DOCUMENTATION OF SERI MENANTI PALACE USING THREE-DIMENSIONAL PHASE SHIFT TERRESTRIAL LASER SCANNER

CHEONG SIEW CHIN

UNIVERSITI TEKNOLOGI MALAYSIA

DOCUMENTATION OF SERI MENANTI PALACE USING THREE-DIMENSIONAL PHASE SHIFT TERRESTRIAL LASER SCANNER

CHEONG SIEW CHIN

A thesis submitted in fulfilment of the
requirement of the award of the degree of
Master of Science (Geomatic Engineering)

Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia

AUGUST 2013

DEDICATION

To my beloved family that support me throughout the time,

who believe and trust me with faith, especially my beloved parents,

Cheong Hoe Thiam and Tan Guat Eng

And lovely siblings,

Jason Cheong Chao Quan and William Cheong Chao Yong

To friends who stand by my side, listening and concerning me throughout the journey

Alice Lim, Regina Liau & Ngoh Wan Zing

And lastly, special thanks to

Jeffrey Ong Chee Wei

For accompany me with his love, time, patience and effort in all time

AKNOWLEDGEMENT

In preparing this thesis, there are many people had contributed towards my project by giving thought, ideas, technical discussion. In particular I wish to express my appreciation to both of my supervisors, Professor Dr. Halim bin Setan and Dr.Zulkepli bin Majid for instrument arrangement, critics, advice and guidance. I would like to thank Dr Albert K. Chong for his encouragement, ideas and advices. With their support and interest, the thesis report was successfully completed for my project.

I would also like to thank Dr Shahir Shamsir for providing the data processing tools and moral support, and Dr Raja Nafida Bte Raja Shahminah supplying the literature of Seri Menanti Palace, giving her professional view in heritage building documentation and her sharing of knowledge in the important of preserving heritage. Also, I would like to acknowledge Centre for the Study of Built Environment in the Malay World, known as KALAM for providing the history, literature, measured drawing of Seri Menanti Palace as reference in my project.

Besides that, I also thank my friends and colleagues who have been in Photogrammetry and Laser Scanning Research Group (PLS) in Department of Geomatic Engineering and 3D Measurement Lab for their helps, all the fruitful discussion and experience together in the research. I also acknowledge Bajet Mini 2009 for support my master course study fees for two years and UTM RSG (Research Student Grant) for support my monthly allowance for one year.

Additionally, I am indebted to my family members. I would like to thank my parents for emphasizing the importance of education. I owe a lot of gratitude to my parents and brothers. Last but not least, I must thank my research project partner One Chee Wei for his support, presence, encouragement beginning from the data collection phase till the end of the project.

ABSTRACT

Generally, traditional documentation methods are time consuming, having limitation in collecting information and not able to provide re-visit of a historical building to present the artwork and design by the craftsman. The modern Geoinformation technology, laser scanning was used in this research and proven its effectiveness to record spatial data of Seri Menanti Palace, located in Negeri Sembilan, which was fully built by timber. The main goal of this research was to to digitally preserve and document heritage building by produce three-dimensional (3D) model of the historical building mentioned above with Level of Details 4 (LoD 4) as prescribed by CityGML. FARO Photon 120 laser scanner was integrated with high resolution Nikon DSLR D300s digital camera to collect 3D point clouds data and panoramic coloured image in full angular of 360°. A total of 165 scanning stations were required in data collection process which involves 120 stations for the interior and 45 stations for the exterior part of the palace. The collected point clouds data were registered by using the surveyed target and natural feature on the palace. The registered 3D point clouds that were geo-referenced with Cassini coordinate system and were integrated with panoramic images to produce 3D colourized point clouds which later rendered as animation aspect for "*Fly Through*" presentation purpose. Besides animation, this research also produce 3D surface model and floor plan of the palace. Several 3D measurements were taken from the generated 3D model and being compared with the measurement performed by the conventional method. Generally, this research had successfully proven that TLS technology can be used to record the palace data that built from timber. However, several parts of the palace cannot be recorded perfectly due to the cause of dark facade and the tall rooftop also is the limitation of the laser scanner used.

ABSTRAK

Secara am, kaedah-kaedah dokumentasi traditional lebih memakan masa, terdapat limitasi dalam pengumpulan data, dan tidak mampu untuk menyediakan kunjungan maya terhadap bangunan bersejarah untuk membentangkan kerja seni dan rekabentuk yang dibuat oleh tukang seni. Penggunaan teknologi geoinformasi moden yang dikenali sebagai teknologi pengimbasan laser terrestrial telah diuji keberkesanannya untuk merekod data-data spatial Istana Seri Menanti di Negeri Sembilan yang dibina berasaskan kayu. Tujuan utama penyelidikan ini adalah untuk memelihara dan mendokumen bangunan warisan dengan menghasilkan model tiga dimensi (3D) bangunan bersejarah di atas dengan tahap terperinci 4 (LOD4) seperti yang telah ditetapkan oleh CityGML. Alat pengimbas laser FARO Photon 120 telah diintegrasikan dengan kamera digital Nikon DSLR D300s yang beresolusi tinggi untuk mengutip data-data 3D titik-titik awan dan imej panoramik berwarna bersudut penuh 360°. Sebanyak 165 stesen pengimbasan diperlukan dalam kutipan data di mana 120 stesen di dalam istana dan 45 stesen di luar istana. Data-data titik-titik awan didaftar dengan menggunakan sasaran berkoordinat dan butiran semulajadi istana. Titik-titik awan 3D yang telah siap didaftar kemudiannya digeo-rujuk dalam sistem koordinat Cassini. Hasil titik-titik awan 3D itu juga diintegrasikan dengan imej panoramik bagi menghasilkan titik-titik awan berwarna 3D yang kemudiannya dilengkapi dengan aspek animasi bagi tujuan persembahan "terbang-melalui". Selain animasi, penyelidikan ini juga menghasilkan model 3D permukaan dan pelan lantai istana. Beberapa pengukuran telah dilakukan di atas model 3D yang dihasilkan dan dibandingkan dengan hasil pengukuran yang dilakukan dengan kaedah konvensional. Secara keseluruhan, penyelidikan ini telah berjaya membuktikan bahawa teknologi pengimbasan laser terrestrial boleh digunakan untuk merekod data istana yang berasaskan kayu. Namun terdapat beberapa bahagian istana yang tidak boleh direkod dengan lengkap disebabkan kesan fasad warna yang gelap dan bahagian bumbung yang tinggi merupakan limitasi peralatan pengimbas laser yang digunakan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

3D	-	Three-Dimensional
Act 465	-	National Heritage Act 2005
AVI	-	Audio Video Interleave
BIM	-	Building Information Modelling
CAD	-	Computer Aided Design
CCD	-	Charge Coupled Device
CG	-	Computer Graphic
CityGML	-	City Geography Markup Language
CMM	-	Coordinate Measuring Machine
DSM	-	Digital Surface Model
DTM	-	Digital Terrain Model
FAIA	-	Fellow of the American Institute of Architects
ICH	-	Intangible Cultural Heritage
ICT	-	Information and Communication Technology
IFM	-	Interferometer
KALAM	-	Centre for the Study of Built Environment in the Malay World
LIDAR	-	Light Detection and Ranging
LoD	-	Level of Details
OGC	-	Open Geospatial Consortium
PC	-	Personal Computer
PWD	-	Public Works Department
RGB	-	Red, Green and Red
RSG	-	Research Student Grant
TLS	-	Terrestrial Laser Scanner
UCS	-	User Coordinate System
UK	-	United Kingdom

UNESCO	-	United Nations Educational Scientific and Cultural Organization
UTM	-	Universiti Teknologi Malaysia
VR	-	Virtual Reality

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Needs for Cultural Heritage Documentation

Cultural Heritage ("national heritage" or just "heritage") is the legacy of physical artefacts (cultural property) and intangible attributes of a group or society that are inherited from past generations, maintained in the present and bestowed for the benefit of future generations as stated by WIKIPEDIA.

Cultural heritage includes:

i. tangible culture such as buildings, monuments, landscapes, books, works of art, and artefacts,
ii. intangible culture such as folklore, traditions, language, and knowledge, and
iii. natural heritage including culturally-significant landscapes, and biodiversity

Cultural heritage is unique and irreplaceable, which places the responsibility of preservation on the current generations. The deliberate act of keeping cultural heritage from the present for the future is known as **Preservation** (American English) or **Conservation** (British English), though these terms may have more specific or technical meaning in the same contexts in the other dialect.

Preservation is the protection of cultural property through activities that minimize chemical and physical deterioration and damage and that prevent loss of informational content. Conservation means the profession devoted to the preservation of cultural property for the future and the conservation activities include examination, documentation, treatment, and preventive care, supported by research and education as defined by American Institute for Conservation of Historic and Artistic Works (AIC).

Many valuable heritage information is threaten throughout destruction or disappearance as affected by climate, environment, time past, vandalism. The issue that archaeologists, historians, museologists and conservators are working on and concerning is how to conserve, utilize, and preserve the cultural heritage items as well as their values. The development of information technology become important in heritage preservation including digitization, digital aided research, conservation, exhibition, and utilization as discussed by Lu and Pan (2009).

"Today the world is losing its architectural and archaeological heritage faster than it can be documented." (LeBlanc and Eppich, 2005) as noted by the Getty Conservation Institute. In last decade, we had witnessed the increasing of papers and articles concerning the cultural heritage documentation, preservation, conservation and reconstruction by different method and technology. However, all the culturally significant sites in the world are disappearing faster than they are being documented, not even need to mention its chance to be preserved or conserved.

The awareness of conserving the cultural property has strived to preserve varieties of local and colonial architectural heritage from the Portuguese, Dutch and British. With the recognition of several heritage sites likes Penang and Malacca state by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in Malaysia had vigorously impact the heritage conservation in the country. Local planning departments, management agencies and local government are responsible for the implementation of heritage conservation.

The conservation projects practices for building research included the documentation, investigation, preservation and reconstruction (Siti and Kamarul, 2002). The historical buildings are in risk as most of them facing normal defects. The historical buildings in Malaysia are not being well cared for, due to lack of knowledge and high cost of repair and maintenance. The related local government should involve in the protection of the cultural assets, academic institutions and researchers should involve in heritage preservation research. The local arts and cultural agencies should involve in public awareness creation about the importance of preserving cultural heritage.

The cultural heritage risk can be addressed by various means, as noted by (Abhas *et al*, 2010) the documentation of cultural heritage is one of the important means out of all the six instrument listed below:

a. Disaster risk management plans, incorporate cultural heritage consideration
b. Culturally sensitive land use and spatial plans
c. Raising cultural sensitivity of disaster management authorities, users that occupy heritage properties.
d. Systematic documentation of cultural heritage
e. Regular maintenance and monitoring of heritage properties
f. Recovery programs, consistent management plans together for heritage sites

Cultural heritage contain rich information regarding society, history and cultural values. How to investigate and utilize such information effectively is extremely important and significant technological issue. In Chapter 2, the overview of cultural heritage management in Malaysia is presented, giving the current situation, discussion and suggestion for cultural heritage conservation in Malaysia.

The lack of efficient preservation methodology in local agencies and related government department caused the heritage building in Malaysia was not able to be digitally preserved, and conserved before it was loss due to various environmental impacts.

Creation of heritage building model for conservation purposes and the realization of 3D Virtual Model of historical for viewer were interested by researcher, academician and all related industries. There is an increasing demand for three-dimensional (3D) city models for many applications and users worldwide (Dursun *et al.*, 2008). One of the major purposes of creating 3D heritage building model is to increase the effectiveness on information distribution to the public, through visualization dissemination. Some of this growth in demand has been caused by the increase in public availability of open geospatial viewers (e.g. Google Earth, Virtual Earth).

Several disciplines like urban planning, architecture, telecommunication, tourism, environmental protection and many others have an increasing demand for digital 3D models, in order to use such complex data for planning, analyses, visualization and simulation in different applications.

This project used a phase shift type terrestrial laser scanner to generate 3D heritage building model and produce the 2D measured drawing of Seri Menanti Palace. A detailed 3D historical building model is essential for user to visualize the heritage building object and provide the information of the building structure to relevant individuals. The importance of persevering cultural heritage for future generation is also being discussed by study the legislations in Malaysia.

This research project focuses to produce the methodology of producing a framework, guidance for 3D heritage building documentation by using point clouds data. The issues, problems and solutions of heritage documentation work was elaborated in the following chapters. The building measured drawing and 3D model was produced. The 3D model LoD achieved was refer to CityGML LoD (Level of Details) standard. The standard of LoD by CityGML was widely used in 3D city modelling and other 3D modelling applications. In this thesis, the definition of LoD was discussed and the LoD standard being used in producing building drawing was explained.

The term LoD is also used by architect for (BIM) building information modelling. The different is that LoD used by contractor, architect, building designer starts from LoD 1 to 5 and their concern is before the building construction at 3D building design stage and for producing as-built drawing after the construction process completed. The LoD term for contractor in the implementation of BIM is not only the level of details but might involve also the level of development for the construction process of a specific building. But in this project the LoD that is put into concern is the level of details for a heritage building. More information can be found in Chapter 3.

The 3D point clouds data captured and utilised to produce several deliverables such as 3D animation, 2D floor plan and 3D model. The benefits of implementation of 3D laser scanning in heritage documentation were also discussed in this research. The history of target heritage building – The Royal Palace, Seri Menanti Palace was discussed in section 1.2 , followed with the statement of problems in section 1.3 as it explained the reasons of carried out this research. In section 1.4 the objectives of the research was discussed, following by the scopes of the research in section 1.5 and lastly the significance of study and purposes of the project in section 1.6.

1.2 History of The Old Palace Seri Menanti

"Historical buildings are ones that give us a sense of wonder and make us want to know more about people and culture that produced it" as discussed by Fielden (1996). The 3D model with higher LoD can be used for documentation, preservation and future reconstruction of heritage building.

The historical structure involved in the project is a well known cultural heritage, The Royal Palace Seri Menanti, as shown in Figure 1.1 is located at Kuala Pilah, Negeri Sembilan in Malaysia. Seri Menanti is the royal capital of the state of Negeri Sembilan, Malaysia. The Royal Palace, Seri Menanti Palace served as the official residence of the royal family until 1931, before it was converted to a Royal Museum in 1992.

In February 2009, the Unity, Culture, Arts and Heritage Minister Datuk Seri Shafie Apdal announced that the Seri Menanti Palace is among ten historical structures in Malaysia gazette as a national heritage, along with Victoria Institution in Kuala Lumpur and The Stadthuys in Malacca. The wooden palace, Seri Menanti Palace was one of the oldest cultural heritage that presented the art and craft of woodcarving skills of the Malay people of Malaysia

Figure 1.1 The old palace Seri Menanti Palace

The palace was designed entirely by two local Malay master carpenters named Kahar and Taib and it was constructed the traditional way without using a single metal nail and the entire four-storey building is literally held together only by mortise-and-tenon joints and hardwood dowels and rivets (Anuar, 2007).

"The four-storey edifice features 99 others of the *cengal* wood to denote the 99 warriors of the various clans. The upper roof structure employed technique called *"Lipatan Gunting"* (folded scissors). The first floor of the palace was used as the *"Balai Rong Seri"* (audience hall), while the second was used as chambers for the royal family and the third reserved for the Yang Dipertuan Besar. The central tower called the "Tingkat Gunung" was used as treasurer as adapted from the description written on Stone Plaque in Seri Menanti Palace" (Figure 1.2).

Figure 1.2 Descriptions from Seri Menanti Palace Plaque

The Seri Menanti Palace is full with uniqueness and beauty in its building architecture and it symbolised the royal family of Negeri Sembilan. This palace is still standing with its monument witnessed the development of trend and harbour from the past. The palace became Malay culture symbol with its firm originality that makes it beautiful and fascinating throughout the time. The palace plan has been analysed by the Chief drafter, Mr Woodford from Public Works Department Seremban and were approved in November 1902 by state engineer and British resident that time.

According to ARKIB NEGARA MALAYSIA, Seri Menanti Palace was itself a replacement for an older, grander palace, Istana Pulih. Istana Pulih were burned by English soldiers when occurrence of Bukit Putus War at that time. The Istana Pulih was destroyed in the fire. The construction starts in year 1902, it was completed in 1908. It costs about 45,000 US dollar for the palace construction. The Yang Di-Pertuan Besar wanted the palace design showed and had relationship with Minangkabau nature, so this palace not merely similar to the building design of Minangkabau but also equipped with parts which symbolises family, education, natural aesthetic and others that have close association with Minangkabau.

Today, as with so many traditional crafts, there are very few young carvers with the skills and the backing to reproduce such a masterpiece. Despite all the careful preservation work done on the Seri Menanti Palace, eventually, inevitably, time will take its toll and Malaysia will lose another irreplaceable treasure. In Malaysia, many heritage buildings with architectural and historical significance that influenced by several architectural styles such as Malays architecture, Portuguese architecture and Dutch architecture worthy to be listed or gazetted as National Heritage Building under National Heritage Act 2005 (Act 465) (Salleh and Ahmad, 2009).

Cultural heritage deliver conventional environment and craftsman’s artwork in the development and civilization progress. However the preservation of historical building is not efficiently perform as there is always constraint in budget and timing.

Figure 1.3 Interior part of Seri Menanti Palace

Cultural heritage conservation helps a community to protect the valuable physical assets, also its practises, history, and environment, and a sense of continuity and identity (Figure 1.3).

1.3 Statement of Problems

The idea of using TLS is because the existing available techniques, e.g.: conventional hand sketching, photogrammetry for data capturing does not provided data as detailed as data collected by TLS method. Each methods and sensors in the market having own strength in producing 2D, drawing and 3D model.

But each of them has its limitation to deliver the 3D model. The weakness of the existing method is that it does not allow the re-visit of site throughout the time. All the available mentioned techniques can be used for the 3D digitization of cultural heritage and each consists of various processes and exhibit variation in accordance with specific applications.

The review by George *et. al.* (2009) stated that the complete recording of cultural heritage is a multidimensional process. For the complete recording of the cultural heritage, it involves the 3D digitization, processing, storage of 3D data, achieving and management of 3D data, visualization and dissemination of 3D data and lastly the replication and reproduction of the 3D data.

Due to the different complexity of the digitization needs that emerged for the cultural heritage, there is a plethora of methods and techniques to fulfil particular demand and needs of a specific application. The criteria that affect users selection to the available 3D digitization systems for recording of the cultural heritage includes:

a. Complexity in size and shape
b. Morphological complexity (LoD)
c. Diversity of raw materials

Hence, in order to perform a complete recording of cultural heritage, the choosing of appropriate systems for data capturing is crucial. The photogrammetry method is more accurate in determining building outlines but does not provide high quality data for interior aspect of 3D building modelling. Particularly, in this project the final product provide methodology and review the techniques in producing 3D model of complex four level historical building which includes interior, exterior and the rooftop of the structure.

As for conventional method, a lot of manual work have to be done to get the measurement of the entire building feature, and this techniques might contribute to human measurement error and not able to supply the real 3D scene of the heritage building site to interested audience. The result after the tedious workload and time consumed measurement process is not able to give the realism situation of the heritage.

It becomes very significance when come to system selection, as the suitability and applicability of the method with the 3D data acquisition system decide the quality of the output. The criteria used for choosing an appropriate 3D data acquisition system for cultural heritage recording are listed in Table 1.1.

Table 1.1: Criteria of Choosing Appropriate System

No	**Criterion**	**Description**
1.	Cost	Most cost effective in giving satisfying results
2.	Material	Object surface , texture and condition of the digitization objects
3.	Size	Range can be captured, refer to specification of the system
4.	Portability	Mobility of the equipment or system
5.	Accuracy	Accuracy provided by the system
6.	Texture	Texture acquisition available for the object texturing purpose
7.	Productivity	Efficiency of the system to carry out the work
8.	Skill	User friendliness, the skill needed to handle the system
9.	Standards	Output compliance with the standard, reference or requirement

By referring to the criteria in Table 1.1, the entire criterion was considered and it assured that the 3D data acquisition system capable in succeeded the three main phases in the process of 3D digitization of heritage building in this project. After the consideration of the entire nine criteria in data acquisition system, 3D laser scanning technology was chosen.

The detailed methodology and procedure that further described the three phase in 3D digitization is discussed in Chapter 4. The three main phases is the process of how the 3D digitization was carrying out whereby it consists of the preparation, digital recording or data capturing and data processing.

a. **Preparation** is the preliminary activities, tools preparation, equipment, methods and methodology adopted as well as the site planning.

b. **Digital Recording** is the process for the cultural heritage object data acquisition of heritage object to be stored in digital format

c. **Data Processing** included the modelling, geometric data processing, texture data processing, texture mapping.

Even though photogrammetry method is more cost effective, but, still its shortage is it unable to capture a good coverage of data from the interior, exterior and rooftop of the cultural heritage. The processing of the photogrammetry method to generate model is hectic and the accuracy is said to be slightly less than the laser scanning method. Nevertheless, photogrammetry method is not the most appropriate method to produce a more realistic heritage building model that able to present the building artwork of the craftsman. Therefore, terrestrial laser scanning was adopted.

The most important reason that laser scanning method was chosen in this project is because only the 3D data allows the "revisit" of the heritage building structures through the computer. The 3D point clouds data captured able to present the actual situation or conditions of the heritage structure to audiences in future.

As time passed, only the 3D digital deliverable allows the visualization of the valuable heritage objects from the past to the audiences. This is what photogrammetry method or conventional hand sketch cannot provide to future generation; it is the realistic 3D scene of the heritage building in true measurement and scaling.

The argument of the available technique had been risen point to the reliability of the method. On one hand terrestrial laser scanners was tested from the instrumental point of view using investigations to check whether the instruments meet the accuracy specifications given by their manufacturers (Harald and Thomas, 2007). Terrestrial laser scanning can acquired dense 3D environment data accurately in short time. However, terrestrial laser scanning is not cost effective for data capture of rooftop aspect but is best in deriving building heights, extracting planar roof faces and ridges of the roof.

In a project that desired high quality 3D model, it is looking for the premium solution to obtain the output needed. The trend of cultural heritage for documentation and future preservation activity are growing tremendously. The historical heritage required high detailed modelling techniques to present it in most photorealistic condition. The lack of knowledge and no sufficient maintenance and management methodology failed to gives an efficient guidance for the conservation and documentation to preserve heritage effectively.

The need to document the existing high historical value structure was foreseen in United Nations Educational, Scientific and Cultural Organization (UNESCO). “In last decade, we have witnessed an increased number of publications related to systems that combine laser scanning and close-range photogrammetry technologies in order to address the challenges posed by application fields as diverse as industrial, automotive, space exploration and cultural heritage to name a few” as mentioned by Beraldin (2005). The lack of guideline and methodology framework for the heritage building conservation for the existing heritage is the main problem that this research aimed to resolve.

1.4 Objectives of Thesis

This study has the following objectives:

1. To develop procedure for cultural heritage building modelling using point clouds data acquired from terrestrial laser scanner to produce floor plan, elevation plan, animation and 3D model.

2. Use the accuracy requirement of LoD to compare the heritage building model produced in objective 1 with the measurement of measured drawing produced with conventional tape measurement method.

1.5 Scope of Study

The scopes of this study are listed below as the thesis covers the discussion of all the below scope in the research work:

a. Provide the procedure of site works, data collection and discussed the problems and solutions using terrestrial laser scanning method to produce a high historical value old palace building in 3D.

b. Research the method to link the interior and exterior scan data and produce a report on the accuracy of the registered datasets.

c. Produce the procedure of 3D modelling and the feature extraction of the cultural heritage building in CAD environment with 3D point clouds with using LoD as modelling reference standard.

d. Produce 3D RGB point clouds model and create 3D animation for the Old Palace, Seri Menanti Palace for visualisation purpose.

e. Provide the guideline for the digital preservation, documentation and presentation purpose for the related agency, either private or government, for the cultural heritage management activities in Malaysia.

1.6 Significance and Purpose

This study focuses on the 3D TLS method to preserve digitally a cultural heritage palace. The data recording system used consists of multi sensors. The sensors in FARO Photon 120 system are referring to the digital camera and laser scanner to carry out data capturing.

For the past decades, development of laser scanning technology had foreseen that the trend of the cultural heritage structures require high accuracy 3D modelling technique for photorealistic presentation and many other GIS application such as cultural heritage conservation and management.

As the historical buildings require fast and compact data capturing for the cultural heritage conservation and management concerns, TLS is an effective tool known by researcher in the world. This project make used of terrestrial laser scanner as the primary tool to produce 3D model of the Old Palace Seri Menanti Palace. The 3D information captured through the field work had also being utilised to digitize the 2D drawing of the building such as floor plan and elevation plan.

The laser scanning method not only provides the 2D drawing result, but also the 3D drawing of the Seri Menanti Palace. Every single details captured by the laser scanner can be re-access from time to time. Also, it is an undeniable fact that only 3D information with actual value and environment allow users or audience to experience the Seri Menanti Palace scene visit using 3D animation.

The available methods like photogrammetry are proven useful but the advancement of new laser scanning technology providing a higher accuracy choice to carry out this approach, by using 3D laser scanner. This study has determined the capability of terrestrial laser scanner to achieve high quality detailed data collection and produced several deliverables. Benefits that obtained with the implementation of 3D laser scanning technique to produce a complete documentation methodology of cultural heritage building, The Old Palace Seri Menanti Palace, are as follow:

a. Determine the technique of TLS can be used to digitally preserve historical building.

b. Provide guidelines for the 3D heritage digital documentation or preservations for irreplaceable heritage objects in Malaysia.

c. Pioneering 3D historical buildings model creation in Malaysia using Terrestrial Laser Scanning.

d. 3D visualization of historical heritage building in animation, with texture mapping applied for 3D point clouds data

e. Trend of virtual reality (VR) merging the utilization of the virtual 3D data to create model and video for presentation, visualization purpose and many applications e.g.: planning, tourism, photorealistic structure, navigation, town planning, environment planning and management.

1.7 Research Methodology

The literature research was done by determine the method to be used so that can achieve the goal set by this research. Feasibility study and applicability of the research methodology to contribute to digital heritage conservation project was done based on the literature research methodology shown in Figure 1.4.

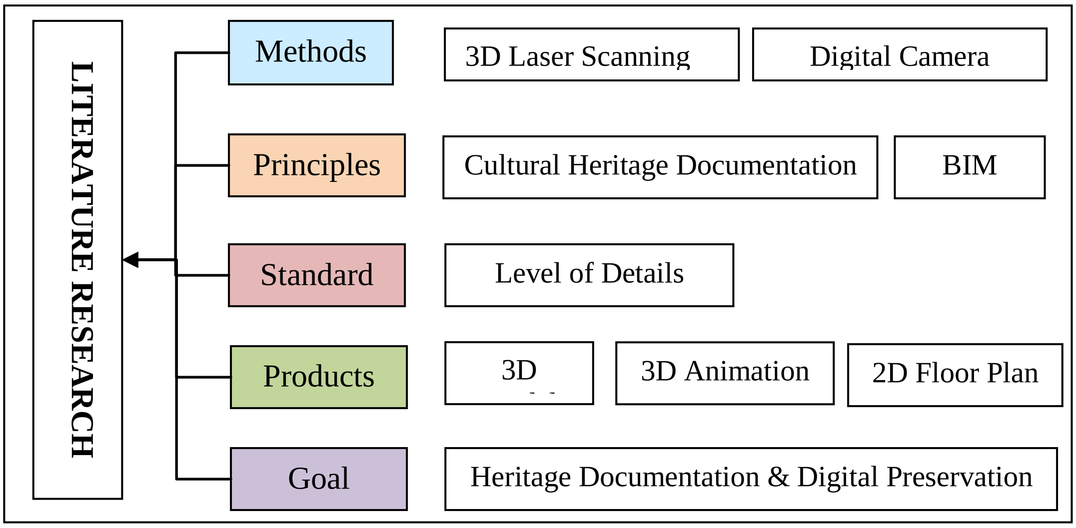

Figure1.4 Literature Research Methodology for 3D Documentation of Seri Menanti

The literature research was done based on the methods available, the principle involved in this project, the standard to benchmarking the research product, the required results for and also the goal achieved in the end of this research

1.8 Thesis Outline

The input to the pipeline, depicted in Figure 1.5, is a set of point clouds data with high resolution intensity image captured using the phase shift laser scanner and camera device used in FARO laser scanner system.

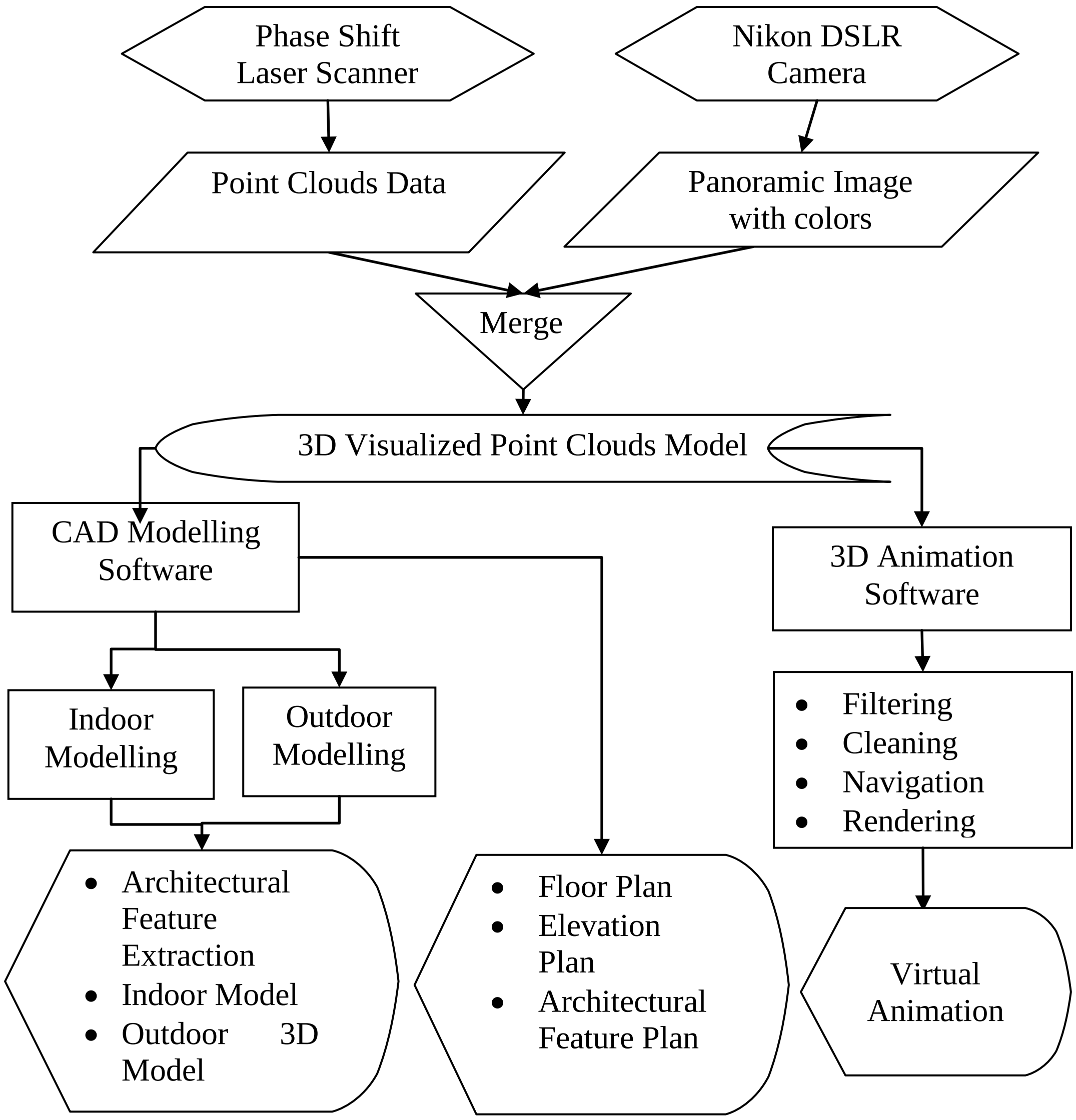

Figure 1.5 The workflow of the work done for thesis

The developed methodology was used to provide a guideline to potential users the procedure to carry out laser scanning project on cultural heritage. The point clouds from laser scanner was registered, colourized and converted to be used in CAD environment.

The point cloud was processed using laser scanning processing software to generate building floor plane using digitization method. The 3D model of Seri Menanti Palace was generated by using feature extraction plug-in in AutoCAD 2011. Another deliverables of this project is the fly through animation of the building structure.

This research aim to provide a comprehensive coverage report of laser scanning technologies in cultural heritage preservations, including point clouds registration, texture mapping by point clouds colourization, digitization, building modelling, heritage conservation, digital exhibition and digital utilization. In this project, the cultural heritage preservation or conservation was to study the overall methodology of using laser scanning point clouds to produce the 2D and 3D results for the Seri Menanti Palace.

This thesis consists of six chapters. Chapter 1 gives the introduction discussed the needs for historical heritage documentation, the brief information of the heritage structure in this project, statement of problems, objectives of thesis, scope of the project and most important the significant and purpose of this high level of details heritage building modelling project.

Chapter 2 presents a survey covering the cultural heritage conservation and heritage management situation in Malaysia, the literature on the needs and benefits of 3D documentation, laser scanning in cultural heritage, overview of heritage building modelling and the discussion on the advantages and drawbacks of the method in heritage building modelling. It give an idea of why the heritage conservation and 3D documentation is important and provide the method available in the market. In this chapter also discusses the type of the laser scanner and its technology ending with the comparison discussion on the methods used in heritage building modelling projects.

Chapter 3 elaborates the definition, standard, accuracy and requirement of the LoD 4 standard by CityGML. In this section the role of LoD 4 in building topology was explained. The modelling methodology developed in this project involved the modelling of interior, exterior and rooftop of the building. Hence, LoD is chosen as the standard to evaluate the 3D model produced. The LoD 0-4 used by (GIS) Geographic Information System researchers in producing 3D city models was used in this research.

Chapter 4 explains the entire research phase by going through the main process of 3D recording, 3D processing, 3D modelling, documentation and analysis. It includes the survey planning, laser scanning for range data collection, intensity image capturing, registration target distribution study, hardware setting determination in data recording process while data processing consists of data registration, texture mapping, laser data analysis, floor plan production and animation creation. There are several software and plug-in involves in this chapter. Through this approach any potential users that need the instruction or guideline to carry out similar project can find this section useful as the issue and problem faced was brought up for discussion in this chapter.

Chapter 5 presents the 3D virtual textured visualization model of Seri Menanti Palace by using the point clouds data and show the output of point clouds colourization. In this chapter the layout of the building is illustrated as the floor plan as well as the final 3D model of Seri Menanti Palace which combine the part of the interior and exterior model. Analysis of the building was done by giving the weighted statistic from Scene 4.8, showing the data min, max, mean of deviation of the combine 3D point clouds database. Comparison was done by comparing the measurement from measured drawing from KALAM with the measurement done by using list (LI) command in the AutoCAD for the floor plan and the building features.

Chapter 6 summarizes the contribution and findings, draws out the conclusions of this research work and indicates the direction for future researches.

REFERENCES

Abhas, K..J., Jennifer, D. B., Priscilia, M. P., and Daniel, P., Stephen, S. (2010). Cultural Heritage Conservation. In Abbas, K.J. (Ed) *Safer Homes, Stronger Communities: A Handbook for Reconstructing after Natural Disaster (173-180)* Washington: World Bank.

Abdelhafiz, A. (2000). Factors affecting the accuracy of digital photogrammetric applications. Master thesis, civil engineering department, Assiut university, Assiut, EGYPT, 160 pages.

Abdelhafiz, A. (2009). *Integrating Digital Photogrammetry and Terrestrial Laser Scanning*. PhD thesis, Institute for Geodesy and Photogrammetry, Technical University Braunschweig, Germany.

Agnello, F., and Brutto, M. Lo. (2007). Integrated Surveying Techniques in Cultural Heritage Documentation. *Proceedings of the 2nd ISPRS International Workshop. 3D-ARCH 2007: "3D Virtual Reconstruction and Visualization of Complex Architectures"* ETH Zurich, Switzerland, 12-13 July 2007.

Ahmad, A. G. (2006). Cultural Heritage of Southeast Asia: Preservation for World Recognition. *Journal of Malaysian Town Plan*, Vol. 03 (Issue 01), pp. 52-62.

American Institute for Conservation of Historic and Artistic Works (AIC). Retrieved on 14 June, 2010 from http://unfacilitated.preservation101.org/session1/expl_whatis-definitions.asp

Anuar, A.H. (2007, January 29). A Craftsman's Marvel: The Wooden Palace of Seri Menanti. *Holiday City. Com.* Retrieved on 14 June, 2010 from http://www.holidaycityflash.com/malaysia/seri_menanti.htm

Arayici, Y. (2007). An Approach For Real World Data Modelling With the 3D Terrestrial Laser Scanner for Built Environment. Automation in Construction. 16, 816–829

Arefi, H., Engels, J., Hahn, M., and Mayer, H. (2008). Levels of Detail In 3D Building Reconstruction From Lidar Data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Vol. XXXVII. Part B3b. Beijing 2008, p.p. 485-490.

ARKIB NEGARA MALAYSIA. Istana Lama Seri Menanti. Retrieved on 13 August 2012 from http://www.arkib.gov.my/istana-lama-seri-menanti

Avrahami, Y., Raizman, Y., and Doytsher, Y. (2005*). Extraction Of 3d Spatial Polygons Based On The Overlapping Criterion For Roof Extraction From Aerial Images.* In Stilla, U,, Rottensteiner, F., and Hinz, S. (Eds). *International Archives Of Photogrammetry And Remote Sensing, Vol. XXXVI, Part 3/W24.* (43-48).

Bagchi, S. (2001). *The Digital Reflection*: *Implications of Three-Dimensional Laser Scanning Technology on Historic Architectural Documentation*. Texas Tech University; 2001.

Barber, D.M., Mills, J.P., and Bryan, P.G. (2003). Towards A Standard Specification for Terrestrial Laser Scanning of Cultural Heritage. *XIX CIPA Symposium*. 30 September- 4 October 2003. Antalya, Turkey.

Beraldin, J. A. (2005). Integration Of Laser Scanning And Close-Range Photogrammetry – The Last Decade And Beyond. *National Research Council Canada*, Ottawa, Ont., Canada, K1A0R6, Commission V, WG V/2.

Bohler, W., and Marbs, A. (2002). 3D Scanning Instruments. *Proceedings of CIPA WG6 Scanning for Cultural Heritage Recording.* September 1–2. Corfu, Greece: CIPA

Boehler, W., Bordas Vicent, M. and Marbs, A. (2003). Investigating laser scanner accuracy. *Proceedings of the XIXth CIPA Symposium at Antalya,* 30 September – 4 October, 2003. Turkey.

Boehler, W. and Marbs, A. (2005). *Investigating Laser Scanner Accuracy*. Retrieved at http://scanning.fh-mainz.de/scannertest/results300305.pdf on 02 September 2009.

Brenner, C. (2000). Towards fully automatic generation of city models. *IAPRS*, Vol. 33, Part. B3, Amsterdam, Netherlands, pp.84-92.

Brooks, R.J., and Tobias, A. M. (1996). Choosing the Best Model: Level of Detail, Complexity, and Model Performance. *Mathematical and Computer Modelling*, August 1996, Vol. 24, Issue 4, pp. 1-14. Great Britain: Elsevier Science Ltd.

Burns, J. A. (1989). *Recording Historic Structures*. Washington: The American Institute of Architects Press.

Clarke, T. A., Wang, X. and Fryer, J. G. (1998). The principal point and CCD cameras. The Photogrammetric Record, 16(92), pp. 293-312.

Chikomo, F.O., Mills, J.P., and Barr, S. L. (2007). An Integrated Approach to Level-Of-Detail Building Extraction and Modelling Using Airborne Lidar and Optical Imagery. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Science.* Volume 36, pp 13-18

Dursun, S., Sagir, D., Buyuksalih, G., Buhur, S., Kersten, T.P. and Jacobsen, K.. (2008). 3D City Modelling of Istanbul Hstroric Peninsula by Combination of Aerial Images and Terrestril Laser Scanning Data. *4th EARSel Workshop on Reote Sensing for Developing Countries/GIS DECO 8.*June 4-7, 2008.Istanbul, Turkey, 1-9.

El-Hakim, S. F., Beraldin, J.A., Picard, M. and Vettore, A. (2003). Effective 3D Modelling Of Heritage Sites. *4th International Conference of 3D Digital Imaging and Modelling*, Banff, Canada, October 6-10, 2003, pp. 302-309

El-Hakim, S. F., Beraldin, J.-A. and Blais, F. (2003a). Critical factors and configurations for practical 3D image based modelling. VI Conference on Optical 3D Measurement Techniques, Zurich, Switzerland (Eds. A. Gruen and H. Kahmen). Vol. 2, pp. 159-167.

El-Hakim, S., Whiting, E., Gonzo, L. and Girardi, S. (2005). 3D reconstruction of complex architectures from multiple data, ISPRS Int. *Workshop on 3D virtual reconstruction and visualization of complex architectures*, 22-24 August, Venice-Mestre, Italy.

Fai, S., Graham, K., Duckworth, T., Wood, Nevil., and Attar, R. (2011). *Building Information Modelling and Heritage Documentation. CIPA 2011 Conference Proceedings: XXIIIrd International CIPA Symposium,* 2011.

FARO EUROPE GmbH & Co. KG. (2009). *FARO Laser Scanner Photon 120/20*. [Brochure]. Europe: FARO

.

FARO website. (2012). FARO Laser Scanner Focus^{3D}. Retrieved on 11 April, 2012, from,http://measurement-guide.faro.com/glossary-of-measurement-technology/ faro-laser-scanner-focus3d.php

Fielden, B. M. (1996). Conservation of Historical Building, Butterworth Architecture. Oxford, U.K.

Fraser, C. S. (2001). Network design. *Close Range Photogrammetry and Machine Vision* (Ed. K. B.Atkinson). Whittles, Caithness, Scotland, pp. 256-281.

Forstner, W. (1999). *3D-City Models: Automatic and Semiautomatic Acquisition Methods*. In Fritcsch, D. and Spiller, R. (Eds) *Photogrammetric Week 99.* (291-303). Wichmann Verlag, Heidelberg.

George, L.H. and Andrew , R. G.L. (2009). *Principles of 3D Laser Scanning*. George, L.H. and Andrew , R. G.L. (Ed.) *Laser Scanning for the Environmental Sciences.* (p.p 22-33). United Kingdom: Wiley Blackwell Publishing Ltd.

Gröger, G., Kolbe, T. H., Czerwinski, A., and Nagel, C. (2008). *OpenGIS® City Geography Markup Language (CityGML) Encoding Standard: OGC 08-007r1*. Open Geospatial Consortium, Inc.

Grun, A. (2000). Semi-Automated Approaches To Site Recording And Modelling. *IAPRS, Vol. XXXIII*, 16-23 July 2000. Amsterdam, 309-318.

Gruen, A. and Beyer, H. A. (2001). System calibration through self-calibration. In Calibration and Orientation of Cameras in Computer Vision (Eds. A. Gruen and T. S. Huang). Springer, Berlin. Vol. 34, 235 pages, pp. 163-193.

Gulch, E., and Muller, H. (2001). New Appications of semi-automatic building acquisition. *Automatic Extraction of Man-made Objects from Aerial and Space Images.* (3rd) Netherlads:A.A. Balkema.

Harald, S. and Thomas, P.K.(2007). Comparison Of Terrestrial Laser Scanning Systems In Industrial As-Built Documentation Applications. *Optical 3-D Measurement Techniques VIII*, Gruen/Kahmen (Eds.), Zurich, July 9-12, 2007, Vol. I, pp. 389-397

Herbig, U. and Waldhäusl, P. (1997). Architectural photogrammetry information system. *ISPRS - International Archives of Photogrammetry and Remote Sensing*, Vol. XXXII, Part 5C1B, October 1-3, Goteborg, Sweden.

Höfle, B., Pfeifer, N. (2007). Correction of Laser Scanning Intensity Data: Data And Model-Driven Approaches. *ISPRS Journal of Photogrammetry & Remote Sensing.* Vol 62. (2007). p.p. 415–433.

Huising, E. J. and Gomes Pereira L.M. (1998). Error and Accuracy Estimates of Laser Data Acquired By Various Laser Scanning Systems for Topographic Applications. (1998). *ISPRS Journal of Photogrammetry & Remote Sensing*. Vol. 53. (1998). p.p. 245–261.

Idrus, A., Khamidi, F., and Sodang, M. (2010). Maintenance Management Framework for Conservation of Heritage Buildings in Malaysia. *Modern Applied Science*. Volume 4 (11).

Jones, D. M. (2007). *3D Laser Scanning for Heritage : Advice and guidance to users on laser scanning in archaeology and architecture*. Swindon, United Kingdom: English Heritage Publishing.

Kaartinen et al. (2005). Accuracy of 3D City Models: Eurosdr Comparison. *ISPRS WG III/3, III/4, V/3 Workshop "Laser scanning 2005".* September 12-14, 2005. Enschede, the Netherlands, 227-232.

Kersten, T.P. (2006). Combination and Comparison of Digital Photogrammetry and Terrestrial Laser Scanning for the Generation of Virtual Models in Cultural Heritage Applications. *The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage, VAST*, pp. 207–214.

Kh’ng, C. F., Darbak, H. A., Zin, K.F., Zin, N. M, Aziz, H., and Ahmad, H.(1993). Seri Menanti Palace Pekan Diraja Seri Menanti, Kuala Pilah, Negeri Sembilan. *Kajian Lukisan Terukur Jabatan Senibina Univerisiti Teknologi Malaysia.*

Kobayashi, Y. (2001). *3D City Modeler with Fuzzy Multiple Layers Perception: Application of Soft Computing in Computer Aided Architectural Design Systems.* Doctor of Philosophy, University of California, Los Angeles.

Kolbe, T. H., Gröger, G., Plümer, L. (2005). CityGML – Interoperable Access to 3D City Models, In: van Oosterom, Peter, Zlatanova, Sisi, Fendel, E.M. (eds.): *Geo-*

information for Disaster Management. Proceedings of the 1st International Symposium on Geo-information for Disaster Management. March 21-23. Delft, The Netherlands, 1-16.

Kolbe, T. H., Grger, G., Czerwinski, A. and Nagel, C. (2008). OpenGIS City Geography Markup Language (CityGML) Encoding Standard. *Technical Report OGC 08-007rl*, Open Geospatial Consortium Inc 2008.

LeBlanc, F., and Eppich, R. (2005). Documenting Our Past for the Future. *Gretty Conservation Institute Newsletter*. 20(3), 5-9.

Lichti, D.D. (2008). A Method to Test Differences Between Additional Parameter Sets with a Case Study in Terrestrial Laser Scanner Self-Calibration Stability Analysis. *ISPRS Journal of Photogrammetry & Remote Sensing.* Vol 63. (2008). p.p P169 –180.

Lockhart, L. B. (2008). *Conservation Principles, policies And Guidance For The Sustainable Management Of The Historic Environment*. United Kingdom: English Heritage.

Lu, D. M. and Pan, Y. H. (2009). *Digital Preservation for Heritages: Technologies and Applications*. China: Zhe Jiang University Press.

Martin, E. C., Seamus, J. C., and Timothy, M. (2009) Issues In Laser Scanning. George, L.H. and Andrew, R. G.L. (Ed.) *Laser Scanning for the Environmental Sciences.* (p.p 34-48). United Kingdom: Wiley Blackwell Publishing Ltd.

Nagai, M., Chen,T., Ahmed, A., and Shibasaki, R. (2008). UAV Borne Mapping By Multi Sensor Integration. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. XXXVII Part B1, 1215-1222.

Ng, G. P., Chai, H. P., Parhizkar, B., and Lashkari, A. H. (2011). Augmented Reality For Museum Artifacts Visualiztion. *International Journal of Computer Science and Information Security*. Volume 9. (5), 174-185.

Nikon DSLR D300s Specification. Retrived on 9 May, 2012, from http://imaging.nikon.com/lineup/dslr/d300s/spec.htm

OGC CityGML.(2012). LoD Standard. *OGC City Geography Markup Language (CityGML) Encoding Standard.* Retrived on 25 March 2012, from, http://www.opengeospatial.org/standards/is.

Ogleby, C. (2009). Virtual world heritage: More than three dimensional models. GIS Development. Retrived on June 14, 2010, from, http://www.gisdevelopment.net /application/archaeology/genaral/index.htm.

Pajon, J.L. et al. (1995). Building and Exploiting Levels of Detail : An Overview and Some VRML Experiments. *Proceedings of VRML'95, San Diego C*A, p.p. 117-122.

Parent ,R. (2002). Computer Animation: Algorithms and Techniques. (2nd ed.) Morgan Kaufmman, USA: Elsevier Inc.

Phase Shift Method for Distance Measurements: Encyclopedia of Laser Physics and Technology. (2010). Retrieved on 11 April, 2012 from http://www.rp-photonics.com/phase_shift_method_for_distance_measurements.html

Satyaprakash (2007). Laser Scanners in Terrestrial Surveying. Geospatial World 2007, September Issue. Retrieved on 21 May, 2012 from http://www.geospatialworld.net/ index.php?option=com_content&view=article&id=20244&Itemid=1259

Pop, G., Bucksch, A., and Gorte, B. (2007). *3D Buildings Modelling Based On A Combination Of Techniques And Methodologies.* XXI International CIPA Symposium. 01-06 October 2007. Athens, Greece.

Salleh, N.H. and Ahmad, A.G. (2009). Fire Safety Management In Heritage Buildings: The Current Scenario In Malaysia. *22nd CIPA Symposium*. 11-15 October. Kyoto, Japan.

Schilling. A and Zipf, A. (2003). Generation of VRML City Models for Focus Based Tour Animations - Integration, Modelling and Presentation of Heterogeneous Geo-Data Sources. *Web3D '03*, 9-12 March. Saint Malo, France.

Siti, N. H. and Kamarul, S. K. (2002). Building Research Methodology In The Conservation of The Historic Buildings in Malaysia. *International Symposium Building Research and the Sustainability of the Building Environment in The Tropics.* 14-15 October 2002. University Tarumanagara, Jakarta, Indonesia.

SGI® OpenGL Shader™ Level-of-Detail White Paper: 007-4555-001. (2002). Silicon Graphics, Inc. Retrieved on 8 December, 2010 from http://techpubs.sgi.com/library/dynaweb_docs/linux/SGI_Developer/books/OpnGLshader_WP/sgi_html/pr01.html#id5187198

Takase, Y., Sho, N., and Shinjuku, A. (2003). Automatic Generation Of 3d City Models and Related Applications. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science.*Volume XXXIV-(5)/w10.

Tan, C.S. (2012). BIM's impact on the bottom line: Autodesk Malaysia. *COMPUTERWORLD MALAYSIA*, Retrieved on 29 March ,2012 from http://computerworld.com.my/print-article/18871/.

Vermeij, M., and Zlatonova, S. (2001). Semi-automatic 3D building reconstruction using *Softplotter*. *International Symposium On "Geodetic, Photogrammetric And Satellite Technologies - Development And Integrated Applications*. 08 - 09 November 2001. Sofia.

Wolf, P. R. and Dewitt, B. A. (2000). *Elements of Photogrammetry*. (3rd ed.) Boston: McGraw-Hill.

Wang, C.Y. and Zhao, Z.M. (2008). A Building Reconstruction From Lidar Data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Vol. XXXVII. Part B3b. Beijing 2008. p.p. 203-208.

William, E., and Ramon, B. (1989). *Handbook of Jig and Fixture Design* (2nd ed.) Society of Manufacturng Engineers,Mchigan, USA.

WIKIPEDIA, The Free Encyclopedia. Cultural Heritage. Retrieved on 8 August, 2012 from http://en.wikipedia.org/wiki/Cultural_heritage

Z+F. (2013) *Z+F Imager 5006h, 3D Laser Scanner* [Brochure]. Zoller + Fröhlich GmbH.

1971 National Cultural Policy. The Ministry of Information, Communication and Culture, Malaysia. Retrieved on 26 March, 2012 from http://www.malaysiamerdeka.gov.my/v2/en/achievements/services/154-1971-dasar-kebudayaan-kebangsaan