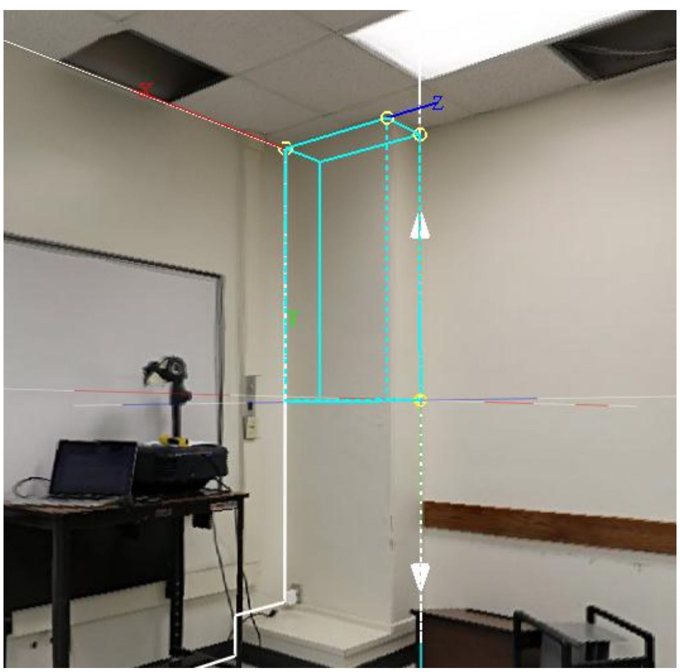


Figure 21 Create primitive

Figure 22 Split face for door

Figure 23 Extrude face for door frame

All of the lines of faces and primitives (except room section 106 AA) are drawn parallel to the axis. In other words, axis has priority than panoramas. This is simply because of the texture which will be retrieved from panorama could be edited and modified in the following step. Furthermore, modeling according to axis could ensure that every sectional model would be in the right shape, even though the panoramas are not perfect (Figure 24).

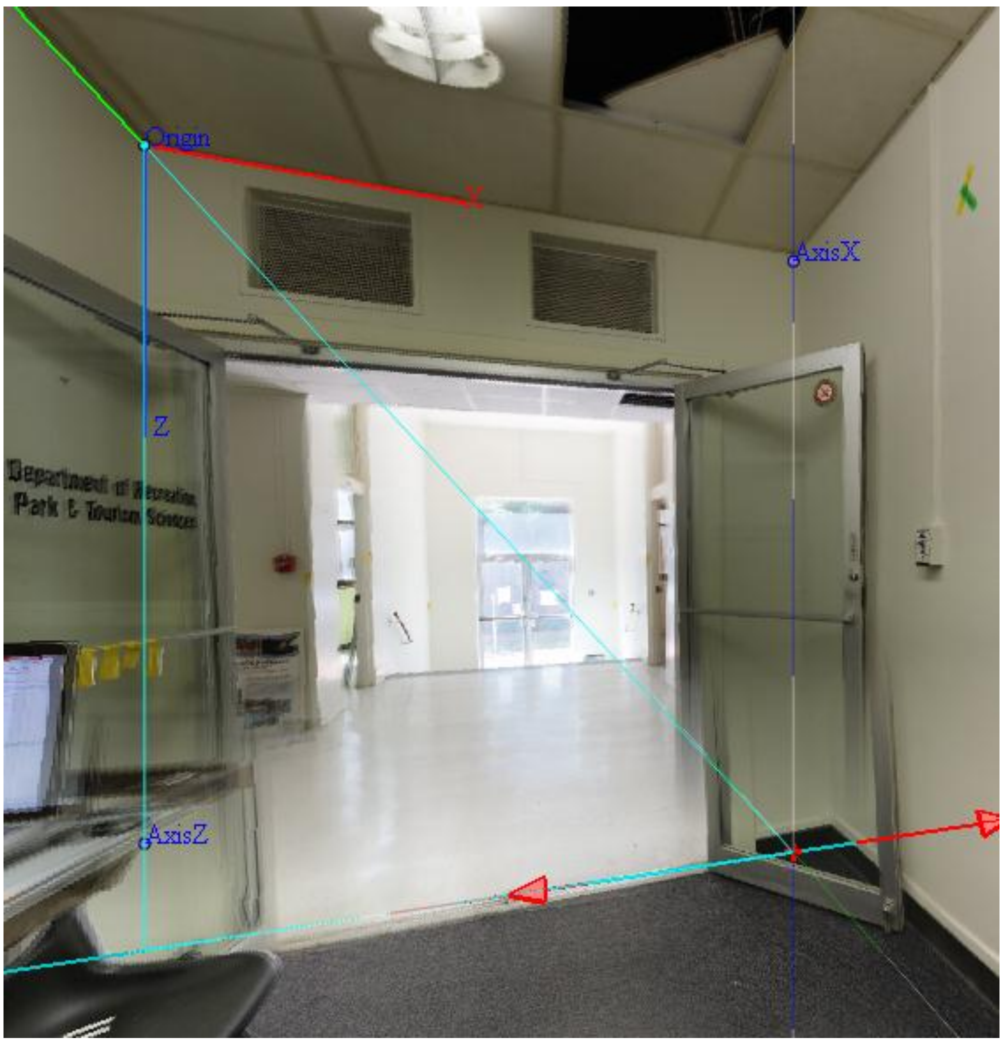


Figure 24 Draw lines according axis

Texturing

You apply a material to the surface of a model in a process called “texturing”. ImageModeler can extract a texture from a 2D image and apply it to a model. By default, projects have a single material with a default color and this material is automatically assigned to all faces. When you extract textures from photographs (or assign an RGB color), ImageModeler creates a new material and assigns it to the model’s faces (Autodesk, Inc., 2009).

The main steps in the texturing workflow are: create the mapping group for each object, edit UV mapping (optional), extract textures, and edit textures in an external 2D application (optional) (Autodesk, Inc., 2009).

The mapping group could be a face, a primitive, or a combination of them. The author usually only chooses either a face or a primitive to project the mapping group. The mapping group could be planar, cubical, cylindrical, or spherical which is depended on the shape of the target object (Figure 25) (Figure 26).

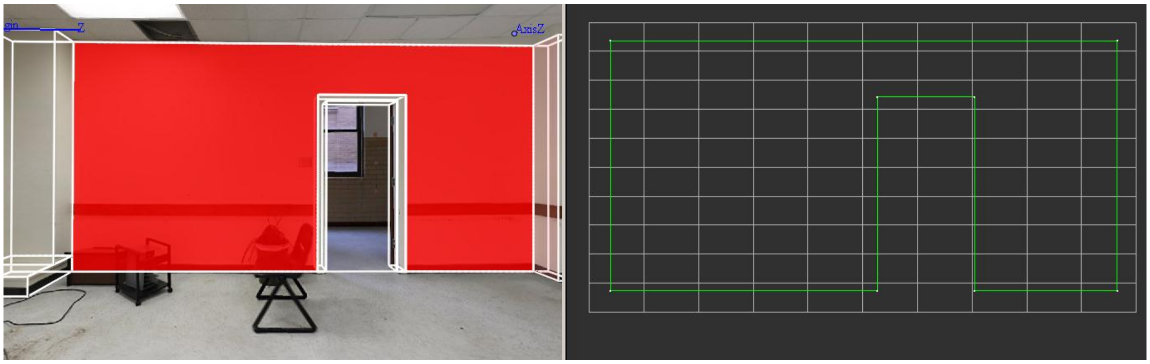


Figure 25 A planar UV mapping group

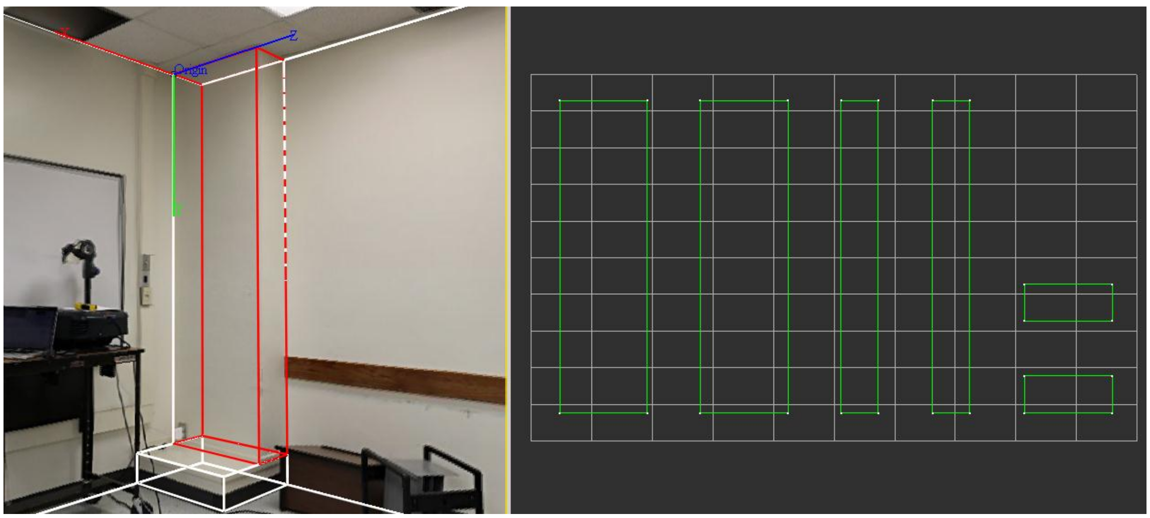


Figure 26 A cubical UV mapping group

The operator could edit the UV mapping in the means of normalize, rotate, and flip etc. The need of edit is depended on the mapping result. The software may generate the map in a wrong direction, or a wrong size. Then, the edit is needed.

Extracting textures means deform or blend calibrated images to create textures (Autodesk, Inc., 2009). The only things an operator needs to do to retrieve textures are select the way to compute texture size which includes best, custom, and density, and the extraction mode. The author usually chooses texture size computed by density with 500 pixels per surface unit. The result is shown in Figure 27.

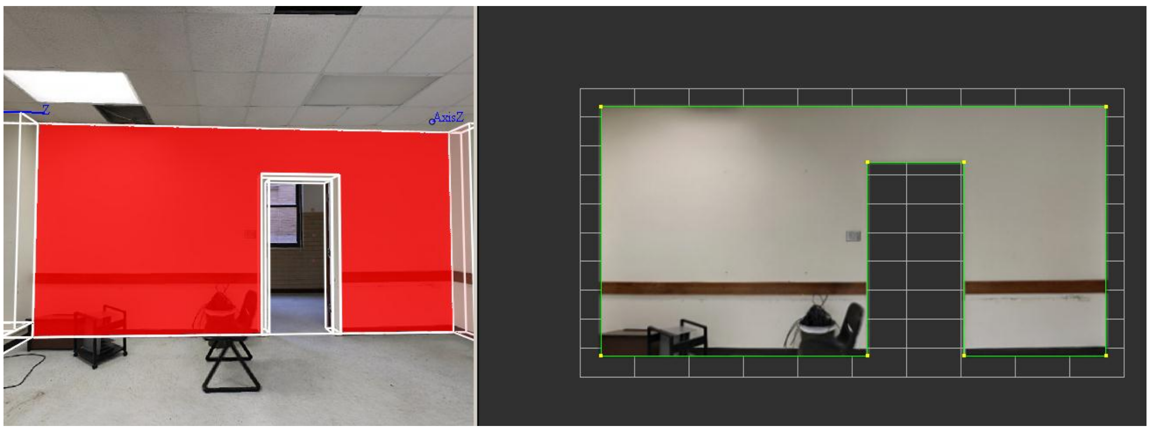


Figure 27 Extracting texture from panorama

The textures could also be edited in an external 2D application, such as Photoshop. However, the author never used an external editor to edit texture.

Export

The ImageModeler export feature allows you to export files in a number of popular formats (in *.dwg, *.fbx, and *.ma), as well as allowing you to export only selected objects (in *.rzi and *.obj formats) (Autodesk, Inc., 2009).

The author usually exports *.fbx file which could be viewed and edited in some popular applications, such as AutoCAD, Autodesk 3ds Max, and Navisworks, etc. A set of *.jpeg files also will be exported together with the *.fbx file.

Changing the File Type

Navisworks could only open the *.fbx file without texture. the author used Autodesk 3ds Max exported *.nwc file from *.fbx. Each *.nwc file consists not only a *.nwc file, but a folder of presenter maps (*.jpeg files) of the sectional model as well. The reasons for the author to choose Navisworks as the application assembling the sectional models are: firstly, it is easy to conduct a walkthrough in Navisworks; secondly, Navisworks could help edit (rotate, move, scale, etc.) the sectional model very efficiently; thirdly, the selection tree in the application could help the author choose any component of any model very easily.

Sectional Models Assembly

The author used Autodesk Navisworks to assemble all the sectional models into an integrated 3D textured model of the first floor of Francis Hall interior. An existing AutoCAD drawing was firstly loaded into Navisworks as a template to locate each sectional model. A sectional model will be appended to it, and the model will be scaled to the right size according to the dimensions measured with the sonic laser tape measure.

Then, the sectional model will be rotated and moved to the right location according to the drawing (Figure 28).

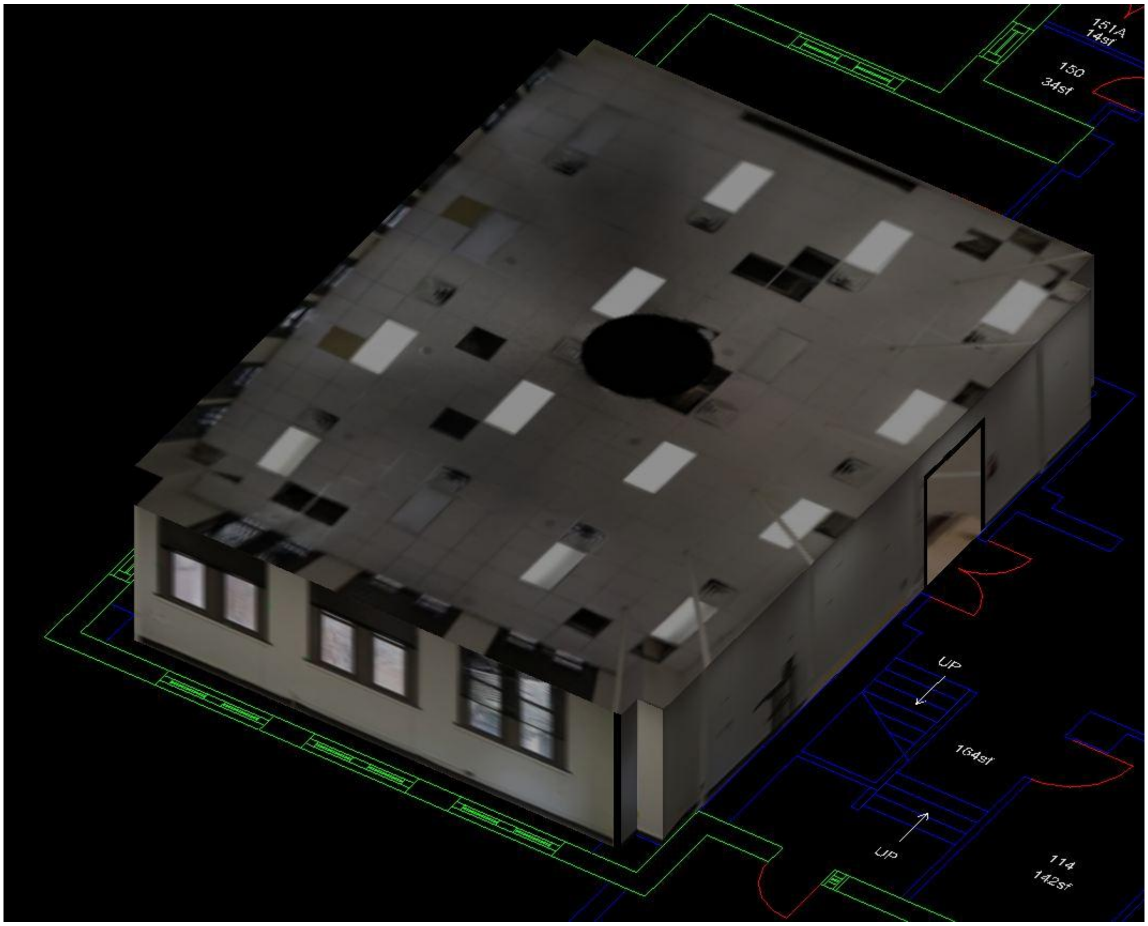


Figure 28 Locate a sectional model according existing CAD drawing

The author assembled the integrated model not only depended on the CAD drawing, but also the texture of two conjoint sectional models, the edges of two conjoint sectional models, and door frame, etc. There is no single way that the models could be assembled perfectly. While assemble the sectional models the operator needs to compare the results from different assemble approaches, and select the best one. The final result of the author's integrated model is shown in Figure 29.

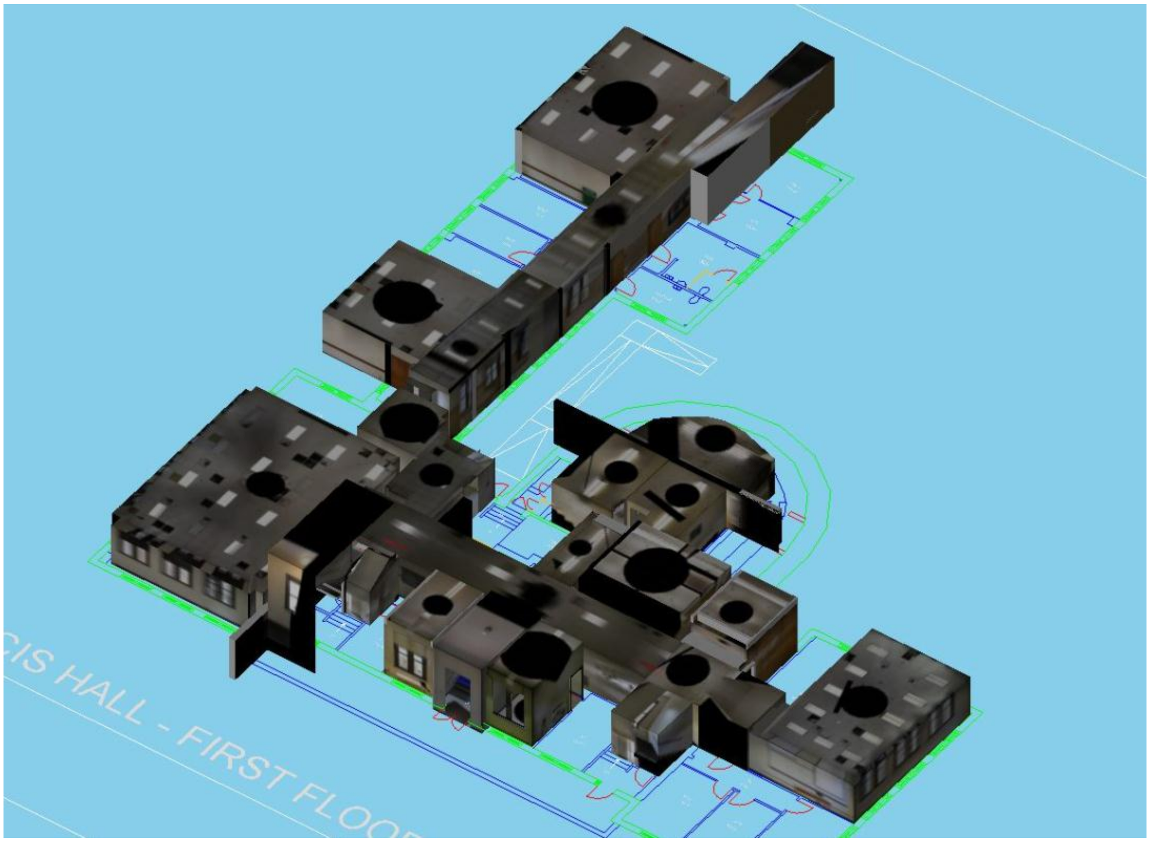


Figure 29 An integrated model

Problem Met and Solutions

Several problems have been met while the author was trying to generate sectional models. Problems could be categorized into problems for camera calibration, problems for modeling, and problem for texturing.

Even though the origin point and the edges of walls are clear, sometime the calibration accuracy is still very low and cannot be fixed no matter how many axis helpers have been added. Figure 30 is an example of section Hallway 6 showing the problem of low calibration accuracy. In the picture there are one Calibration Triedron and four calibration axis helpers. However, the calibration accuracy was 61.569%, and no matter how many helpers were added the accuracy was never exceed 71%.

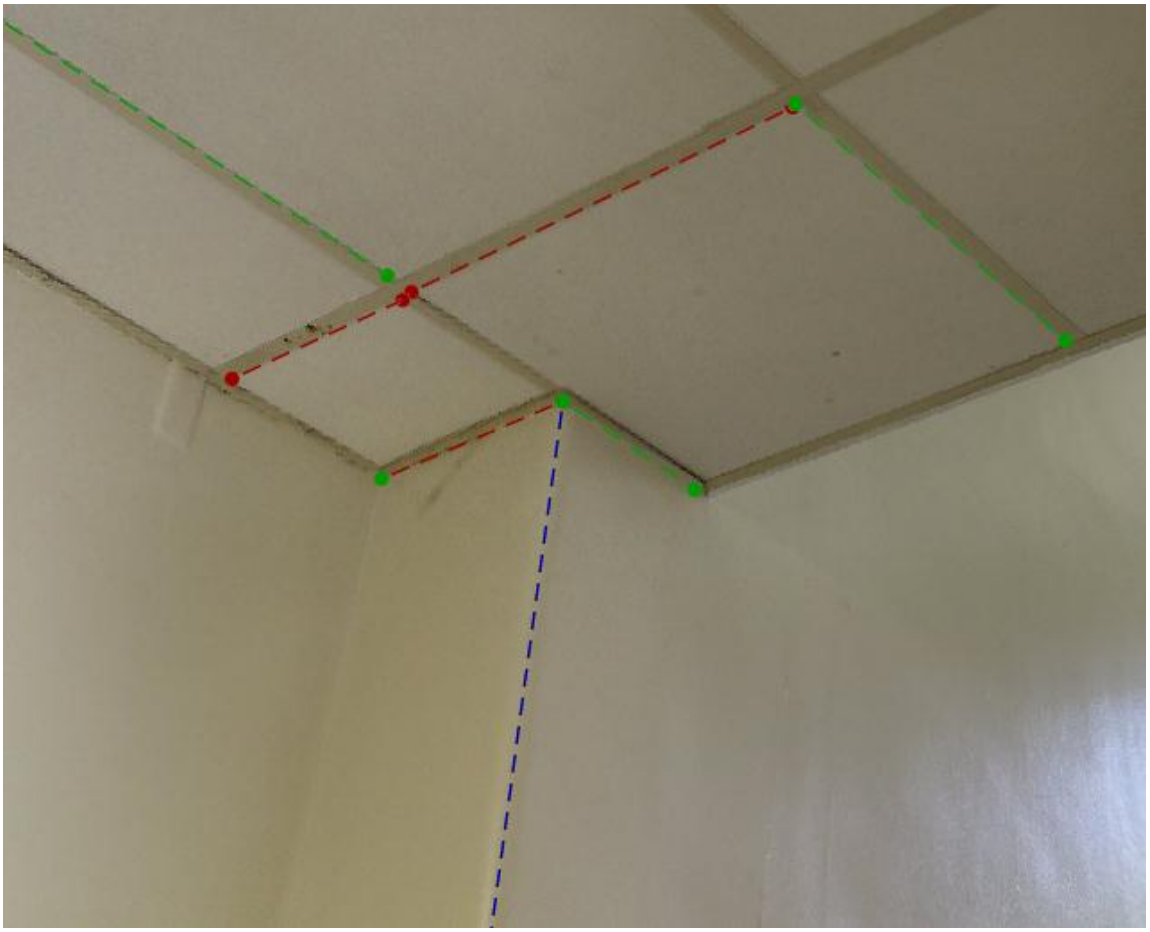


Figure 30 Coordination system with very low calibration accuracy

The author's solution is deleting all the previous axis and helpers, and picking a new origin point to set up a different calibration system. Figure 31 shows that the author picked another point on the other side of the hallway as the origin point, and set up the axis and added only two X axis helper. The calibration accuracy for the new condition system is 99.1608%.

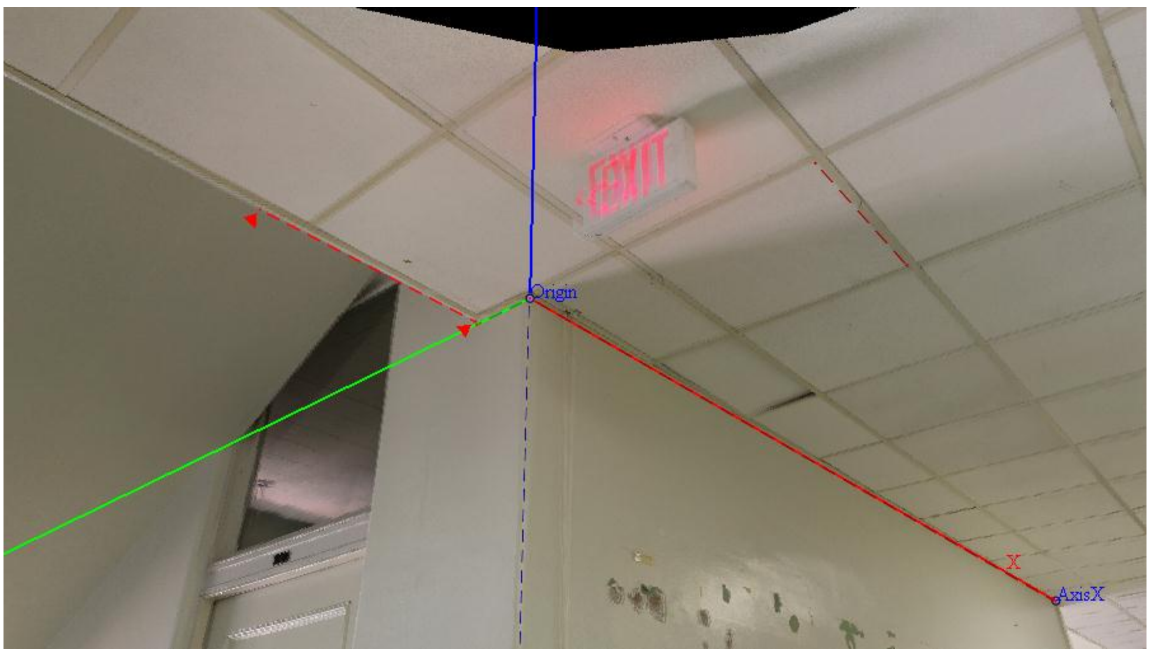


Figure 31 Setting up a new calibration system

Problems also have been encountered while the author was generating some of the sectional models. As it has been described before the axis has priority than panorama while the sectional model was created. However, the 3D geometry model may be not fit to the texture in panorama (Figure 32), and the model cannot be closed sometimes (Figure 33). In the author’s point of view this is because of the distortion of the panorama. Figure 34 is showing the bottom of section Room 151’s panorama; it is obviously that the panorama is distorted.

Figure 32 Geometry model does not fit to texture of panorama

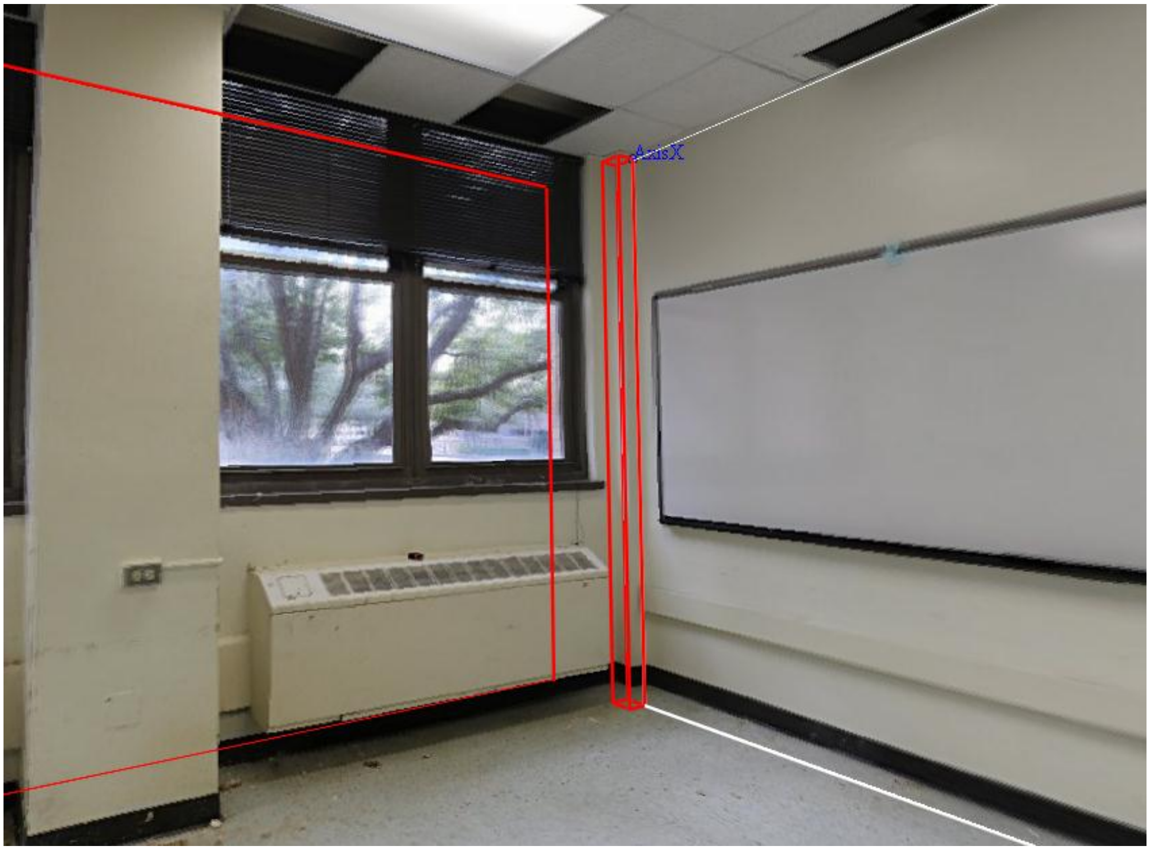


Figure 33 Sectional model cannot be closed

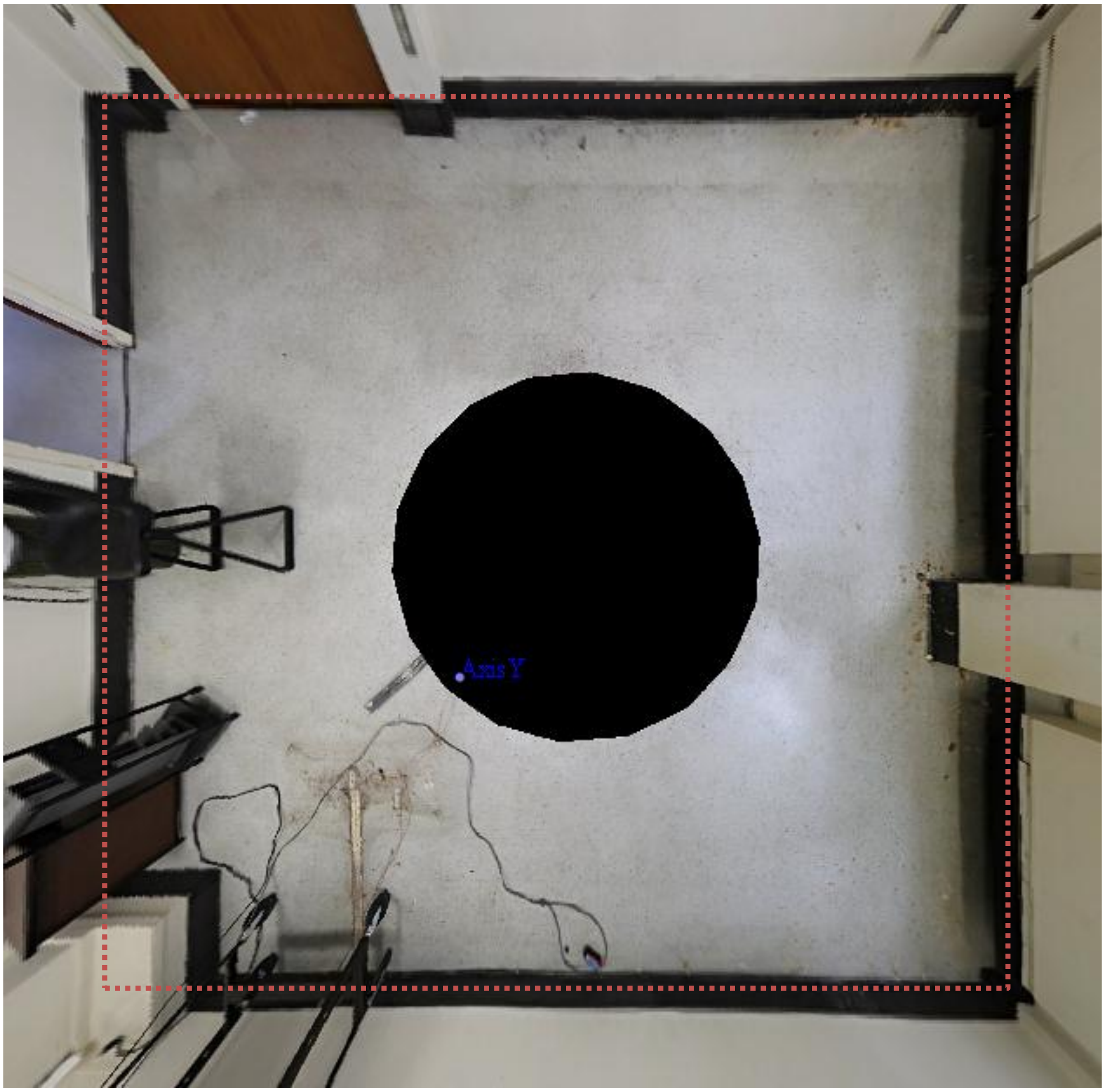


Figure 34 Distorted panorama

It is relatively easy to fix the texture problem and it will be introduced later. Let us focus on how to close the model for now. Firstly, all the faces and primitives need to be drawn according to axis. The author used wall A (Figure 35) on which has two axis as the reference, and drawn wall B according to wall A and make sure they have the save length and height. Then, wall C could be drawn to connect wall A and wall B. Even though the three axis have absolutely priority than panorama, the author was still try his best to obey both of them while creating 3D models.

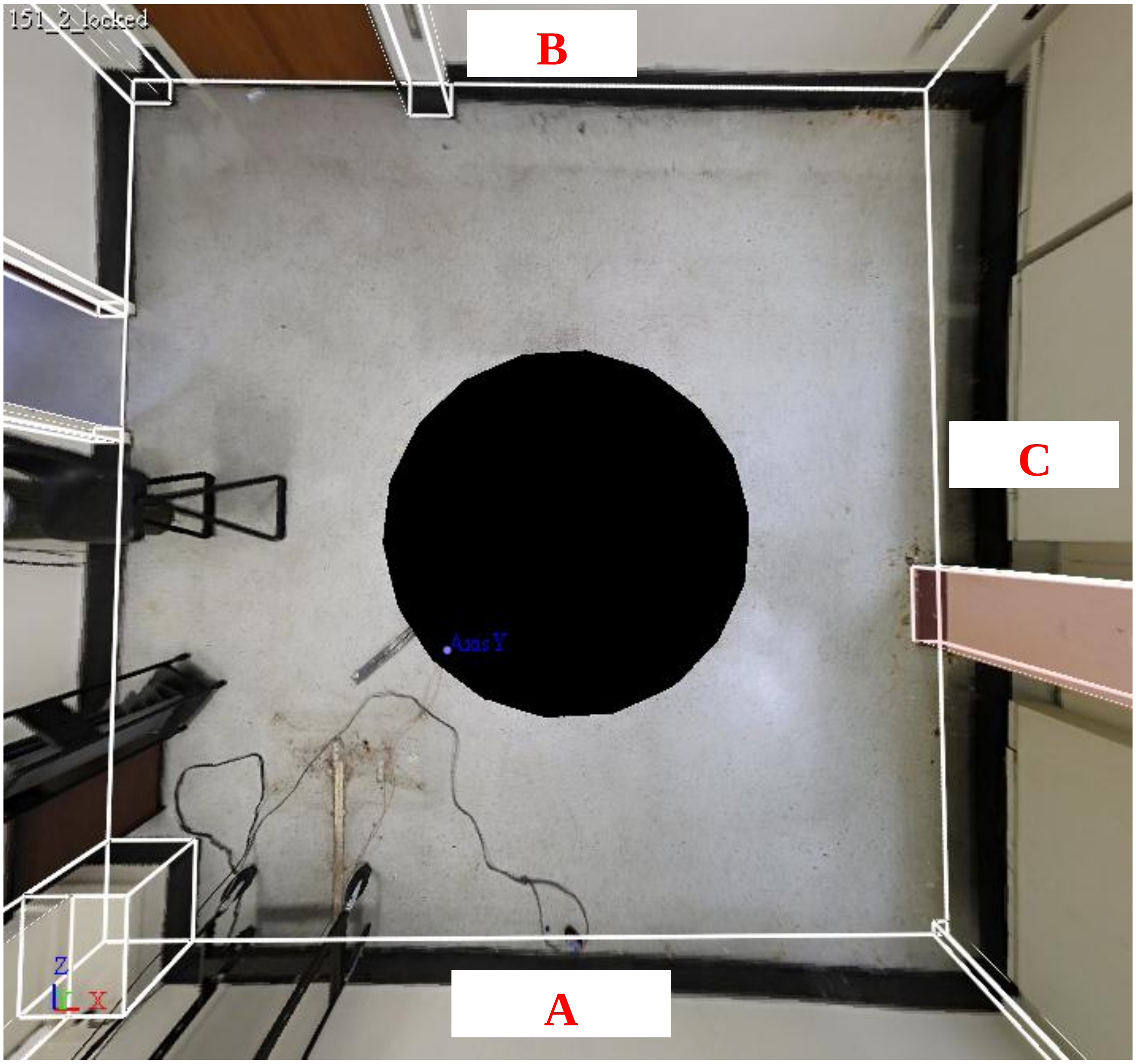


Figure 35 Closed 3D geometry model

Another problem has been met while the author was trying to modeling section Room 106 AA which is a semicircular room. This is the only section without a rectangular shape. The author started modeling with the flat wall and the columns attached to it. Then, the author started to model the semicircular staircase. After tried several time with cylinder and circle tools in primitives, they are considered to be not good for the stair modeling, because the cylinder and circle are hard to be used and the shape created is not satisfied. Following is the way that the author generated the model of the semicircular stair. First, create a floor plane according to the existing wall model. Second, split the floor plane according to the edge of first level stair (Figure 36), and delete unwanted part. Third, repeat first and second step to create a surface for top of first level stair (Figure 37). Forth, create faces to connect the surfaces just created (Figure 38). Fifth, repeat the previous steps and finish all this room.

Figure 36 Splitting the floor plane

Figure 37 Create a surface for top of first level stair

Figure 38 Faces connect two level planes

As introduced before, in certain models the panorama cannot fit the model perfectly. This problem could be fixed by utilize a function which is call Capture Pattern within ImageModeler. Use wall C in Figure 35 as an example. The only thing that an operator needs to do is to select the capture pattern function and creates the right shape to cover the pattern needed (Figure 39), and drags the captured pattern to the relevant face. However, the operator needs to notice that the capture pattern function could only capture rectangular shape.

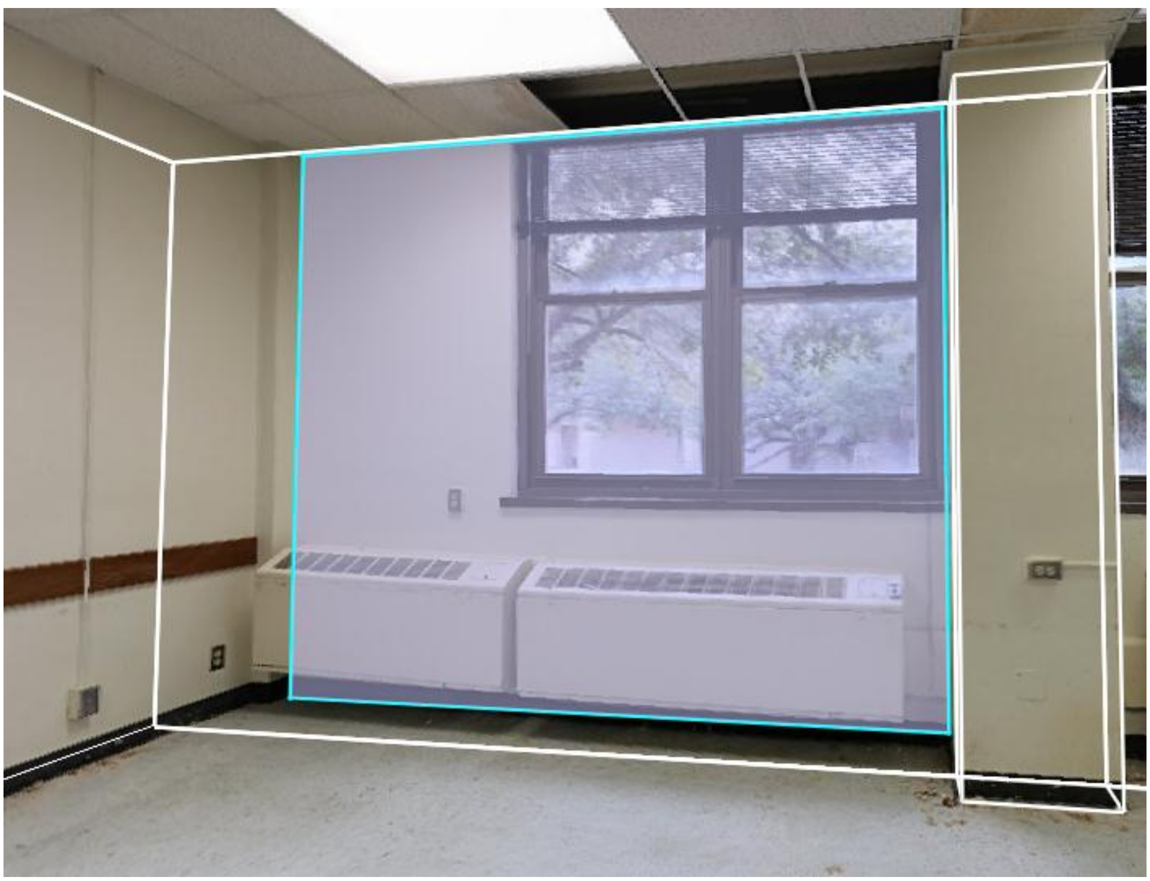


Figure 39 Capture pattern for face with wrong texture

Time Consumption

The time used for 3D image-based modeling for each section has been recorded in the following table. In Table 6 time consumption for Modeling includes time for calibration and modeling; time consumption for Texturing includes time for texturing and export files. The time consumption for scaling and assembling all sectional models was 187 minutes.

Table 6 Time consumption table for 3D image-based modeling

	Time Consumption (Minutes)		
Section	Modeling	Texturing	Total
Room 106	27	8	35
Room 106 A	55	19	74
Room 106 AA	260	25	285
Room 106 B	13	15	27
Room 106 C	45	26	71
Room 107	20	150	170
Room 109	40	11	51
Room 112	15	29	44
Room 113	26	13	39
Room 151	46	20	66
Room 153	13	28	41
Room 115	20	42	62
Stairwell	20	25	45
Hallway 1	75	12	87
Hallway 2	38	30	68
Hallway 3	20	15	35
Hallway 4	10	5	15
Hallway 5	38	21	59
Hallway 6	38	10	48
Major Hallway	49	20	69
Total	**848**	**524**	**1372**

CHAPTER VII

3D MODEL ASSESSMENT

The assessment of the 3D model will be divided into two phases. They are difference comparison and interviews.

Difference Comparison

The dimensions of 3D sectional models generated using photos are compared against the existing CAD drawings provided by the University repository. Although the existing drawings may not well represent the as-built conditions of the building, the comparison is still considered worthy to provide-evidences. A total of 38 items in the building were measured either in the image-based 3D model or existing drawings. The measurement of these items and the difference between them are shown in the following Table 7. The measurements include width and length of each section.

Following equations are used in Table 7:

Difference (inch) = CAD drawing (inch) – Image-Based Model (inch)

Difference (%) = Difference (inch) / CAD drawing (inch) x 100

Table 7 Table of raw data comparison

NO.	Measured Item	Image-based modeling (inch)	CAD drawing (inch)	Difference (inch)	Difference (%)
1	106 W	94.09	94.20	0.11	0.11%
2	106 L	198.82	197.50	-1.32	-0.67%
3	106 A W	129.92	147.22	17.30	11.75%
4	106 A L	172.83	186.78	13.95	7.47%
5	106 B W	140.94	139.20	-1.74	-1.25%
6	106 B L	182.28	186.78	4.50	2.41%
7	106 C W	223.62	221.00	-2.62	-1.19%
8	106 C L	194.09	201.00	6.91	3.44%
9	107 W	143.31	138.00	-5.31	-3.85%
10	107 L	201.57	201.00	-0.57	-0.29%
11	109 W	280.31	281.00	0.69	0.24%
12	109 L	388.98	386.50	-2.48	-0.64%
13	112 W	110.24	109.92	-0.32	-0.29%
14	112 L	188.19	171.70	-16.49	-9.60%
15	113 W	107.09	116.62	9.53	8.17%
16	113 L	172.83	172.96	0.13	0.07%
17	115 W	336.22	336.28	0.06	0.02%
18	115 L	460.24	446.44	-13.80	-3.09%
19	151 W	243.70	252.48	8.78	3.48%
20	151 L	255.12	256.30	1.18	0.46%
21	153 W	257.48	252.48	-5.00	-1.98%
22	153 L	365.75	365.40	-0.35	-0.10%
23	Hallway 1 W	101.57	96.00	-5.57	-5.81%

Table 7 Continued

NO.	Measured Item	Image-based modeling (inch)	CAD drawing (inch)	Difference (inch)	Difference (%)
24	Hallway 1 L	439.37	439.60	0.23	0.05%
25	Hallway 2 W	97.64	96.00	-1.64	-1.71%
26	Hallway 2 L	494.09	358.80	-135.29	37.71%
27	Hallway 3 W	141.73	145.90	4.17	2.86%
28	Hallway 3 L	143.31	142.06	-1.25	-0.88%
29	Hallway 4 W	143.31	139.44	-3.87	-2.77%
30	Hallway 4 L	216.54	214.50	-2.04	-0.95%
31	Hallway 5 W	155.12	153.00	-2.12	-1.38%
32	Hallway 5 L	126.77	123.92	-2.85	-2.30%
33	Hallway 6 W	123.23	123.92	0.69	0.56%
34	Hallway 6 L	150.00	132.92	-17.08	12.85%
35	Major Lobby W	621.65	600.32	-21.33	-3.55%
36	Major Lobby L	122.44	123.92	1.48	1.19%
37	Stairwell 2 W	96.46	120.48	24.02	19.94%
38	Stairwell 2 L	105.12	102.50	-2.62	-2.55%

According to the table above, the mean (μ) and the standard deviation (σ) of all differences are 0.87% and 8.14% respectively. A statistical quality control method which is called 6 Sigma is employed by the researcher. 6 Sigma was a term which firstly used by Motorola Inc. 6 Sigma means that less than 3.4 defects per million opportunities, and almost achieved perfect. In most company, the defect rate is range from three to four sigmas meaning that 6210 defects per million opportunities (Baidu, 2013).

The researcher used four sigmas to eliminate the outliers of errors (Figure 40), meaning that differences which fall out of the range of $\mu \pm 2\sigma$ meaning will be eliminated and 95% of the following analyses will be right.

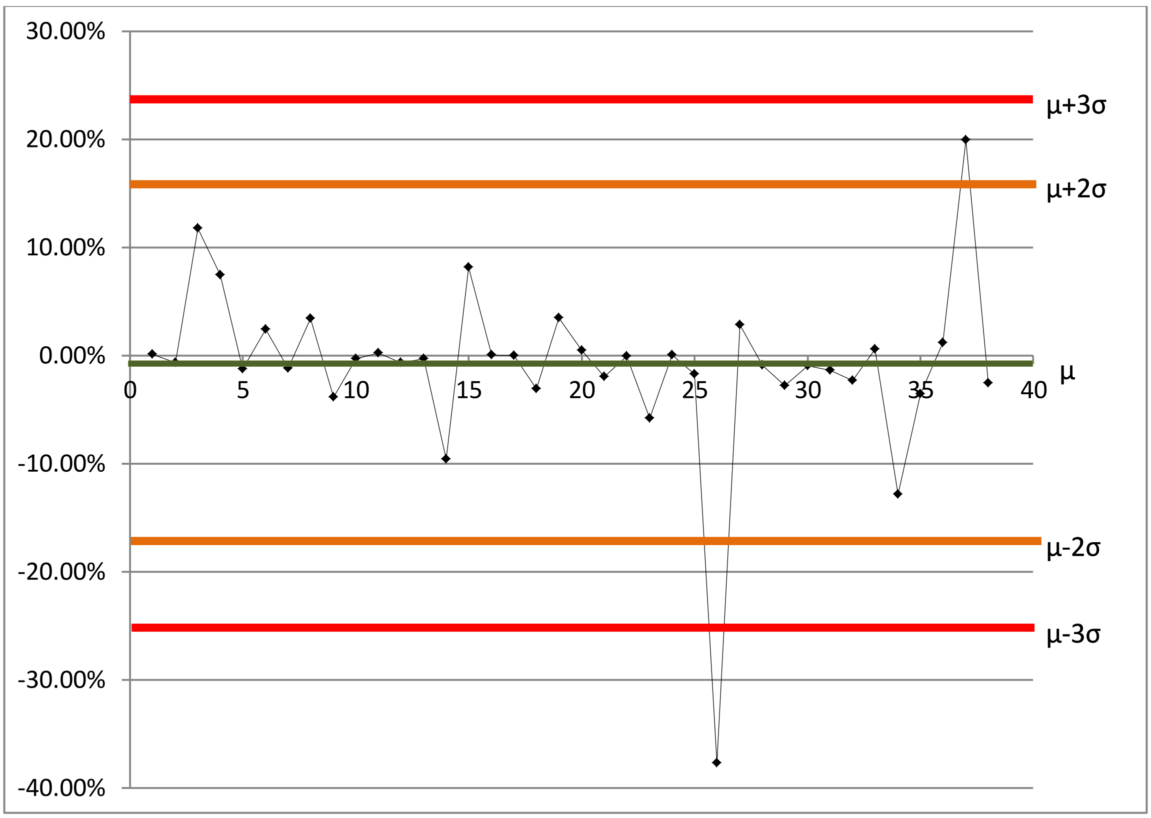


Figure 40 Chart for 6 sigma analyses

After eliminating the outliers, the mean and standard deviation are -0.43% and 4.33% respectively. Then, the dimensions are grouped into four groups which are 0<X1<150, 150<X1<250, 250<X1<400, and X1>400. Then the author calculated the mean and standard deviation for each group. The result is shown in the following Table 8. The result shows that when a length of a section is less than 150 inches or more than 400 inches the accuracy level of the model drops. The reason for this inaccuracy may result in the distortion of panoramas, or the operator's mistakes when creating the model using panoramic photos.

Table 8 Mean and standard deviation for groups by dimension

	Mean	STD
0<X<150	-0.01	0.06
150<X<250	0.00	0.04
250<X<400	0.00	0.01
X>400	-0.02	0.02

The author also analyzed the data with a different grouping method which is grouping according to the shape of the section. The shape of a section is defined by X2 which is equals to the longer dimension divided by the shorter dimension of a section. The groups are: 1<X2<1.3, 1.3<X2<1.5, 1.5<X2<2, and X2>2. The result is shown in the following Table 9. The result means that the shape of a section may not influence the accuracy of 3D model generated from photos.

Table 9 Mean and standard deviation for groups by shape

	Mean	STD
1<X<1.3	-0.01	0.04
1.3<X<1.5	0.01	0.05
1.5<X<2	-0.01	0.06
X>2	-0.01	0.03

Interviews

Interview Organization

A phenomenological study which is defined as a study that attempts to understand people's perceptions, perspectives, and understandings of a particular situation (Leedy, 2005) is employed in this research to evaluate the acceptability of the 3D model generated from photographs through phenomenological study. A typical sample size for a phenomenological study is from 5 to 25 individuals, all of whom have had direct experience with the phenomena being studied (Leedy, 2005). Six participants were invited to the BIM CAVE and went through two 3D models, 1) the model generated by project architects, and 2) the image-based model created by the author. The conversation with the interviewees was videotaped. In order to protect the privacy of the participants, this thesis does not reveal their identities. Instead, they were referred as Interviewee 1, 2, 3, 4, 5, and 6. Since, the results from this study is based on the feedback given by the six participants, their credibility is a major factor for obtaining reliable results.

The qualifications of the participants of this study are as follows:

Interviewee 1 is an AIA member, LEED AP, Senior Associate and Project Architect at a 27-year-old architecture firm with more than 70 employees in Texas. He has more than 15-year experience with in architecture and planning industry.

Interviewee 2 has more than 11-year experience as an architect and project manager in architecture firms, more than 1-year experience as a senior BIM project coordinator in the construction industry, and almost three-year experience as a project manager in an educational institution in Texas.

Interviewee 3 is an assistant professor in a higher education institution, and has more than two years' experience working as a field manager in real estate industry.

Interviewee 4 is a graduate student of construction science in a higher education institution, and has more than 1-year experience as a civil engineer.

Interviewee 5 is a Ph.D. student working on construction management in a higher education institution, and has an experience to run a construction company.

Interviewee 6 is an associate professor in a higher education institution. The interviewee also has experience in the architecture and planning industry for about 28 years, and worked in the construction industry as a team director for more than 3 years.

The following questions were asked by the researcher to the interviewees during the interview sessions:

1. Describe the differences of the two 3D models, and describe the feeling while you were in two different models.

2. If the image-based 3D model is available for you to use, what do you think you can use it for? What decisions do you think you can possibly make using it?

3. How much time and money do you think you can invest on this model?

The interview questions helped to know the participant's opinion about people's feeling about the 3D image-based model of an existing building. It also facilitated to understand the various applications of the 3D image-based model as well as the market value of it. Appendix-B contains the transcripts of the six interviews conducted.

Interview Results

The video tapes of the interviews were used to transcribe the statements of the interviewees and the data was analyzed to understand the acceptability of a 3D photogrammetric model generated without using control points for a building renovation project. This section shows the findings from interviews.

The interview transcripts were analyzed and grouped based on the following three topics of interest:

1. The experience of walking through the image-based 3D model comparing with walking through a traditional BIM model in BIM CAVE;

2. The potential applications of the image-based 3D model;

3. The acceptable time consumption and cost of generating the photogrammetric 3D model.

Walk Through Experience

All of the interviewees felt that the image-based 3D model portrayed the existing condition of the building very well. They could feel more reality while they were in the model. Also, the image-based 3D model contains some more detail information that traditional CAD drawings or BIM models usually do not have, for example the location of outlets, view out of the windows, texture of interior walls, etc.

However, some of the interviewees also gave comments on the clarity of the model. They were expecting to see an image-based model with less distortion, and higher resolution of images.

Potential Applications

Each interviewee gave their opinions on the potential usages of the photogrammetric model from the perspective of an owner, an architect, and a contractor. The potential applications of it could be grouped into following six categories. They are a model that could save travels, detail showing model, coordination tool, design tool, facilities management tool, and marketing tool.

Most of the interviewees considered an image-based 3D model could be an effective tool to start a renovation project. First of all, it provides a general idea of the existing conditions of the building and general location of walls, doors, and windows, especially when you do not have any drawing to start with. Also, it could be a good survey tool comparing with taking pictures and taking field notes. Furthermore, it is not only a good depiction of what is going to be changed in the perspective of architect; it also gives the demolition contractor an reference to verify the existing condition, as well as the utilization of space from the owners' stand point.

This model could also reduce the number of visiting the actual space to know about the general condition of the space, general dimension of the space and the function of the space. In the owner's point of view, it could save their tenants' building occupancy time for them to give tours to show the existing conditions. In the architects' point of view, it helps them put themselves in the site. In practices, architects do two to four walks of the existing site, but with this availability, they could save several visits since the photogrammetric model is the existed walk through of reality.

Some of the interviewees also mentioned that it could be a good tool for a coordination meeting or a pre-bid meeting. For example, if the architect is in Dallas, the owner is in College Station, and the contractor is in Houston, they can still walk through together in the image-based 3D model and talk about the issues that they are interested in. Also, if the owner could provide the model to different groups who would propose the architectural design, it could help architects get a very good idea about the existing condition of the building at the save time saving the time of having a tour.

The photogrammetric model is also a good tool to record and show details of the existing structure. Traditionally, the surveyors of a renovation project only record the general dimensions of spaces in their field notes, and generate an existing plan according to the field notes or pictures. However, they missed lots of other information such as the locations of certain elements, material of walls, and the condition of certain building components which also could be important. An image-based model could help surveyors and architects pick up all the details that they missed, but needed for certain usage.

The model also has certain potential applications in the field of facility management. Facility manager or facility maintenance staffs could actually see the function and layout of the space in the model before they go and perform their work, so they could possibly prepare their work better.

One of the interviewees also mentioned that the model could be an effective marketing tool in the field of real estate. Residential is so emotionally connected to the buyer; in the way of walking through the model the potential customers could experience their new home with a warm feeling.

Time Consumption and Cost

In most cases of the interviews, the photogrammetric model was compared with the as-built plan generate by architects. The image-based model should be either time-saving or budget-saving to make it practical or valuable. Thus, in general condition, take Francis Hall as an example, it should be done within about two weeks, and the cost of it should be around 5,000 dollars.

CHAPTER VIII

CONCLUSION

This chapter provides a summary of this research that briefly explains the motivations, and findings. Then, recommendations for future research are presented.

Research Summary

Photogrammetry has been regarded as one of the most cost-effective, flexible, and portable approaches to record the existing condition of a certain object. However, it has never been used actively to achieve a 3D model of the building especially for a building renovation project. The researcher conducted the previous research to study 1) whether we can create a 3D model using photos, 2) how we can create it without using any other technology such as laser scanning, and 3) if owners, architects, or construction professionals can use it for construction planning or project control.

By modeling the entire first floor of Francis Hall interior with a set of software including using Stitcher Unlimited 2009 generate sectional panoramas, using ImageModeler create 3D sectional image-based models, and using Navisworks scale and assemble all the sectional models to deliver an integrated 3D image-based model, and conducting interviews the following conclusions have been made. Image-based 3D model portrayed the existing condition and details of the building very well. It could be a useful survey tool in terms of picking up elements that are not mentioned in the field notes. It is an effective walking through model to reduce the times of field trips. It is also a good coordination tool in terms of enabling a coordination meeting without gathering all the parties of a project in the same room. The model also contains a large amount of detail information which usually does not contain in the as-built drawings. Furthermore, facilities manager and staffs could benefit from the model as well in terms of getting a general idea about function and layout of the space before they go and perform their works.

The time consumption for generating the photogrammetric model is expected to be less than or at least the same as the time consumption for architects to generate a set of as-built plans or drawings. It was the first time that the researcher utilizes this method to generate an interior building model, and it cost the author about 40 man hours to learn the software, solve problems, and deliver the 3D model of entire first floor of Francis Hall. Thus, it is possible that take a trained person 60 to 80 hours to create the image-based model of the entire building of Francis Hall which is equal to the time consumption for architects to deliver a set of 2D drawings or a BIM model.

The cost of the model is hard to be determined through interviews. However, some of the interviewees considered that the cost of generating the image-based model should not more than the cost for architects generating the as-built drawings. Again, taking Francis Hall as an example, the total cost of generating an image-based model should be around 5,000 U.S. dollars.

Future Research

Considering all the suggestions from the participants, the following topics may be considered for future research:

1. Improve the quality of the photogrammetric model in terms of eliminating distortion as much as possible, increasing the number of pixels per square unit as much as possible to make the texture more clear;

2. Improve the accuracy of the image-based model;

3. Test the possibility of creating more comprehensive image-based model which is combined with different construction phase models, such as foundation model, structure model, and MEP model, etc.;

4. Test the photogrammetric model with real renovation projects to study how design and construction professionals could utilize the model practically;

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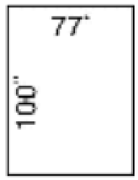
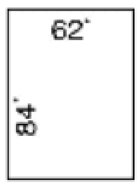
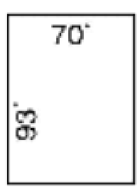
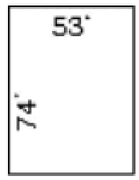
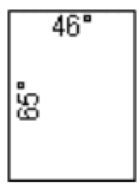
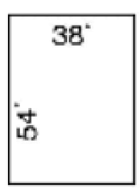
Focal length	Image FOV	Images required
15 mm		14
Image layout	One image at +90° pitch; six images every 60° at +30° pitch; six images every 60° at −30° pitch; one image at −90° pitch	

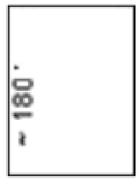
Focal length	Image FOV	Images required
20 mm		26
Image layout	One image at +90° pitch; eight images every 45° at +60° pitch; eight images every 45° at 0° pitch; eight images every 45° at −60° pitch; one image at −90° pitch	

Focal length	Image FOV	Images required
17 mm		18
Image layout	One image at +90° pitch; eight images every 45° at +30° pitch; eight images every 45° at −30° pitch; one image at −90° pitch	

Focal length	**Image FOV**	**Images required**
24 mm		29
Image layout	One image at +90° pitch; nine images every 40° at +50° pitch; nine images every 40° at 0° pitch; nine images every 40° at –50° pitch; one image at –90° pitch	

Focal length	**Image FOV**	**Images required**
28 mm		32
Image layout	One image at +90° pitch; ten images every 36° at +45° pitch; ten images every 36° at 0° pitch; ten images every 36° at –45° pitch; one image at –90° pitch	

Focal length	**Image FOV**	**Images required**
35 mm		50
Image layout	One image at +90° pitch; 12 images every 30° at +60° pitch; 12 images every 30° at 20° pitch; 12 images every 30° at –20° pitch; 12 images every 30° at –60°; one image at–90° pitch	

Focal length	**Image FOV**	**Images required**
8 or 10.5 mm (fisheye lens)		3-8 depending on the camera
Image layout	3 or 6 images at 0 pitch; 1 at +90° pitch; 1 at –90° pitch	

APPENDIX B

Interview 1

Interviewer: You just walk through from two 3D models in the BIM CAVE environment, one is a BIM model created by architect, and the other one is photo-based 3D geometry model created by myself for my graduation research. I assume you have two different experiences within the two different 3D models. Could you please describe what the differences between two models are, and how you feelings are different when were in two different models?

Interviewee 1: I think the photographic model portrays the existing conditions of the building. Some of the model we are completely documented in our existing drawings that we do for a building, some of them are not included in our plans and notes. So it gives us some additional information, in an easier way to find perhaps than taking numerous photographs.

Interviewer: If this photo model is available for you to use in a renovation project, will you or how will you utilize this model and what kind of decision you think you can make with this model?

Interviewee 1: I think there probably pros and cons for both of the models. The pro for the model from photos is that we can see all the existing details that you may not pick up as we were surveying. For example where this electric panel is or where the stair is, the relation to the other door and you can just quickly see that. Draw your memory about things you need to remember, what decision you need to make about how to resolve this issue. I think another thing we may normally see in a 3D model that we would create for an existing facility we would not necessarily model all the little elements that would potentially show up on the photographic model. The baseboards we may not ever model these. In our design, when we get a 2-D elevation or 2D plan, that would be typically line work and so because it would be too comprehensive to physically model all the elements in a building which you can actually see in and portray in a photographic model. One thing I notice too is that would be very different from having a model you created is that there is not always a sensitive which direction you are facing. A lot of time you lose your direction, in a virtual model you do not have necessarily all the sun angles. So here you got a quality of light for different spaces, some space seem darker than the others. But in a created model you do not get that feel, here you start to see that. Also, what you may looking at behind. About what decision I may make with it. It documented the existing condition but not the design intent. So the importance is that I think it quickly provides a general idea of the existing conditions of the building and general location of walls especially when you do not have any drawing to go from. So I think it provides a quick model to work from, to base your assumptions about size of rooms, general heights. For example, a ten-foot ceiling looks like this, how if it is eleven feet. I think you could tell the owner the existing space, and how the space feels, explain to them what happen if you modify the space, and you can still explain the client how it feels.

Interviewer: Let’s assume that you will use this model for the renovation project, and I am the one who will make the model? How much time you think you could give me to make this model? What is the budget you could spend on this?

Interviewee 1: It took two people probably a full day of field measuring and documenting the existing condition of Francis Hall so about 34,000 square feet, two people and we pretty much did only the interior of the building and first floor exterior. It also took about another week to create the interior shell of the building model. We will expect the same time as the hand measure and modeling. About the cost, we are talking about 20 to 40 man hour of field measure, and create notes, and another 60-80 hours to trans the notes to a BIM model. So we are talking about 100 to 120 man hours. 10,000 to 15,000 dollars.

Interview 2

Interviewer: You just walk through from two 3D models in the BIM CAVE environment, one is a BIM model created by architect, and the other one is photo-based 3D geometry model created by myself for my graduation research. I assume you have two different experiences within the two different 3D models. Could you please describe what the differences between two models are, and how you feelings are different when were in two different models?

Interviewee 2: I think the photo model is quick for getting a good in sense of what you starting with. The architect is really what the building going to look like, it is clean and maybe it is too clean. In this particular BIM model we don't see lots of texture and things like that, so you lose information of it. The photography model is really great, because even through it is a little bit distorted and maybe not as clear, I think a feel of you are really in the space because you get the texture, you get the finishes. It is more grounded into the reality. I think it would be a good tool to able to really go back to inform what you are doing in your design processes. I think it does have some applications here.

Interviewer: If this photo model is available for you to use in a renovation project, will you or how will you utilize this model and what kind of decision you think you can make with this model?

Interviewee 2: I think it would help in getting feeling of the space is like currently. From the owner perspective, we have to deal, particular with the school here, with occupied space and lots of things going on. So if there is a time that you could document the as-built condition, it would save a lot of time of visiting the actual space to know about what is going on in this space and what's the function of this space. For instance, we have a veterinary hospital. We could schedule a time get in there do this kind of photographs and document the operation room, and save those for later, so we don't have to try to get in there to figure out what was in there. Before the architects on board, you can put this kind of model together. So you can give it to different groups who would propose the architectural design, so that could help them inform what is really there. It would save our user group in the building occupancy time for us always going to and give tours to show what the existing conditions look like. So I think that would be very helpful for them. In terms of facilities management, those folks don't have to go to the building; they could look at it in a computer. Furthermore, during a pre-bid meeting or a coordination meeting with architects and contractors, we can show them and tell them this is what is it, save the time of having a tour. It would help them to feeling they are actually in the building.

Interviewer: Let's assume that you will use this model to do what you just said, and I am the one who will make the model? How much time you think you could give me to make this model? What is the budget you could spend on this?

Interviewee 2: The time that I could give you depend on what is it used for. If we are trying to use it for historic document, we definitely have more time. If it is a renovation project and we are trying to use it for design, it also depends. If we are going ahead of time, and we are doing this to give it to design firms, you may have 1 month to do it. If we are trying to get it while we are designing it would be much quicker. For the cost, I think you would like to put into a hourly basis, either hourly or square footage. I would think about 20,000 to 25,000 for a building like Francis Hall. It would be pretty economical to be able to do it. Is it going to replace the architects' as-built drawings? You have to add that cost to the top. The model may cut down the design fee a little bit. Because, for example you may tell the design this model could give you an idea what's there already, so it could cut down the number you have to go there, and verify the type of finishes is there.

Interview 3

Interviewer: You just walk through from two 3D models in the BIM CAVE environment, one is a BIM model created by architect, and the other one is photo-based 3D geometry model created by myself for my graduation research. I assume you have two different experiences within the two different 3D models. Could you please describe what the differences between two models are, and how you feelings are different when were in two different models?

Interviewee 3: Experiences are very different. With the picture model I get a very dirty feeling. It is dirty in the building. The space feels just dirty and gross verses the more accurate detail model very thing is clean since it is all computers generated. That was one difference really striking me. But conversely the picture model feels much more, I feel it gives me a better feeling of what is really in the building.

Interviewer: If this photo model is available for you to use in a renovation project, will you or how will you utilize this model and what kind of decision you think you can make with this model?

Interviewee 3: Because all of the works that I did, the owner lived in the space. They knew what is there already. So I don't know how I will use it as a remodeling contractor. But for a new construction, occasionally we have remote buyers. For them I think it would be quite effective, in terms of showing them, we are letting them experience their home. I think the photo model would be more desirable for a home buyer. Residential is so emotionally connected to the buyer. So I want to make sure that I could tap in to that sort of the emotion that they are feeling about their home with something much warmer. Even though I said this is dirty I would say it's a much warmer feeling.

Interviewer:

Interviewer: Let's assume that you will use this model to do what you just said, and I am the one who will make the model? How much time you think you could give me to make this model? What is the budget you could spend on this?

Interviewee 3: I think it really depends on what the project is. If I am a one-time builder and it's a spec home, I probably have no interest. As a production builder, I would say there probably a moderate level of interest. For a high-end customer, I think it would be market driven. If it is a home more than 1 million dollar, I might be willing to spend a few thousand dollars maybe as much as 5 thousand dollars to have some sort of documentation like this done. For the time consumption, as a home builder I would probably expect less than two weeks turn around and probably a week. Except my customer ask for it, I am using it probably for market my home. So I want it frankly as quickly as I have it, so I can turn around and be marketing the home. And again, if I am asking it, that may change.

Interview 4

Interviewer: You just walk through from two 3D models in the BIM CAVE environment, one is a BIM model created by architect, and the other one is photo-based 3D geometry model created by myself for my graduation research. I assume you have two different experiences within the two different 3D models. Could you please describe what the differences between two models are, and how you feelings are different when were in two different models?

Interviewee 4: The BIM model feels more animated like a game. You can tell it was a good representation of what is going to be built, but it doesn’t feel real. The second walkthrough was a real depiction of what is there. I would encourage you to refine the clarity of it, because it is a little bit out of focus. But it does have a better feel of the real depiction.

Interviewer: If this photo model is available for you to use in a renovation project, will you or how will you utilize this model and what kind of decision you think you can make with this model?

Interviewee 4: I think base on the information that is there, it is a good depiction and benchmark of what you going to change whether it is from design stand point or from an actual alter stand point with a contractor, or from the utilization of space from the owner stand point. So having the clear depiction of what is exactly there is very useful in terms of that space. Another best thing you can do is the boss doesn't want to travel, you can take the whole model and show the inside, what is going on. You can have a perfect idea if the entire team of this renovation project come and see this model, whatever construction you have. For sure you have a better look of what's inside, the windows, the finishing, and the small detail, what materials are, that very important. All the team, the owner, architects, and general contractor could get together, have a walk through in this structure. If the architect is in Dallas, the owner is in College Station, and the contractor is in Houston, we can still have this walk through. And once again, for example the outlets between those two windows, if that is something we want to talk about specifically, we can pin point that we can clearly see that and it's easy to identify for all the party involved, so it's a good tool, in terms of we are not looking at a set of 2 D drawings any model, saying which outlet is it, which sheet you on. If you are doing a 3D model, the detail will not as perfect as you can see here.

Interviewer: Let’s assume that you will use this model to do what you just said, and I am the one who will make the model? How much time you think you could give me to make this model? What is the budget you could spend on this?

Interviewee 4: For the limit information I have I would guess 1 week to 2 weeks for Francis Hall minus plus 34,000 square feet. For the cost, if you look at just basic rate for professional services if you are looking at somewhere 60 to 70 dollar per man hour, you are looking at somewhere around 80 hours, so somewhere around 5,000 dollars.

Interview 5

Interviewer: You just walked through both of the 3D models. One of them is generated by architecture; the other is an image-based model created by myself. And I assume that you have two different feelings when you were in two different models. Could you please describe what the differences between two models are, and how your feelings are different when you were in two different models?

Interviewee 5: The feelings of course are different. Because one is a finished product that the architects created through the design, while yours is existing condition, which is the information that is needed to get to the finished design. There are two totally different animals that one is based on the other. So the existing condition predicts what is there and is used as point of reference; and the other one is what the architects’ vision that the base would be at the end once it is constructed. So, as far as the feelings, there is no feeling that comes out, other thing the feeling was really what you are looking for, or what you are looking for is the use of the information that both of them are very useful. Definitely, what you have created is beautiful to the architects, to the review condition, review this bases, and go back and make sure what the abashes that can actually be done. And there is no hinted condition that they are not getting into consideration.

Interviewer: If this photo model is available for you to use in a renovation project probably in the pre-construction phase, will you or how will you utilize this model? (as an owner, as an architect, and as a contractor) and what kind of decision you think you can make with this model?

Interviewee 5: Just like I was mentioning, that most of us when we do a walk through, we have to take very careful notes and we take pictures, and we have to come back to create the scene that existing in our minds to know what is need to demolish, for example. Then what needs to be put in this place. Notes and pictures are nor as comprehensive as having a real walk through which bring thing to live what you have seen. So first of all, from an architects' point of view, which I am also besides a builder, it helps me put myself on the place, which is called in situate, and in the site. As if I was doing the walk through, so it can save me another trip to the place, to take another walk sometimes. In practices, we do two to four walks of the existing site, but with this availability, unless you really want some very specific details that may have been missed by your model, the walk through what you have is the existed walk through of reality, so you could save several visits. So yes, I find it is very useful and it would be employed mainly because it saves time, saves efforts. And also it is a ready tour if I have this walk through, I would not need to have my notes either I would choose taking pictures or writing them, either of this methods is not as helpfully as your model.

From the owner perspective, I don't think it would be quite useful. Because the owner doesn't care what it has been rather than what it is going to be. So as the architects care about the condition, what is there, so they would use it. And the general contractors would use it for demolition. So both the architects and most the demolish general contractors would use the model to verify what is there. However, in terms of facility management, you could do another wale through like you did this after the building was built one only from the architects' side but from the equipment, the operation and the maintenance. That would be an excellent time to do a video and that model would have some value for the owner. This could be done by the general contractors as part of their delivery to explain their product and the facility.

Interviewer: Let's assume that you want to use this model for the renovation project of Francis Hall, and I am the one who will make the model? How much time you think you can give me to make this model? And what is the budget you could spend on this?

Interviewee 5: Well, if it could save the time for the architects so the architects should provide this model with BIM. But the owner would not go to pay for BIM. The general contractor pays for the BIM, because it saves time and makes the workflows very smooth to prevent the job that is very expensive and very time consuming. For example, in this case, the architects are in Dallas, if they need to come back several times if would a wasted of time and money. So the architects should make the model and pay for it. I double the owner would pay for it very much like the older model, the BIM model.

Possibly, the model would distribute between the architects and the builders. The value of this model is the relationship of the time it saved, so if the model cost half or one third of the money the project managers and architects need to come to the existed site for several times, it would be a good investment no matter have much time it could cost.