GENERATING MULTI-LEVEL OF DETAILS FOR THREE-DIMENSIONAL BUILDING MODELUSINGTERRESTRIAL LASER SCANNINGDATA

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UNTUK TUHAN, BANGSA, DAN ALMAMATER,

dedikasi terbesar untuk restu orang tua,

dan dukungan sahabat-sahabat setia.

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ABSTRACT

Terrestrial Laser Scanner (TLS) has been used by various applicationsto measure three-dimensional (3D) objects. Developments in 3D modelling open the possibility to visualize the environment more fascinating. 3D city model, as a city representation, is an essential tools for many applications. City Geographic Markup Language (CityGML) has defined a standard for 3D building models in 3D city model at five different levels of detail (LOD) for enabling the flexibility in visualization. In this research, the advantages of TLS for generating point cloud of building details and the modelling process of point cloud were explored. Point cloud from TLS was used to generate a building model in multi-LOD. Themethodology in this research generatedLOD3, LOD2, and LOD1 from the same point cloud data. Results from this research were models in LOD3, LOD2, and LOD1 in surface models and also in Extensive Markup Language (XML) files. In the data validation, the Root Means Square Error (RMSE) for the LOD3 was 0.037 meter. Based on the CityGML requirement, minimum accuracy for LOD3 is 0.5 meter. The results show that TLS can be used to generate the multi-LODs.

ABSTRAK

Laser Pengimbas Bumi (TLS) telah digunakan dalam pelbagai aplikasi untuk mengukur objek tiga-dimensi (3D). Perkembangan dalam pembuatan model 3D membuka kesempatan untuk menggambarkan persekitaran dalam 3Ddengan lebih menarik. Model3Dbandar, sebagai gambaran bandar, adalah alat penting untuk banyak aplikasi. Bahasa Penanda Geografi Bandar (CityGML) telah mentakrifkan satu piawaian bagi model bangunan 3D di lima tahapan terperinci (LOD)untuk membolehkan kepelbagaian dalam visualisasi. Dalam kajian ini, kelebihan TLS untuk menghasilkan titik awan daripada butiran bangunan dan proses pemodelan titik awan telah diterokai. Titik awan daripada TLS telah digunakan untuk menjana modelbangunan dalam pelbagai LOD. Kaedahdalam kajian ini menjana LOD3, LOD2, dan LOD1 daripada titik-titik awan yang sama. Hasil dari kajian ini adalah model dalam LOD3, LOD2, dan LOD1 dalam model permukaan dan juga dalam fail Bahasa Penanda Boleh Perluas(XML). Dalam pengesahan data, Ralat Purata Akar Kuasa Dua (RMSE)untuk LOD3 adalah 0.037 meter. Berdasarkan kepada ketentuan CityGML, ketepatan minimum bagi LOD3 adalah 0.5 meter. Hasil kajian menunjukkan bahawa TLS boleh digunakan bagi menjana pelbagai LOD.

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LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
ADE	Application Domain Extensions
ALS	Airborne Laser Scanner
AMCW	Amplitude-Modulated Continues Wave
APSS	Algebraic Point Set Surfaces
BRep	Boundary Representation
BSP	Binary Space Partitioning
BW	Black/White
CAD	Computer-Aided Design
CityGML	City Geographic Mark-Up Language
COLLADA	Collaborative Design Activity
CSG	Constructive Solid Geometry
DSM	Digital Surface Model
DTM	Digital Terrain Model
FMCW	Frequency-Modulated Continues Wave
GPS	Global Positioning System
HDS	High Definition System
IFC	Industrial Foundation Class
IMLS	Implicit Moving Least Squares
IMU	Inertial Measurement Unit
KML	Keyhole Markup Language
LASER	Light Amplification by The Stimulated Emission of Radiation
LiDAR	Light Detection And Ranging

LOD	Levels Of Details
MLS	Moving Least Squares
OGC	Open Geospatial Consortium
RIMLS	Robust Implicit Moving Least Squares
RLS	Randomized Linear Scan
SPSS	Simple Point Set Surface
TLS	Terrestrial Laser Scanner
TOF	Time-Of-Flight
UAV	Unmanned Aerial Vehicle
X3D	Web 3DConsortium
XML	Extensive Markup Language

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nowadays, representing features on the earth could be more fascinating since the two dimensional (2D) map has been replaced by the development ofthree-dimensional (3D) map. Within the last 10 years, a term ‘3D city model’, has become more popular(Meng & Forberg, 2007). As illustrated in Figure 1.1, the 3D city model is a digital representation of a city or an urban area. It is an important tool for managing the urban area since the increasing growth in urbanization.

Various fields such as urban planning and management, facility location, disaster management, car-navigation systems, use 3D city model as an essential tool to facilitate further analysis related to urban or environmental issues. Itintegrates large numbers of spatial objects in different classes and different data models and structures.

Figure 1.13D City Modelling (Doellner *et al.*, 2006)

In a 3D city model,building is the main object.In order to fulfil the requirement for efficient visualization of 3D city model, the new Open Geospatial Consortium (OGC) created City Geographic Mark-Up Language (CityGML) defining 3D city model in five Levels of Details (LOD).Itcategorizes3D model from LOD0 to LOD4for efficiency in visualization(OGC, 2012).

Higher levels of detail represent more detailed and accurate 3D model.LOD0 is used to represent Digital Surface Model(DSM)(Fan & Meng, 2011). Building structure is formed from LOD1 to LOD4,as can be seen in Figure 1.2.

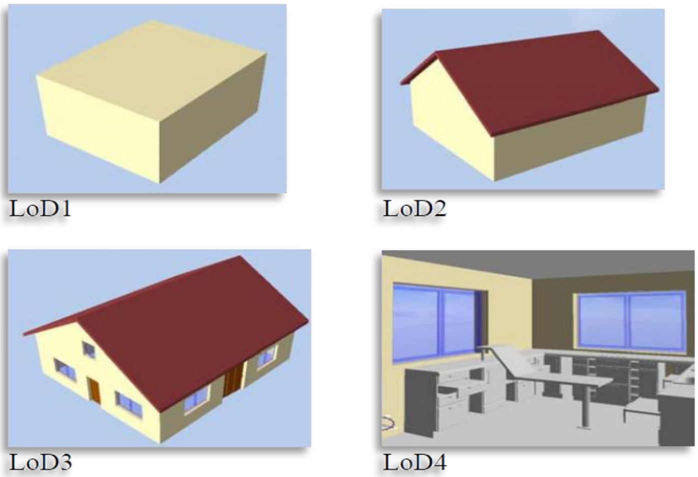
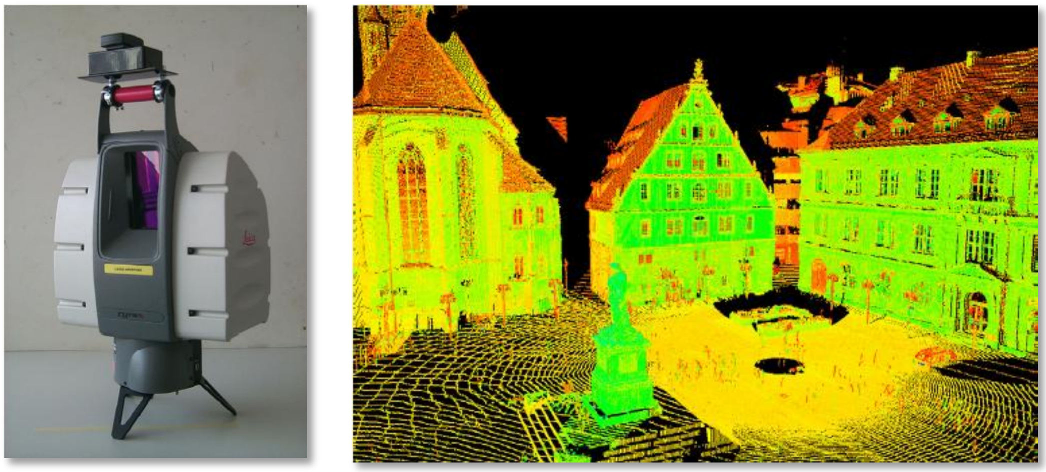


Figure 1.2 Level of Details for 3D Building Model (Fan & Meng, 2011)

As shown in Figure 1.2, eachLOD has different style to visualize the same building. LOD1 is the most simplest and LOD4 is the most complex. The interior details are visualized in LOD4. This standard can help 3D model provider in communicating with the user aboutthe type of LODrequired by user. Thus, visualization of 3Dbuilding model can be categorized according to the complexity of the model.

To generate3D model of building, especially fordifferent LODs (multi-LOD), become an interest topic in surveying. In recent years, great progress has been made in terms of accuracy and speed in order to obtain and render 3D models of buildings (Martinez *et al.*, 2012). Techniques for generating 3D model vary from instruments used to capture 3D data up to methods to process the data into 3D model. Meanwhile, previous works(Radosevic, 2010;Koch & Kaehler, 2009; and Remondino *et al.*,2009) integrated several sensors e.g. laser scanner and photogrammetry to obtain a 3D model in different LOD.

On the other hand, studies on Terrestrial Laser Scanner(TLS) application as a 3D measurement tools are increasingly investigated. TLS has been established as a measurement method for fast, area-wide 3D-surveying (Zogg, 2008). Ithas a promising technique andpotential to be accepted as an additional surveying technology (Schulz, 2007). Using TLS, a large area can be scanned, resulting point cloud, as shown in Figure 1.3.



(a) **(b)**

Figure 1.3(a) Example of TLS and (b) point cloud resulted from TLS (Boehler & Marbs, 2003)

Unlike photogrammetry, TLS is an active sensor that can generate point clouds in 3D coordinate system directly. It is manufactured with laser emitter and receiver to capture 3D object and represent it with thousands point clouds containing3D information of scanned area without scaling. However, in the process of 3D city modeling, this tool is usually used as an additional tool to capture the building detail in LOD3 or LOD4(Boulaassal*et al.*, 2011).

1.2 Problem Statement

3D city model, especially LOD1, LOD2, and LOD3, is necessary tools in the process to represent a city(Delavar & Majdabadi,2001;Doellner *et al.*,2006; and

Falkowski *et al.*,2009). During the process of generating multi-LOD for 3D model of buildings, there were severalissuessuch as in the data acquisition and in themodelling process of multi-LOD. In the data acquisition, previous works usually integrate several sensors to generate multi-LOD which cost more time and money. On the other hand, processing for integrating data from several sensors is more difficult than using single sensor.

TLS is still in investigation to be functioned as a single measurement tool for capturing detailed object, especially building details such as roof of buildings(Radosevic, 2010). Its application and data processing has also developed into specific issues such as automatic data filtering and point cloud processing.

Though TLS produces point clouds directly after scanning the object, to obtain a 3D model, it is still required to be processed. Point cloud contains very rich of geometric details and a large number of polygonal elements, producing problems for further procedures (Manferdini & Remondino, 2010). Point cloud processing usually takes a longer time compare to its data capturing(Remondino, 2011). Also, users are required to switch between several software products during the data processing (Mumtaz, 2008).According to Zogg(2008), state-of-the-art for 3D point cloud processing is still far behind compared to the data acquisition.

Another problem related to this topic isthe process in generating CityGML models. Although CityGML defines the multi-LOD and specifically addresses the object’s semantics and the representation of thematic properties, it does not indicate any method in the process of generating multi-LOD. Custom program to generate the multi-LOD is still required to generate lower LODs from a higher LOD.Acomplete method to cover the construction of multi-LOD from the data acquisition up to the visualization is necessary.

1.3 Objectives of Study

The aim of the study is to develop a method for generating multi-LOD of building.The objectives for the research are:

1. To investigateefficient method of capturing 3D data of building using TLS
2. To enhance method in generatingbuilding details in 3D model from point cloud
3. Toinvestigateprocess of generating LOD1, LOD2, LOD3 from the same data source.

1.4 Research Questions

In order to fulfil the objectives of study, this research will be carried out to answer the following questions:

a. How to scan building efficiently using TLS?
b. How to optimize the quality of the point cloud for LOD application?
c. How to generate3D model in LOD3from point cloud?
d. How to generatemulti-LOD from the same data source?
e. How to generate CityGML data from surface model?

1.5 Scope of Study

In this research, the mainobject is a building. Data capture was conducted using Terrestrial Laser Scanner (TLS) as a measurement tools.Point clouds generated by TLS were used to generate 3D digital detailed model of building, from LOD1 to LOD3.

Focus in this research isto createa3Dmodel of building in LOD3, LOD2, and LOD1using TLS, as a single measurement tool. The process to generate the multi-LODfollows the LODs standard defined by CityGML.

Final results area building model in multi-LOD, from LOD1 up to LOD3 in surface model and also in CityGML format. All the models were managed to be ready for visualization in CityGML. In this research, visualization for the multi-LOD is only for showing a frame of the static mode of visualization, not for the dynamic map visualization.

1.6 Significance of Study

As the 3D model plays an important role in many sectors, the demand of 3Dcity model is increasing. Requirement for representing the 3D model in different scale and detail is necessary for 3D city model users.Thus, this research addresses the variety of needs of 3D model for different applications.

Study about TLS for data acquisition, point cloud processing, modelling, generalization, and visualization wereconducted in this research. Visualization on different LOD that usually made by integrating sensors was replaced by using point cloud from TLS. Thus, this research givescomprehensive discussion ongenerating and visualizing 3D model using TLS for 3D city modelling.

1.7 Thesis Design

The thesis is divided into six chapters elaborating on concept, process and result in generating multi-LOD. In the literature review section, previous works and related study are also included. Content of those six chapters are described in Table 1.1.

Chapter 1 explains a brief introduction of this study. This chapter containsthe basic concept of the research including background, problem statements, scope of study, and also the significant of this research.

Related studies in this topic are explained in Chapter 2. This chapter discusses the brief theories and experiments from previous works about generating multi-LOD of building in CityGML, the use of TLS, and also 3D modeling.

In Chapter 3 and Chapter 4, methodology and implementation are explained. Chapter 3 explains the methodologythat is used in this research using flowchart and a brief description.In Chapter 4, the implementation of methodology is explained in detail for each process.

Results and analysis of this research is explained in Chapter 5. Results from the implementations are reportedwith the aid of figures and tables. Final outputs from the methodology are also analyzed in this chapter. Lastly, Chapter 6 discuss about the answer for the entire research questions with conclusion and recommendation.

Table 1.1 : Thesis Design and Content

Introduction	Background, Problems, Objectives, Research Questions, Scope, Significance, Thesis Design		
Literature review	Intro CityGML		
	LODs in Building Model	Concept	
		Previous Works	
	Principle of TLS	Basic Theory	
		Coordinate System	
	Data Capture For Building Model		
	3Dmodelling	Concept of Representation	Surface
			Solid
		Previous Works	Pre-Processing
			Façade Reconstruction
	Summary		
Methodology	Data Capture		
	Processing	Registration	
		Meshing, Filtering	
		3DModeling	
		Generating Citygml Files	
	Analysis		
	Summary		
Implementation	Object Study		
	Scanning		
	Point Cloud Processing		
	3DModeling	LOD3	
		LOD2	
		LOD1	
	Visualization		
	Summary		
Result & Analysis	Point Cloud Processing		
	3DModel		
	CityGML File		
	Measurement Comparison		
	Summary		
Conclusion & Recommendation	Conclusion		
	Recommendation		

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