THREE-DIMENSIONAL (3D) RECONSTRUCTION OF A BUILDING FROM TERRESTRIAL LASER SCANNING AND PHOTOGRAMMETRY DATASET USING IDENTICAL POINT PICKING (IPP) REGISTRATION METHOD

AHMAD FIRDAUS RAZALI

UNIVERSITI TEKNOLOGI MALAYSIA

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AHMAD FIRDAUS RAZALI

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DEDICATION

Alhamdulillah

Segala puji bagi Allah, Tuhan sekalian alam

Selawat dan salam ke atas Rasullullah SAW

Buat Mak Ayah dan keluarga yang disayangi

Allah merahmati Mak Ayah dan seluruh keluarga

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ABSTRACT

Building is an immovable asset that requires accurate mapping and efficient documentation. Limitation of 2D- based data acquisition and insufficient semantic information on its geometry make the building documentation becomes less effective. Plus, even 3D- based data acquisition is used, it does not cover whole details optimally. The objectives of this research are to combine two geospatial surveying techniques; terrestrial laser scanning (TLS) and unmanned aerial vehicle (UAV) photogrammetry dataset into 3D modelling and to determine accuracy of the point clouds and the rendered 3D model. A geodetic laser scanner-2000 (GLS- 2000) terrestrial laser scanner was used to record existing details of Dewan Muafakat Johor, Taman Kobena, Tampoi, Johor Bahru, Johor. Meanwhile, UAV-photogrammetry was utilized to capture the rooftop and the aerial view of the building. Both pointcloud data from TLS and UAV-photogrammetry are integrated using Identical Point Picking (IPP) registration method until combined clouds called hybrid point cloud dataset are produced. A level of detail (LOD 3) of a three-dimensional (3D) model was developed using Sketchup and Undet For Sketchup (UFS) software based on the hybrid pointcloud. The root mean square error (RMSE) obtained shows that point cloud dataset is more accurate with 0.132m compared to higher RMSE, 0.455m of rendered 3D model dataset. As this study focuses on 3D data representation which significant for asset documentation, building monitoring and building information modelling (BIM) are the example of applications in the industry that suit with the purpose. Hence, the output from this study especially in terms of measurement and accuracy would be referable for decision making in building documentation.

ABSTRAK

Bangunan adalah aset tidak alih yang memerlukan pemetaan yang tepat dan pendokumentasian yang berkesan. Batasan pengumpulan data yang berasaskan 2D dan maklumat semantik yang tidak mencukupi pada geometrinya membuatkan pendokumentasian bangunan itu kurang efektif. Tambahan lagi, walaupun pengumpulan data berasaskan kaedah 3D digunakan, kaedah ini tidak merangkumi butiran secara optimum. Objektif kajian ini adalah menggabungkan dua set data dari teknik pengukuran geospatial; pengimbas laser daratan (TLS) dan fotogrametri pesawat tanpa pemandu (UAV) dalam pemodelan 3D dan mengenal pasti kejituan *point cloud* dan model 3D yang dibangunkan. Sebuah pengimbas laser daratan, pengimbas laser geodetik- 2000 (GLS- 2000) telah digunakan untuk merekod butiran sedia ada di Dewan Muafakat Johor, Taman Kobena, Tampoi, Johor Bahru, Johor. Sementara itu, fotogrametri UAV telah digunakan untuk merakam bumbung dan imej udara bangunan tersebut. Kedua-dua data *point cloud* dari TLS dan fotogrametri UAV telah digabungkan menggunakan kaedah pendaftaran *Identical Point Picking* (IPP) sehingga sebuah *cloud* yang digabungkan terhasil. Satu model 3D dengan Butiran Tahap 3 (LOD 3) telah dibangunkan dengan menggunakan perisian *Sketchup* dan *Undet for Sketchup* (UFS) berpandukan set data *point cloud* dari kedua-dua teknik yang digunakan yang dipanggil *hybrid point cloud*. Nilai punca ralat purata kuasa dua (RMSE) pada set data *point cloud* menunjukkan bahawa *point cloud* adalah lebih jitu dengan nilai yang lebih rendah iaitu 0.132m berbanding set data model 3D yang dibangunkan dengan nilai yang lebih tinggi iaitu 0.455m. Memandangkan kajian ini menumpukan perwakilan data 3D di mana tumpuan ini adalah signifikan dengan pendokumentasian aset, maka pemantauan bangunan dan pemodelan informasi bangunan (BIM) adalah contoh aplikasi dalam industri yang sesuai dengan tujuan ini. Justeru, dapatan kajian ini terutama sekali dari aspek pengukuran dan kejituan boleh dirujuk untuk kerja-kerja membuat keputusan dan pendokumentasian bangunan.

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LIST OF ABBREVIATIONS

RMSE	-	Root mean square error
TLS	-	Terrestrial laser scanning
GPS	-	Ground positioning system
UAV	-	Unmanned aerial vehicle
LOD	-	Level of detail
GCP	-	Ground control point
RTK	-	Real time kinematic
GNSS	-	Global navigation satellite system
TLS	-	Terrestrial laser scanning/scanner
SfM	-	Structure from motion
LAS	-	Laser format
ICP	-	Iterative Closest Point
IPP	-	Identical Point Picking
PPP	-	Point Pair Picking
MBBC	-	Matching Bounding Box Center
FEM	-	Feature Extraction and Matching

LIST OF SYMBOLS

$\bar{x}_n$	-	Set of point clouds
λ	-	Scale
x_i	-	True value
$\hat{x}_i$	-	Observed value
μ	-	Mean
e	-	Constant exponent

CHAPTER 1

INTRODUCTION

1.1 Overview

In an urban area, land use involves the effort of economy and social development agenda by the authorities. The development of land takes place every single day to fulfil human daily demands to provide a conducive and peace place to live in a country. These factors are influenced by how far knowledge and awareness of getting better planning in land development should be taken care of. Land development in a country is important to define the quality of living for the people and the growth of the economy. This is where many infrastructures, utilities, houses of residence and whatever engineered construction are developed and highly need maintenance and monitoring. The maintenance and monitoring process is called asset management where decision making about planning, acquisition, inventorying, auditing, assessing, operating, maintaining, renewing or eliminating of asset system is applied (Saptari, Hendriatiningsih, & Apriani). While all construction, social and economy development are taken place, buildings, infrastructures and facilities are designed and developed for asset investment and profit that contribute to the country (Geoinformation et al., 2018).

Buildings and infrastructures are the facilities provided by the government that is basically used for living and working in daily lives. There are various types of asset buildings attached with many infrastructures and details. The responsibility of role players in the industry such as surveyors, engineers, architects and asset owners is to ensure that the asset system works as it was meant to be. One of the task to fulfil the requirement is to provide an interpretative view about the as built structure known as semantic information. Semantic information is the knowledge of how geometry and information management are applied to the 3D documentation work especially in heritage modelling (Yang et al., 2020) or any as- built reconstruction.

The idea of making measurement and visualisation about the details is the capability of reality 3D scanning in geomatics field. Details and surrounding topography are collected through geodetic measurement and controls so that the accuracy is acceptable. Asset buildings are located in specific land region and the architectural design of its physical is also the nature of building construction. Hence, with their various complexity of details and high-density data requirement, as built survey for a building can be optimized from 3D spatial and geometry extraction survey system.

1.2 Research Background

The focus of this research covers three (3) geospatial surveying techniques on a building for the purpose of developing a digital model. As geomatics field and geospatial techniques such as terrestrial laser scanning (TLS) and photogrammetric measurement; close range photogrammetry and UAV- photogrammetry seems to have certain roles in that particular scope, a measurement called 3D scanning of a building using TLS and photogrammetry method is proposed. The need of applying TLS and photogrammetry survey methods is to obtain an optimum detail of scanned data. This can be done by integrating point clouds from each data source to produce a complete semantic model of the surveyed building.

The scope of the research is basically to carry out a geodetic measurement that applies to all kind of as built structures. This distinguishes between as built survey and as designed detailing. In geomatics industry, as- built survey is done to acquire existing data of a building or built infrastructures such as roads, highways, or tunnels which it happens after the construction is finished. Meanwhile, as designed detailing is performed to plan a design of an idea which it happens before the model is built.

As short, with the ability of 3D survey system and its high dense data processing advantage, a virtual model representing real structure (as built detail) on the ground can be developed. Moreover, RGB and real world in the TLS and photogrammetry survey techniques improves conventional detail survey using total station and GPS with the advantage of photorealistic capture.

1.3 Problem Statement

Firstly, conventional methods of acquiring as- built data using total station and GPS are limited to 2D point- based data acquisition. According to Chekole (2014), total station provides single measurement (2D) which are angles and distance while terrestrial laser scanner provides dense information (3D) along homogenous surface. Plus, Vacca, Mistretta, Stochino, and Dessi (2016) states that total station takes long time for its monitoring operation especially for high complex data where high numbers of points have to be surveyed. Additionally, GPS does not work indoor due to its signal transmission through the atmosphere. GNSS has indoor obstruction issue (Vacca et al., 2016) even though it is capable to monitor condition of structures (Buffa et al., 2017; Carta & Stochino, 2013). Alternatively, a three- dimensional (3D) survey techniques such as terrestrial laser scanning can be used to overcome this issue.

Secondly, outputs from the common practice only limits to geometry interpretation, without further semantic information. Compared to laser scanning (Kurz, Buckley, & Howell, 2012) and photogrammetry (Hassan & Fritsch, 2019), data imaging with RGB advantage is applied, making the scanned scene becomes semantically photorealistic. The data capture which translated to two-dimensional (2D) drawings and fragmented asset data are the traditional asset management manual practice (Hossain & Tarmizi, 2018) which the data source such as map, attributes and geographical information could be obtained from as- built survey. In addition, for documentation aspect, if attributes data are recorded with manual inspection method, this could lead to inefficient, tedious and error output (Chen, Chen, Cheng, Wang, & Gan, 2018). With the advantage of point clouds, geometry can be optimally reconstructed with semantic value from Level of Detail 3 (LOD 3). LOD 3 is an interior and exterior digital representation of details and visualisation of a building.

Thirdly, even though 3D scanning survey technology is applied, somehow the point cloud generated by the sensor used is not sufficient to represent all details on the scanned scene. For example, a laser scanner may be able to record almost thorough scene of a building with its 360° horizontal and 270° vertical rotation ability, but there might be some ‘hidden’ details that the scanner unable to capture. According to Al-kheder, Al-shawabkeh, and Haala (2009), even though laser scanners are capable to record high dense homogenous surface, but some critical details such as fractures may be difficult to be analysed because lack of resolution data. On the other hand, photogrammetry would be the solution where imaged data can be integrated with laser scanner data. As a result, an optimum photorealistic data with its best visualisation from combined technologies can be produced.

1.4 Aim and Objectives

The aim of the research is to study the reliability of 3D geospatial survey techniques for developing a digital model of a building.

The objectives of the study are listed as follows:

(a) to integrate two (2) types of geospatial survey techniques; TLS and UAV-photogrammetry dataset into 3D modelling; and

(b) to determine accuracy of the point clouds and the rendered 3D model.

1.5 Research Questions

To achieve the objectives, there are certain questions that require to be answered and engaged with possible methodologies. The research will be conducted to answer following research questions:

(a) How to integrate two (2) types of datasets in 3D modelling from various sensors?

(b) Which techniques has best accuracy for dimensional and geometrical measurement?

1.6 Scope of Work

This research focuses on development of digital 3D model of a building from geospatial survey methods namely, laser scanning and photogrammetry survey approaches. The laser scanning method covers the terrestrial area of the building while aerial photogrammetry from a UAV covers rooftop area. Hence, the method used is basically involving two (2) types of survey data. Geometric information such as volumetric properties and dimensional measurement can be extracted from point clouds while semantic information can be obtained from the digital 3D model rendered from the point clouds. Hence, the reliability of the data source used (TLS and UAV) could be studied from the rendered model by looking at how geometry could be affected from 3D modelling assessment.

A building named Dewan Muafakat Johor Taman Kobena is in Taman Kobena, Tampoi, Johor Bahru. The one- storey building is owned by Majlis Bandaraya Johor Bahru. The building is surrounded by neighbourhood area. The building has two (2) master rooms, one (1) fitting room, male and female toilets and one (1) hallway. The data acquisition covers the interior and exterior details of the building. The coordinate system chosen in the scope of work was geographical coordinate system, GDM 2000 projected to Malaysian RSO. Before data acquisition was carried out, a DJI Phantom 4 unmanned aerial vehicle (UAV) was used to perform site recognition to view the physical environment, or any obstacles exists on the area of interest. Figure 1.1 shows an aerial photo of the site.

Figure 1.1 Aerial view of Dewan Muafakat Johor Taman Kobena, Tampoi, Johor Bahru. Image taken from a DJI Phantom 4 unmanned aerial vehicle (UAV) from an approximate 35m flight height.

Data collection started with a GNSS survey to establish ground control point (GCP) around and inside the building. There were 21 GCPs were established. An RTK GPS technique was used to establish GCP outside of the building while total station was used to transfer the observed coordinate into the building. Next, scanning process took place by using a Topcon GLS 2000 laser scanner. The coverage area of scanning process was the entire interior details of the building as well as the outside area of the building. The scanning process follows traverse method where bearing and distance computation are applied in each station where the TLS moves. Figure 1.3 shows the equipment used to perform the scanning.

Figure 1.2   Topcon GLS- 2000 (Topcon, 2020)

Meanwhile, dimensional measurement from an as-built layout supplied by the owner of the building (MBJB) was used as a reference for data validation.

Data processing involves TLS and UAV- photogrammetry dataset before a rendering process was fully done. Basically, the geospatial processing from the two (2) dataset was to develop a geometrical measurement on the surveyed model. The geometric model, known as point cloud, is the based reference for modelling process. The point clouds define dimension, shapes, volumetric properties and RGB coloured figurative model. In other words, the point clouds represent geometry primitives as well as visualisation. The separate point clouds output each TLS and UAV-photogrammetry was managed to be integrated into one semantic model (Objective 1), making a full visualisation and interpretative 3D model to be developed. For data integrity aspect involving the two (2) survey techniques used, data validation and accuracy assessment were analysed (Objective 2).

The software used for data management and processing is basically laser scanning and photogrammetric based software. Also, a 3D rendering software. Topcon scan master was selected as laser scanner data processing platform to register, clean and georeference the extracted point cloud. Meanwhile Pix4D was picked as UAV aerial data processing. As point clouds from TLS and photogrammetry generated, they were combined into one (1) complete model that has common reference system. The data integration between two (2) dataset was done using CloudCompare software. Finally, a complete as built model consisting all two (2) types of point clouds was used to develop a 3D digital model representing the real building on the ground. Sketchup 2020 with the support of Undet For Sketchup (UFS) and Undet Indexer were used for 3D reconstruction process.

1.7 Significance of Study

As highlighted in sub chapter 1.4, the focus of the research is to perform 3D measurement of the required building with different approaches. There are six (6) significance of study that can be related with this research. For example:

(a) 3D scanning data acquisition can be the advantage of as built asset documentation.

(b) 3D representation from accurate point cloud measurement through terrestrial laser scanning can be the advantage of building monitoring as part of asset management;

(c) spatial data and dimensional measurement help developers or building owners to prepare better documentation for building, indoor features, facilities and indoor details for them to monitor and visualize any needed maintenance;

(d) automation survey that geospatial- based techniques offer provides supportive 3D modelling for various monitoring elements such as asset position, asset system availability, changes in any details and infrastructure monitoring; and

(e) geospatial- based techniques can be used as data source of performing scan – to – BIM application that improves the efficiency of asset management projects.

The research is managed to demonstrate understanding on fundamental survey and digital data management performed by two (2) techniques; terrestrial laser scanning and photogrammetry as main branch of knowledge in geomatics 3D measurement, and the common practice for building as- built surveying using total station.

1.8 Research Methodology

Generally, the output of the study is a 3D model of the desired building which is used for surveying and measurement interpretation. A brief explanation of methodology including data acquisition, data processing and others is discussed in Chapter 3 Research Methodology. A simple stages of research methodology is shown below.

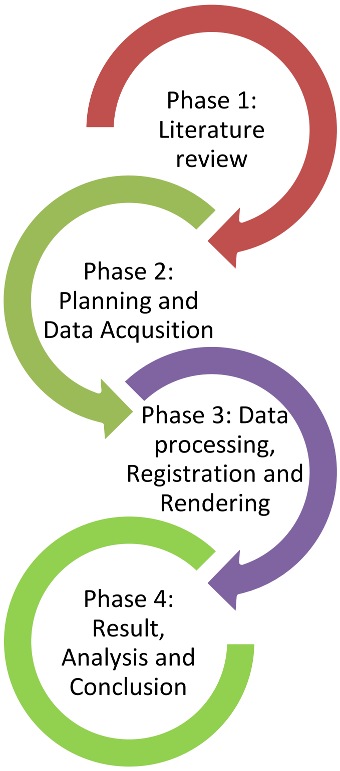

Figure 1.3 Basic Flowchart of Methodology

Phase 1 Literature Review is the starting step where all background of research, scope of study, research gap, objectives, previous studies reading are outlined. This phase can be the technique of familiarizing with applicable equipment and operational procedures related to the proposed research based on readings and reviews. The strength of the research is where the desired topic and approach used are significantly practical and efficient.

Phase 2 Planning and Data Acquisition is important to be taken seriously because this phase is where the desired techniques and methodology are applied. It may require a preliminary data acquisition to test the practicality and skills training. Selection of site and area of interest may be suitable for equipment access as well as the data capture coverage. All technical operation shall be involving skills and knowledge awareness so that the data integrity and accuracy can be taken care of.

Phase 3 Data Processing, Registration and Rendering is a critical step in the research. The responsibility of managing the data and put them into correct place so that they will not mix with other source data must be paid attention to. Moreover, the skill of managing storage, data density and also backup are also important to ensure all data are safe.

Phase 4 Result, Analysis and Conclusion sees that the research are almost done. The processed data are used for testing, accuracy assessment and checking to make sure the outlined objectives are achieved, and the research questions are answered successfully. At the end of this phase usually will come out with a recommendation for future practice and improvement purpose.

1.9 Structure of Thesis

This thesis is written by following the 2018 of Universiti Teknologi Malaysia Fifth Edition Thesis Preparation format. A Thesis in the manual refers to a scientific documented report of original research conducted by a student in an ethical and professional manner. The structure of this thesis is outlined as follows:

Table 1.1 Structure of Thesis

Content	Description
Chapter 1	Introduction • Briefly describes the general idea and basic background of the study
Chapter 2	Literature Review • Briefly demonstrates conceptual review on previous studies related on the proposed topic, principle of method used, importance of the proposed method including its practice.
Chapter 3	Methodology • Brief description about the method used to obtain precise and relevant data including the software to generate output and model for final product. • Contains complete flowchart of procedures to be taken.
Chapter 4	Result and Analysis ▪ Tabulation of data from different method of measurements. ▪ Data presentation from two (2) different surveying methods; TLS and UAV-photogrammetry. ▪ Comparison and statistical analysis ▪ Brief discussion about the result on the reliability of data.
Chapter 5	Conclusion ▪ Recommendation based on the findings. ▪ Repetition the significance of study to highlight the recommendation based on the findings.
Appendix	Attachment; diagrams, charts, photos etc.

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