OPTIMISATION OF 3D POINT CLOUD MODEL FOR ASSET NAVIGATION

HENG JOE EU

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Department of Geoinformation
Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

June 2022

DEDICATION

This thesis is dedicated to my family.

For their endless love and support.

ACKNOWLEDGEMENT

During the preparation of this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In here, I wish to express my gratitude to my mentor and supervisor, Dr Norhadija binti Darwin, for her encouragement, guidance, helps and critics.

I am thankful for my father, Mr. Heng Chu Ung and my late beloved mother - Mdm. Koh Bak Kew in instilling the virtue of perseverance and commitment which allows me to complete this thesis. I express my utmost gratitude to my beloved wife, Heng Yi Hui for her to be standing with me all the time, showering me with love and morale support. Special thanks to my daughter, Heng Kai Lin and son, Heng Qi Zian. Their smiles and laughter are my inspiration to keep going even I am tired and stress.

In addition, I am also truly indebted to Universiti Teknologi Malaysia (UTM) for its excellent facilities, equipment and staff especially those from Faculty of Built Environment and Surveying (FABU), Mr. Anuar Aspuri and Mr. Mohd Faizi Salleh. Unfortunately, it is not possible to list all of them in this limited space. Thank you to all who gives their views, opinions and support.

ABSTRACT

An indoor asset is extremely important in building management and maintaining or increasing a building's value. However, this indoor asset is hardly being tracked due to cumbersome methodology and techniques in the past. Hence, this study looked at the possibility of using a Terrestrial Laser Scanner (TLS) to acquire the internal dimension of the building in addition to the indoor asset. Furthermore, this study aimed to investigate an optimised approach to acquiring point cloud data for asset navigation applications. The objectives of this study were to identify the optimal configuration required, investigate the effect of multi-resolution, and access the navigation application with points cloud data. After a thorough investigation of the subject - namely the two resolutions of 6.3mm and 12.5mm, TLS was used to acquire points cloud data. The points cloud was processed and reduced with the "remove redundant points" function to check the size of the file. In the end, the points cloud was exported in image format to the navigation application. The optimal resolution obtained to scan a small indoor asset was 6.3mm resolution, even though the time to acquire it doubled the amount of time acquired by 12.5mm resolution. The higher resolution is not recommended for acquiring data on-site as the total columns of points across 80mm is only 21columns with a 3m distance from equipment to target. As a result, it is recommended to use 6.3mm to acquire a small indoor asset no further than 6m in the distance from the equipment. The user feedback concluded that the importance of the indoor asset navigation application is based on the point cloud data, and most of them were pleased to see such an application which can develop to help them in building management and maintenance. In conclusion, this study shows that the navigation application with points cloud data can improve building management and maintenance performance.

ABSTRAK

Aset dalaman amat penting dalam pengurusan bangunan dan dalam mengekalkan atau meningkatkan nilai bangunan. Walau bagaimanapun, aset dalaman ini hampir tidak dapat dikesan disebabkan oleh kaedah dan teknik yang menyusahkan pada masa lalu. Oleh itu, kajian ini melihat kebarangkalian untuk menggunakan Pengimbas Laser Terrestrial (TLS) bagi memperoleh dimensi dalaman sebagai tambahan kepada aset dalaman. Selain itu, kajian ini bertujuan untuk mengkaji pendekatan yang lebih optimum untuk memperoleh kumpulan titik data bagi kegunaan aplikasi navigasi aset. Objektif kajian ini adalah untuk mengenal pasti konfigurasi optimum yang diperlukan, mengkaji kesan daripada resolusi berlainan terhadap kumpulan titik awan aset dan mengakses aplikasi navigasi data titik awan. Selepas kajian menyeluruh terhadap subjek – iaitu dua resolusi 6.3mm dan 12.5mm, TLS digunakan untuk kumpulan titik data. Saiz data telah diproses dan dikurangkan dengan menggunakan fungsi remove redundant points untuk menyemak saiz fail. Akhirnya, data telah dieksport dalam format gambar ke aplikasi navigasi. Resolusi optimum yang diperlukan untuk mengimbas aset dalaman kecil ialah resolusi 6.3mm, walaupun masa untuk memperolehnya adalah dua kali ganda jumlah masa yang diperlukan dengan resolusi 12.5mm. Peleraian yang lebih tinggi tidak disyorkan untuk memperoleh data di tapak kerana jumlah lajur titik merentasi 80mm hanyalah 21 lajur dengan jarak 3m dari TLS ke sasaran. Oleh itu, adalah disyorkan untuk menggunakan 6.3mm untuk memperoleh aset dalaman kecil dengan jarak tidak lebih daripada 6m daripada TLS. Maklum balas pengguna menyimpulkan bahawa kepentingan aplikasi navigasi aset dalaman adalah berdasarkan data titik awan dan kebanyakan mereka berpuas hati melihat aplikasi sedemikian yang boleh dibangunkan untuk membantu mereka dalam pengurusan dan penyelenggaraan bangunan. Kesimpulannya, kajian ini menunjukkan bahawa aplikasi navigasi dengan data titik awan dapat meningkatkan prestasi pengurusan dan penyelenggaraan bangunan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
BIM	Building Information Modelling
BKL	Malaysia Cadastral Mark
CP	Control Point
EDM	Electronic Distance Measurement
Geo-BIM	Geographical Building Information Modelling
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
HBIM	Heritage Building Information Modelling
IBS	Industrialized Building System
ISO	International Organization for Standardization
JUPEM	Jabatan Ukur dan Pemetaan Malaysia
LOD	Level of Detail
NFC	Near Field Communication
POI	Point of Interest
RFID	Radio Frequency Identification
SIM	System Information Modelling
TLS	Terrestrial Laser Scanner
UTM	Universiti Teknologi Malaysia
VR	Virtual Reality

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background Study

An asset are valuable resources which holds positive economy value for individual, company or a nation. Asset as according to Cambridge Dictionary is something which is owned by a person, company, or organisation such as money, property, or land. In terms of finance, the asset can then be further breaks down into current asset and capital asset (fixed asset). As the definition of an asset is largely loose, for this research paper, the asset is defined as the fixtures and fittings within a building which bring benefits to the management, maintenance and value of the building.

There are many methods to capture the asset to be in spatial information. The first as most of the company practise, is in the form of checklist – hardcopy paper/files, as point by Lorence & Churchill (2005) - Paper-based record systems are so in-grained in the health-care organizations that they have established a cultural standard. In fact, N. Al-Hanbali and S. Aqel (2001) states that Gaza City municipality data is based on hard copy maps and had some AutoCAD files but have several problems in terms of homogenous, filing system and suitability for generating digital maps for a Geographic Information System (GIS).

True representation of asset in real space allows a better data management and search such as real position of item, better grasps of the asset, and easily shared over a distance. In saying that, data is easily stored and use by many parties.

This research captures the spatial information using Terrestrial Laser Scanner (TLS). Over the past decade, point cloud data become an important and relatively cost-effective component of the remote sensing constellation (Patrick McHaffie, 2019, p. 254). In terms of data acquisition of a building, which is normally built from existing architectural drawing.

One of the important information to support the indoor navigation is the basemap; either in two- or three-dimensional (3D) view. Currently, the widely used platforms for 3D mapping works is TLS (Mat Adnan *et al.*, 2019). This 3D scanning; is the act of mapping an object, structure or area and describing it in the form of X, Y and Z coordinates – a format known as “point cloud”.

Point cloud is a collection of data points defined by a given coordinates system (Rouse, 2016). As the collective of few sets of point cloud to create a scene is known as Point Clouds. These point clouds are used to create 3D meshes and it defines the shape of a physical object or any study area.

Ten years back, the point clouds database may be too heavy and may not be able to view and run-in normal computer, laptop or smartphone. However, the advancement of technology in computer’s hardware and software brings down the cost and which brings another dimension of spatial environment to human. Today, TLS can easily be used in capturing the spatial information and being displayed in most medium-cost computer.

This is important, as in a world where spatial relationship between people and their physical and human environments, economies, and cultures are made clear in ways that never been possible. Patrick McHaffie et al (2019) states that this is the promise of GIS. GIS is a term for the system to create and manage all types of data related to map. This may include indoor map.

M. Moncecchi et al (2021) details the benefits of GIS-based models in power system, analysing Chacas distribution network conversion between procedure from traditional support and GIS model. There is no doubt that the integration of geospatial information and other items brings benefits in management and maintenance.

While the term GIS may be more related to the outdoor spatial data, the development of TLS brings the new term of Level of Detail (LOD) to GIS. The term LOD further explained in sub-sub-section 2.3.2. TLS is reliable in capturing the point cloud in details; however, the limitation is the distance between TLS to targeted objects. The information further discussed in sub-sub-section 2.2.1.

All in all, the advance of TLS and computer's hardware and software brings new perspective in human to capture, view, manage and navigate their indoor asset in the form of spatial data. Hence, this study focuses to provide the 3D point cloud data for assets and inventory navigation system.

1.2 Problem Statement

Maintenance of an asset normally kept in hardcopy method, as paper being kept in files/folder separated by months or years. As time goes by, some files may end up in store room. On the other hand, some company did keep the record in the form of softcopy – excel spreadsheet. However, all of these maintenance records are not being integrated within any system. Over time, some record maybe lost in data migration, files loss, and et cetera.

There are several methods to create the basemap or floorplan. Most commonly, through as-built drawings. Besides that, the commonly used technique includes the traditional measurement tape and rulers to the use of technology equipment ranging from Total Station, High Resolution Camera to latest available technology – Terrestrial Laser Scanner (TLS).

In normal practices, the as-built drawing; the drawing produced after a building is completed is used to generate a 3D model. However, the drawings generally outdated and or even missing as state by Mikhail Giorgini et all (2018) when the author wants to generate floorplan for its automated vehicle. Y. Rezgui et al (2010) states that the conventional method in building management is normally through documented archives. This proven to be costly in the research done by Peter E.D. Love and C.P. Sing (2012).

Besides that, Total Station; the equipment which can measure and record horizontal and slope distance. However, the equipment can only perform a measurement directly to a particular point which consume a lot of time. (Ms. KS Shobana.M.E. et al, 2019). Besides that, Total Station cannot capture the features of the building.

One of the researchers, Lei Hou et al (2014) propose to use the method of photogrammetry, using high resolution camera to capture a refinery in oil and gas to provide an augmented reality in assisting the building (facility) management. The method from the author proven to creates a spatial sense and visualisation for the personnel in charge of building (facility) management.

Recently, the TLS is emerging at an affordable price. This technology allows the capturing of point cloud to produce point cloud data. This point cloud data is in 3D environment; which means every single point contain the X, Y and Z value. Thus, the point cloud data can further be used to create 3D model. This 3D environment provided in three-dimensional space is important to create efficient management (Stanþiü, B., 2014).

The advantage of point cloud data is the ability to give an additional visualisation to true environment and at the same time - measurable. Company can add information of assets; such as fixtures and fittings to the point cloud data, making a single application to maintain, records, position of each asset and navigation.

The main problem with TLS however is the distance between the equipment and objects. The further away TLS with the target object, the resolution scan increase. Besides that, the dense point cloud data capturing increase the size of the file which is too heavy for end user to run. Denser point clouds data acquisition affects not only time on-site, it affects the processing time; and subsequently loading time during filtration and affects end-user products.

In conclusion, this research paper concentrate in identifying the resolution needed to obtain a point cloud data which can be used to identify small asset and at the same time; not consume too much time in acquisition.

1.3 Research Questions

With so many methods and equipment in the market, this research looks into optimal configuration for TLS in capturing spatial information and subsequent developed into navigation system. The point cloud is greatly aided via visual interpretation of roads, buildings and others feature (Charles D. Ghilani and Paul R. Wolf, 2015, p. 817).

i. What is the optimal configuration in capturing point cloud?
ii. What is the effect of multi-resolution in capturing asset?
iii. How reliable of the navigation system?

1.4 Research Objectives

The aim of this study is to investigate optimise approach in acquiring point cloud data for assets navigation application.

i. To Identify an optimal configuration in capturing point cloud of Dewan Muafakat, Taman Kobena
ii. To evaluate the effect of multi-resolution in 3D documenting of assets
iii. To assess the navigation reliability of developed 3D assets navigation system.

1.5 Scope of the study

The general purpose of this research is to identify the best resolution of TLS to capture spatial information which is important for the maintenance of the asset such as fixture and fittings. The word best here refers to the time taken for each resolution and the lowest resolution possible but not jeopardise the required spatial information.

The 3D basemap produced input into software for further integration of positioning and possibilities of navigation. The scope of the study further explained in the following sub-sections; the study area, objects of interest; and the topics and theories.

1.5.1 Study Area

The selected study area is Dewan Muafakat Johor, Taman Kobena, Johor Bahru, Johor as shown in Figure 1.1. The study area is located near the Masjid Al Makmor Taman Kobena. The study area is suitable for capturing point cloud of the indoor asset since the need for monitoring the asset building. This building is owned by Majlis Bandaraya Johor Bahru, Johor.

Figure 1.1 Study Area (Source: Google Earth)

1.5.2 Point Cloud Data of Indoor Asset

The Topcon GLS-2000 is designed for use with known control points. Because of that advantage, it speeds up the processing part in this study. Topcon MAGNET Collage has been optimized to quickly acquire and manipulate 3D data. MAGNET Collage is fast and efficient way to handle mass 3D data and this software was used to handle the whole process from registration of point clouds. This software can clean/filter the noise (unwanted point cloud) from the dataset.

The Topcon GLS-2000 used to capture the spatial information of the asset in point cloud data. Although the Topcon GLS-2000 can be used without the known points, the availability of the known coordinates allows faster scanned data integration.

Topcon MAGNET Collage used to handle mass point clouds data. The Autodesk Recap further be used to analyse the asset within the building. Table 1.1 shows the advantage and disadvantage of spatial information in point cloud model.

Table 1.1: Advantages and Disadvantages of Point Cloud Model

Advantages	Disadvantages
Point Cloud Models can accurately represent complex objects	Point Cloud Models lack the precision of Boundary Representation (BRep), thus cannot create mathematically perfect curves
Point Cloud Models can be the quickest to create and view.	Point Cloud Data does not include information on surfaces
	Point Cloud Data is difficult to translate into an accurate BRep or Polygonal Model

(Sources: Dassault Systèmes, Spatial Corp Website accessed on 31st March 2020)

1.5.3 Scanning Resolution of Indoor Asset

As the power of laser affects the timing of acquisition directly, only Standard Power option used for both resolutions used in this study. As per Topcon GLS-2000's specification, the Standard Power for laser is classified as Class 3R. Class 3R Radiation is consider low risk but potential hazardous. Resolution of 6.3mm and mid-resolution of 12.5mm being chosen for comparison in terms of acquisition time and data quality.

There is advantage and disadvantage for different resolution. Higher resolution may result in large point cloud data file which may be difficult to open and process. On the other hand, lower resolution may be enough for navigation purposes within the building in addition for easier for maintenance.

1.5.4 Indoor Asset Navigation Application

There are various established methods of establishing indoor positioning and possibilities of indoor navigation. Point cloud of 3D were used as a basemap of assets navigation by using open sources software. The software can calculate the distance between two points and shows navigation path to there. It is easy to create a POI within the image-based map.

In order to identify the asset, a questionnaire conducted among public. The questionnaire randomly distributed via online method. The aim of the questionnaire is to identify the perception of public on the asset within a building. The stakeholders are not aim of this research as it aims towards easiness of public to use, navigate and makes direct complain to stakeholders.

1.6 Significance of the Study

This study shows the total time needed on field to scan the asset, in terms of lowest possible resolution to save time but at the same time, not jeopardise the quality of spatial information. The point cloud data show the astonishing amount of information which can helps management in making decision in maintenance, and may save more money in long run.

There are still doubts on the benefits of point cloud data especially in Malaysia. This study shows that the integration of maintenance record for asset's fixtures and fittings with point cloud data basemap are possible. Thus, there a proper way to track all important information which is important for the maintenance of an asset.

1.7 Research Methodology Overview

This research breaks into a total of five (5) phases. This is generalised and its flow is shown in Figure 1.2, which is Preliminary Study, Point Cloud Data Acquisition, Point Cloud Data Processing, Evaluation of Point Cloud Output and Navigation System Development; and Conclusion and Recommendation.

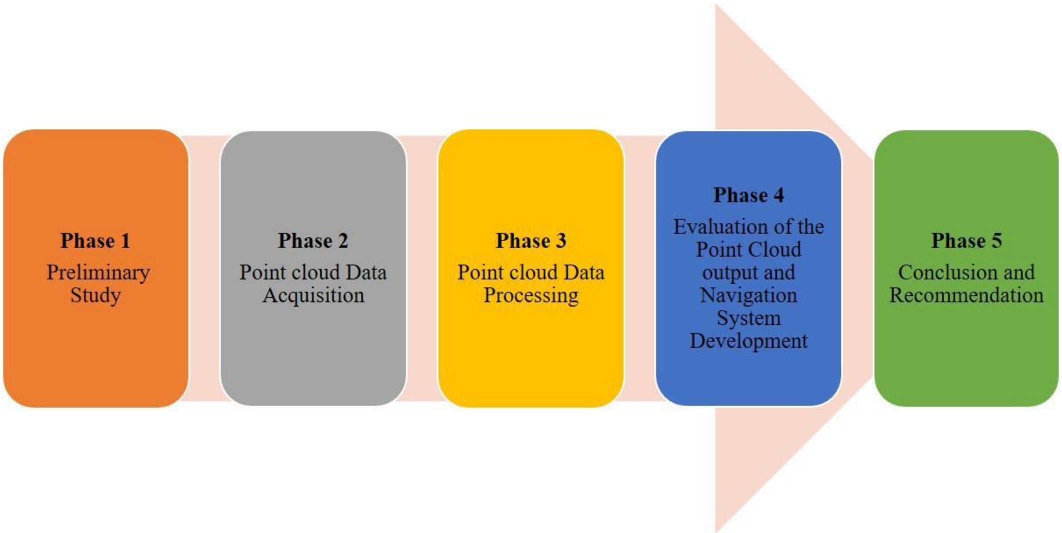

Figure 1.2: General flowchart of the Study

Phase 1 the preliminary study. This phase concentrates on others researches, journals, articles and internet resource in order to gain additional knowledge and better understanding on this topic. Thus, help in preparing this research paper in relating and solving the problem statements.

Phase 2 is the point cloud data acquisition. This phase takes into consideration of site identification, planning and proper location of TLS to allow proper scanning of all assets. On site, the Topcon GLS-2000 is used to capture the spatial information. The spatial information is stored in the form of point cloud and further be processed in Phase 3.

Phase 3 is the point cloud data processing. The software used in this research paper is Topcon MAGNET Collage. As the point clouds consist of several group of point cloud, the common point (such as wall and asset) must be properly matched as it may results incorrect representation of field.

Phase 4 is the result and analysis. The results analysed to prove the significance of this study. Further, the software to display the data given to related users for feedbacks. The Autodesk Recap used to identify the asset in point clouds. Open-Source Software – Navigine used for asset navigation.

Phase 5 is the conclusion and recommendations phase. A conclusion draws with the results captured in Phase 4. All results have strengths and weaknesses. Thus, further recommendations and limitations resulted from this study can be listed for further study.

1.8 Thesis Organization

Chapter 1 is an introduction of study. This chapter consists of background of study, problem statement, objective of study, scope of study, significance of study and research methodology.

Chapter 2 describes the fundamental of this study which provides appropriate knowledge including the theories, definition and applications employed in this study. This chapter reviews the existing research related to this study and some useful references on TLS, assets management and navigation application.

Chapter 3 consists of research methodology which covers the preliminary study, data acquisition and processing, result and analysis as well as conclusion and recommendation for this study.

Chapter 4 presents the result and analysis of this study. This chapter discusses on the accuracy assessment which consists of accuracy and precision assessment point clouds produced. The results and relevant analysis are illustrated and elaborated in various forms such as table, graphic presentation, tabular form and graph presentation.

Finally, Chapter 5 delivers the concluding remarks and recommendations which are drawn from the study that has been carried out. This chapter concludes the finding of this study and achievement of study objectives. Furthermore, suggestions or recommendations on future works can be found here.

REFERENCES

Abby Jenskin (04th November 2020). Oracle Netsuites - Inventory Management vs. Asset Management: What's the Difference?. [Website Last Accessed: 03rd March 2022]

Abdul Lateef, Olanrewaju & Khamidi, Dr. Mohd Faris & Idrus, Arazi. (2010). Building Maintenance Management in a Malaysian University Campus: A Case Study. *Australasian Journal of Construction Economics and Building*. doi: 10. 10.5130/ajceb.v10i1/2.1593.

Adam Satan (2018). 'Bluetooth-based Indoor Navigation Mobile System. Institute of Information Science, University of Miskolc, Miskolc, Hungary. [978-1-5386-4762-2/18]

Allysa Mat Adnan, Norhadija Darwin, Mohd Farid Ariff, Zulkepli Majid, Khairulnizam M Idris (2019). Integration between unmanned aerial vehicle and terrestrial laser scanner in producing 3D Model. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-4/W16, 2019. 6th International Conference on Geomatics and Geospatial Technology (GGT 2019) Malaysia. doi: 10.5194/isprs-archives-XLII-4-W16-391-2019

American Society for Photogrammetry and Remote Sensing (ASPRS) (no date). What is ASPRS? [Website last accessed: 03rd March 2022].

An Zhen-peng, Sui Hu-Lin, Wang Jun (2015). Classify and prospect of indoor positioning and indoor navigation. *2015 Fifth International Conference on Instrumentation and Measurement*, Computer, Communication and Control. [978-1-4673-7723-2/15] pg. 1893-1897. doi: 10.1109/IMCC.2015.402

Aquino, Mekaela L Costales, Kimberly Rose B, Arana, Jasper Meynard P. (2019). Asset Locator with Distance and Altitude Measurement Using GPS and BLE for Future IoT Applications. *2019 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE)* December 11-12-2019, Amity University Dubai, UAE. [978-1-5386-8346-9/19]

ArcGIS Indoors (no date). Indoor GIS for Smarter Building Management. https://www.esri.com/en-us/arcgis/products/arcgis-indoors/overview
[Website last accessed: 01st May 2021)

Autodesk (no date). Design and build with BIM – Building Information Modeling. https://www.autodesk.com/industry/aec/bim [Website last accessed: 01st February 2022]

Bluetooth (no date). Bluetooth Technology Overview. https://www.bluetooth.com/learn-about-bluetooth/tech-overview/. [Website last accessed 01st May 2021]

Brian Ray. (2018). How an Indoor Positioning Works. https://www.airfinder.com/blog/indoor-positioning-system. [Website last accessed: 01st May 2021]

CA Sunny Shah (22nd November 2019). Which is Better Technology for Asset Tracking? 1D or 2D Barcodes?. https://www.linkedin.com/pulse/which-better-technology-asset-tracking-1d-2d-barcodes-ca-sunny-shah/. [Website last accessed: 03rd March 2022]

C. Balletti, F. Guerra, V. Scocca, C. Gottardi. (2015). 3D Integrated Methodologies For the Documentation and The Virtual Reconstruction of an Archaeological Site. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-5/W4, 25-27 February 2015, Avila, Spain.

C. Thomson, G. Apostolopoulos, D. Backes, J. Boehm. (2013). Mobile Laser Scanning for Indoor Modelling. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume II-5/W2, 13th November 2013. Antalya, Turkey.

Charles D. Ghilani, Paul R. Wolf (2015). *Elementary Surveying – An Introduction to Geomatics*. 14th Edition. United States of America. Pearson Education, Inc.

Christos Laoudias, Andriano Moreira, Sunwoo Kim, Sangwoo Lee, Lauri Wirola, Carlo Fischione (2018). A Survey of Enabling Technologies for Network Localisation, Tracking and Navigation. *IEEE Communications Survey & Tutorials*, Vol. 20, No.4, Fourth Quarter 2018. Institute of Electrical and Electronics Engineers (IEEE).

Civil Engineer (no date). What is EDM. https://civiljungle.com/edm-in-surveying/. [Website last accesed: 03rd March 2022]

Dassault Systèmes, Spatial Corp (17 December 2019). The Main Benefits and Disadvantages of Point-Cloud Modeling. http://blog.spatial.com/the-main-benefits-and-disadvantages-of-point-cloud-modeling. [Last accessed 01st May 2020]

D. P. Lorence and R. Churchill (2005), Incremental adoption of information security in health-care organizations: implications for document management. *IEEE Transactions on Information Technology in Biomedicine* vol. 9, June 2005, no. 2, pp. 169-173. doi: 10.1109/TITB.2005.847137.

Dustin D, Liscio E, Eng P. (2016). Accuracy and repeatability of the laser scanner and total station for crime and accident scene documentation. J Assoc Crime Scene Reconstr. 2016; 20:57-67.

Engineer Supply (no date). What is EDM in Survey?. https://www.engineersupply.com/EDM.aspx#:~:text=A%20total%20station%20is%20an,a%20laptop%20or%20data%20collector. [Website last accessed: 03rd March 2022]

ESRI (no date). What is GIS? https://www.esri.com/en-us/what-is-gis/overview [last accessed 03rd March 2022]

E. Turner and A. Zakhor, (2014). Floor plan generation and room labeling of indoor environments from laser range data. *2014 International Conference on Computer Graphics Theory and Applications (GRAPP)*, 2014, pp. 1-12.

F. Matrone, E. Colucci, V. De Ruvo, A. Lingua, A. Spanò (2019).“HBIM in a Semantic 3D GIS Database. 2nd International Conference of Geomatics and Restoration, 8-10 May 2019, Milan, Italy. doi.org/10.5194/isprs-archives-XLII-2-W11-857-2019

Fahim Ahmed, Mark Phillips, Stephen Phillips, Kyoung-Yun Kim. (2020). Comparative Study of Seamless Asset Location and Tracking Technologies, Procedia Manufacturing, Volume 51, 2020, Pages 1138-1145, ISSN 2351-9789, doi: 10.1016/j.promfg. 2020.10.160,

Filip Biljecki, Hugo Ledoux, Jantien Stoter, Sisi Zlatanova, Arzu Çöltekin (2015). Applications of 3D City Models: State of the Art Review. *ISPRS International Journal of Geo-Information*, 2015, 4, 2842-2889, ISSN 2220-9964. doi: 10.3390/ijgi4042842. doi: 10.1016/j.compenvurbsys.2016.04.005.

Filip Biljecki, Hugo Ledoux, Jantien Stoter. (2016). An improved LOD specification for 3D building models. Computers, *Environment and Urban Systems*, Volume 59, 2016, Pages 25-37, ISSN 0198-9715,
doi: 10.1016/j.compenvurbsys.2016.04.005.

Fishbowl Inventory (no date). What’s the difference between inventory management and asset tracking?. https://www.fishbowlinventory.com/the-difference-between-inventory-management-and-asset-tracking [Website last accessed: 16th March 2022]

Greffet, J.-J., Carminati, R., Joulain, K., Mulet, J.-P., Mainguy, S., and Chen, Y (2002). Coherent emission of light by thermal sources. *Nature*, 416(6876), 61.

Haddad, N.A. (2011). From ground surveying to 3D laser scanner: A review of techniques used for spatial documentation of historic sites. *Journal of King Saud University-Engineering*, 23(2), 109-118.

Hexagon - NovAtel (no date). Survey. https://novatel.com/industries/survey#:~:text=What%20is%20GPS%2FGNSS%20Surveying,other%20forms%2C%20boundaries%20or%20points. [Website last accessed: 03rd March 2022]

Hong, Seung Hwan, Cho, Hyoung Sig, Kim, Nam Hoon, Sohn, Hong Gyoo (2015). 3D Indoor Modeling Based on Terrestrial Laser Scanning. *Journal of the Korean Society of Civil Engineers*, Vol. 35, No. 2:525-531/April, 2015. doi: 10.12652/Ksce.2015.35.2.0525

Instruction Manual Post Processing Software – MAGNET Collage. (2018). Topcon Corporation.

International Standard Organisation (ISO) (no date). ISO/TC 251. *Assets are fundamental to your organisation*. https://committee.iso.org/home/tc251. [Website Last accessed 01st May 2020]

J. A.D. C. Anuradha Jayakody, Iain Murray (2014). The Construction of an Indoor Floor Plan Using a Smartphone for Future Usage of Blind Indoor Navigation. 2014 International Conference on Contemporary Computing and Informatics (IC31)

Kissflow (28th December 2020). Investing in an Asset Inventory System? Read This First!. https://kissflow.com/finance/asset-management/asset-inventory-system-features/. [Website last accessed: 03rd March 2022].

Kurkela, M.; Maksimainen, M.; Julin, A.; Rantanen, T., Virtanen, J.-P.; Hyyppä, J.; Vaaja, M.T.; Hyyppä, H. (2021) Utilizing a Terrestrial Laser Scanner for 3D Luminance Measurement of Indoor Environments. *J. Imaging 2021*, 7, 85. https://doi.org/10.3390/ jimaging7050085

Lee Szue Yann, Z. Majid, H. Setan (2014). 3D Data Acquisition for Indoor Assets Using Terrestrial Laser Scanning. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Volume II-2/W1, ISPRS 8th 3DGeoInfo Conference & WG II/2 Workshop, 27-29 November 2013, Istanbul, Turkey.

Lee Szue Yann (2014). *Web-based Geographical Information System for Indoor Asset Management.* Master Degree Thesis. Universiti Teknologi Malaysia.

Lei Hou, Ying Wang, Xiangyu Wang, Nicoleta Maynard, Ian T. Cameron, Shaohua Zhang, Yi Jiao (February 2014). Combining Photogrammetry and Augmented Reality Towards an Integrated Facility Management System for the Oil Industry in Proceedings of the IEEE, vol. 102, no. 2, pp. 204-220, Feb. 2014, doi: 10.1109/JPROC.2013.2295327.

Limble CMMS (02nd March 2021). Asset Inventory Management: Tools and Process Explained. https://limblecmms.com/blog/asset-inventory-management/. [Website last accessed: 03rd March 2022]

Lowry Solutions (no date). What Is the Difference Between 1D and 2D Barcode Scanning?. https://lowrysolutions.com/blog/what-is-the-difference-between-1d-and-2d-barcode-scanning/. [Website Last Accessed: 03rd March 2022].

M. Moncecchi, S. Corigliano, A. Bosisio, L. Pruneri and M. Merlo. (2021). Development of a GIS-based model for the planning and operation of electrical distribution grids in rural areas: a case study in Peru. *IEEE 15th International Conference on Compatibility*, Power Electronics and Power Engineering (CPE-POWERENG), 2021, pp. 1-8. doi:10.1109/CPE-POWERENG50821.2021.9501205

Maguire, M. (2002). User Requirement Analysis: A review of Supporting Methods. Proceedings of IFIP 17th World Computer Congress Montreal 2002 (pp. 133-148). Canada: Kluwer Academic Publishers.

Margaret Rouse (2016). Point Cloud. *WhatIs.com.* https://whatis.techtarget.com/definition/point-cloud [Last accessed: 01st May 2020]

Mat Zam, P., Fuad, N., Yusoff, A., and Majid, Z. (2018). Evaluating the Performance of Terrestrial Laser Scanning for Landslide Monitoring. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 42(4/W9)

ME, Ms KS Shobana, S. Dinesh Babu. D. C. E., R. V. Hemaraj, and S. Isha (2019). Comparison on Measurement of a Building using Total Station, ArcGIS and Google Earth. *International Research Journal of Engineering and Technology (IRJET)*, Volume 06, Issue 06, June 2019. e-ISSN:2395-0056

Mohd Noor, N., Kamaruddin, Z., Abdullah, A., Abdullah, A.A., Eusoff, S.S. and Mustafa, M.H. (2018), "Using terrestrial laser scanner for Malay heritage documentation: preliminary approach to Istana Balai Besar, Kelantan", International Journal of Development and Sustainability, Vol. 7 No. 6, pp. 1886-1897

Mikhail Giorgini, Jacopo Aleotti, Riccardo Monica. (2018). Floorplan Generation of Indoor Environment From Large-Scale Terrestrial Laser Scanner Data. *IEEE Geoscience and Remote Sensing Letters*, Vol 16, No. 5, May 2019.

N. Al-Hanbali and S. Aqel. (2001). Geo-spatial database management system development in Gaza City using aerial images. *IEEE/ISPRS Joint Workshop on Remote Sensing and Data Fusion over Urban Areas* (Cat. No.01EX482), 2001, pp. 178-182. doi: 10.1109/DFUA.2001.985873.

Nicola Moretti, Claire Ellul, Fulvio Re Cecconi, Nilolaos Papapesios, Mario Caludia Dejaco. (2021). GeoBIM for built environment condition assessment supporting asset management decision making. *Automation in Construction*, doi: 10.1016/j.autcom.2021.103859.

Ohori, K. A., Biljecki F., Diakité, A., Krijnen, T., Ledoux, H., Stoter, J., (2017). *Towards an integration of GIS and BIM data: what are the geometric and topological issues*? *ISPRS Annuals of the Photogrammetry*, Remote Sensing and Spatial Information Sciences, IV-4(W5), pg 1-8.

Online Cambridge University Dictionary (no date). https://dictionary.cambridge.org/dictionary/english-malaysian/asset. [Last accessed 01st May 2020]

OpenGIS Standard (no date). https://www.ogc.org/docs/is. [Last accessed: 01st May 2021]

Patrick McHaffie, Sungsoon Hwang, Cassie Follett (2019) *'GIS – Introducition to Mapping Technologies'*, United States of America, CRC Press.

Peter. E.D. Love and C.P. Sing (2012). Determining the probability distribution of rework costs in construction and engineering projects. *Structure.*

Infrastructure. Engineering, vol. 9, pp. 1–13, 2012. doi: 10.1080/15732479.2012.667420

Peter E.D. Love, Jane Matthews (2019). *“The ‘how’ of benefits management for digital technology: From engineering to asset management”*, Automation in Construction, Volume 107, 2019, 102930, ISSN 0926-5805, doi: 10.1016/j.autcon.2019.102930

Segmenting Point Cloud. (13th June 2018). LiDAR News. https://blog.lidarnews.com/segmenting-point-clouds/. [Last accessed: 30th September 2021]

Royal Institute of Chartered Surveyors (RICS) (June 2010). Guidelines for the use of GNSS in land surveying and mapping.

S.A. Abdul Shukor, Razak Wong, E. Rushforth, Shafriza Nisha Basah, Ammar Zakaria (2015). 3D Terresstrial Laser Scanner for Managing Existing Building. *Jurnal Teknologi*, 20th August 2015. 76:12 (2015) 133-139.

S. H. Alkhuraissi, A. A. Alwohaibi (2016). Benefits of implementing a new asset management operating model within buildings and facilities in Saudi Arabia. *Asset Management Conference* (AM 2016), London, 2016, pp. 1-5

Sharaf Al-kheder, Yahya Al-shawabkeh, Norbert Haala. (2009). Developing a documentation system for desert palaces in Jordan using 3D laser scanning and digital photogrammetry. *Journal of Archaeological Science*,Volume 36, Issue 2,2009, Pages 537-546, ISSN 0305-4403, doi: 10.1016/j.jas.2008.10.009,

Shota Takagi, Jun-ya Takayama. (2021). Tracking and evaluation method focusing on continuity of power line based on three-dimensional point cloud data. *Measurement: Sensors*. Volume 18, 2021, 100181, ISSN 2665-9174. doi: 10.1016/j.measen.2021.100181.

Staiger, R., (2003). *‘Terrestrial Laser Scanning: Technology, systems and applications*’. Second FIG Regional Conference, Marrakech, Morocco, December 2-5, 2003.

Stanþiü, B., Roiü, M., Maÿer, M. and Vidoviü, A. (2014). Building Information Management based on Total Station Measurements and Laser Scanning. *INGEO 2014*, 6th International Conference on Engineering Surveying, Prague, Czech Republic, 3rd – 4th April 2014.

Tech27 System (no date). What are Point Cloud. *Tech 27*. 18th February 2018. https://tech27.com/resources/point-clouds/. [Last accessed: 21st September 2021]

University of Otago – School of Surveying (no date). Photogrammetry at the School of Surveying. [Website last accessed: 03rd March 2022]

Xueqin Yu, Tao Zhang (2017). *"Application of Terrestrial 3D Laser Scanning Technology in Spatial Acquisition of Urban Buildings"*. 2017 2nd International Conference on Image, Vision and Computing. [978-1-5090-6238-6/17]

Yacine Rezgui, Christina J. Hopfe, Chalee Vorakulpipat (2010). Generations of knowledge management in the architecture, engineering and construction industry: An evolutionary perspective. *Advanced Engineering Informatics*, Vol 24, Issue 2, April 2010, pages 219-228. doi: 10.1016/j.aei.2009.12.001

Yastikli, N. (2007). *"Documentation of cultural heritage using digital photogrammetry and laser scanning."* Journal of Cultural Heritage, 8(4), 423-427.

Yong K. Cho, Jong Hoon Youn, Diego Martinez. (2010). Error modeling for an untethered ultra-wideband system for construction indoor asset tracking, *Automation in Construction*,Volume 19, Issue 1,, 2010,, Pages 43-54, ISSN 0926-5805, https://doi.org/10.1016/j.autcon.2009.08.001.

Zakaria, M. H., Idris, K. M., Majid, Z., Ariff, M. F. M., Darwin, N., Abbas, M. A., ... & Aziz, M. A. (2019). Practical Terrestrial Laser Scanning Field Procedure And Point Cloud Processing For BIM Applications–TNB Control And Relay Room 132/22kv. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, Volume XLII-4/W16, 2019. 6th International Conference on Geomatics and Geospatial Technology (GGT 2019), 1-3 October 2019. Kuala Lumpur, Malaysia.

Zhijian Yu, Chengyang Yuan, Ke Zheng (2018) *'A University Fixed Asset Database Information Management System Based on Internet of Things'*. 2nd IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC 2018). [978-1-5386-1803-5/18]

Zichu Liu, Qing Zhang, Pei Wang, Zhen Li, Huiru Wang (2020). Automated classification of stems and leaves of potted plants based on point cloud data.

Biosystems Engineering. Volume 200, 2020, Pages 215-230, ISSN 1537-5110, doi: 10.1016/j.biosystemseng.2020.10.006.

Zul-Atfi Ismail, Azrul A. Mutalib, Noraini Hamzah (2015), A Case Study of Maintenance Management Systems in Malaysian Complex and High-rise Industrialized Building System Buildings, *Asia International Conference (AIC 2015*), 5-6 December 2015, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia, pp 28 -35.

APPENDIX D

List Of Publications

Joe Eu Heng, Muhammad Syahrul Izmeer Abdul Razak, Norhadija Darwin, Zulkepli Majid, Mohd Farid Mohd Ariff, Khairulnizam M Idris. (2019). 3D Model by Using Oblique Images From Unmanned Aerial Vehicle (UAV). *2019 IEEE 9th International Conference on System Engineering and Technology (ICSET)*, 7th October 2019, Shah Alam, Malaysia.