UNIVERSITI PUTRA MALAYSIA

BUILDING EXTRACTION FOR 3D CITY MODELLING USING INFUSED AIRBORNE LIDAR AND HIGH-RESOLUTION AERIAL PHOTOGRAPH

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BUILDING EXTRACTION FOR 3D CITY MODELLING USING INFUSED AIRBORNE LIDAR AND HIGH-RESOLUTION AERIAL PHOTOGRAPH

By

OJOGBANE SUCCESS SANI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

In memory of late grand aunty, Mrs Salome Ohioma, the bedrock of my early upbringing, Bro Johnson Ugbede Ocheje, and Pst Arome Moses Odiba, whose Love l cherish, including Umaya Nana Erigha, all of blessed Memories. My Stories will not be told without mentioning your contributions.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

BUILDING EXTRACTION FOR 3D CITY MODELLING USING INFUSED AIRBORNE LIDAR AND HIGH-RESOLUTION AERIAL PHOTO

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Chairperson : Professor Dato' Shattri bin Mansor, PhD
Faculty : Engineering

Accurate and timely mapping of the urban building is crucial for proper planning for planners, managers, and even the government. Nevertheless, the urban environment is complex and heterogeneous, with different features such as buildings (houses), transportation, and vegetation. The extraction of urban features remains a challenge for planners and government due to the issues associated with the urban areas. In the past photogrammetric sensors were deployed. However, it was time-consuming, capital intensive and manual. The revolution of technology has made available Airborne light detection. The ranging sensor (LiDAR) has undeniably brought about detailed, speedy terrain mapping, although with the challenge of many weeks of building feature detection and modelling process due to its discriminate placement of elevation points on everything. It includes cars, houses, and trees. Hence, the focus of this thesis carried out urban building detection and, where possible, had minimal user intervention in its process. In the first instance, LiDAR derivatives were employed via an image algorithm to perform the detection of buildings. Our method achieved promising results over a large scene with completeness, correctness, and the quality matrix we have for the object-based evaluation average values were 97%, 99% and 99%, respectively. The second goal employs a deep learning(DL) algorithm to predict the best sensor for detection, either the LiDAR, optics or the fusion of the LiDAR and high-resolution aerial photography, to know which is most suitable for building detection with little or no user intervention. Whereas an acceptable range for good classifiers (TPR and TNR index) should be 100, none of those mentioned above was below the threshold of ninety. In contrast, we had 97%, 93%, and 91% for the pixel-based evaluation values, respectively, for the deep learning method. We tested on A1, A2, A3, and our discovery DSM had the highest accuracy compared to other sensors alone. For Area 1 (A1), a value of overall accuracy of 93.21%, with a kappa coefficient of 0.798. Also, the optics' overall accuracy value was 87.54%, and the kappa coefficient was 0.630. Whereas for the fusion, the overall and kappa coefficient here was A2(94.30%, 0.859).. in conclusion, the integration of LiDAR and Aerial photography outperformed all the optics and DSM.
The weakness of the image and the LiDAR dataset has been compensated through their

fusion. Moreover, the proposed model was evaluated on three building forms in different locations with different rooftops forms for this research; three forms of housing/building types were considered: the complex, high rise and single low detached apartment buildings only. The result was negligible over the study area by comparing LiDAR DEM heights and differential GPS. The.RMSE is 0.11 for the heterogeneous environment, and mixed building forms for high rise buildings form RMSE is 0.002 m for high rise buildings while for low residential apartments, our RMSE value Root means square error 0.003m. The studies show our models' capacity to improve urban building detection and automate building objects. It is an indicator of excellent performance. The proposed technique can help detect and solve urban building detection problems.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

EKSTRAKSI BANGUNAN UNTUK PEMODELAN BANDAR 3D MENGGUNAKAN INFUSI LIDAR UDARA DAN GAMBAR UDARA BERRESOLUSI TINGGI

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Pemetaan bangunan bandar yang tepat dan tepat pada masanya adalah penting untuk perancang, pengurus dan juga kerajaan untuk perancangan yang betul. Namun begitu, persekitaran bandar adalah kompleks dan heterogen, dengan ciri yang berbeza seperti bangunan (rumah), pengangkutan, dan tumbuh-tumbuhan. Pengekstrakan ciri-ciri bandar kekal sebagai cabaran bagi perancang dan kerajaan kerana isu-isu yang berkaitan dengan kawasan bandar. Pada masa lalu sensor fotogrametri telah digunakan. Ia memakan masa, padat modal dan manual. Revolusi teknologi telah menyediakan pengesanan cahaya Udara.Penderia jarak (LiDAR) tidak dapat dinafikan telah menghasilkan pemetaan rupa bumi yang terperinci dan pantas, walaupun dengan cabaran selama berminggu-minggu pengesanan ciri bangunan dan proses pemodelan kerana penempatannya yang mendiskriminasikan titik ketinggian pada segala-galanya. Ia termasuk kereta, rumah, pokok. Oleh itu, fokus tesis ini menjalankan pengesanan bangunan bandar dan, jika boleh, mempunyai campur tangan pengguna yang minimum dalam prosesnya. Dalam contoh pertama, derivatif LiDAR digunakan melalui algoritma imej untuk melakukan pengesanan bangunan. Kaedah kami mencapai hasil yang menjanjikan ke atas pemandangan yang besar dengan kesempurnaan, ketepatan dan matriks kualiti yang kami ada untuk nilai purata penilaian berasaskan objek ialah 97%, 99% dan 99%. Matlamat kedua menggunakan algoritma pembelajaran mendalam(DL) untuk meramalkan penderia terbaik untuk pengesanan, sama ada LiDAR, optik atau gabungan LiDAR dan fotografi udara resolusi tinggi, untuk mengetahui mana yang paling sesuai untuk pengesanan bangunan dengan sedikit atau tiada. campur tangan pengguna. Manakala julat yang boleh diterima untuk pengelas yang baik (indeks TPR dan TNR) hendaklah 100, tiada satu pun daripada yang dinyatakan di atas berada di bawah ambang sembilan puluh. Sebaliknya, kami mempunyai 97%, 93% dan 91% untuk nilai penilaian berasaskan piksel , masing-masing untuk kaedah pembelajaran mendalam. Kami menguji pada A1, A2, A3 dan penemuan kami DSM mempunyai ketepatan tertinggi berbanding dengan penderia lain sahaja. Bagi kawasan Kawasan 1 (A1), nilai ketepatan keseluruhan 93.21%, dengan pekali kappa 0.798. Juga, nilai

ketepatan keseluruhan optik ialah 87.54%, dan pekali kappa ialah 0.630. Manakala bagi pelakuran, pekali keseluruhan dan kappa di sini ialah A2(94.30%, 0.859).. kesimpulannya, penyepaduan LiDAR dan fotografi Udara mengatasi semua optik dan DSM. Kelemahan imej dan set data LiDAR telah diberi pampasan melalui gabungannya. Selain itu, model yang dicadangkan telah dinilai pada tiga bentuk bangunan di lokasi yang berbeza dengan bentuk bumbung yang berbeza untuk penyelidikan ini; tiga bentuk jenis perumahan/bangunan telah dipertimbangkan: kompleks, bangunan tinggi dan bangunan pangsapuri berkembar tunggal rendah sahaja. Hasilnya boleh diabaikan di kawasan kajian dengan membandingkan ketinggian LiDAR DEM dan GPS pembezaan. The.RMSE ialah 0.11 untuk persekitaran heterogen, dan bentuk bangunan bercampur untuk bangunan tinggi membentuk RMSE ialah 0.002 m untuk bangunan tinggi manakala untuk pangsapuri kediaman rendah, nilai RMSE kami Root bermaksud ralat segi empat sama 0.003m. Kajian menunjukkan kapasiti model kami untuk meningkatkan pengesanan bangunan bandar dan mengautomasikan objek bangunan. Ia adalah penunjuk prestasi cemerlang. Teknik yang dicadangkan boleh membantu mengesan dan menyelesaikan masalah pengesanan bangunan bandar.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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ALS	Airborne Laser Scanning
DP	Douglas Peucker
DSM	Digital Surface Model
GCP	Ground Control Point
Model	LiDAR-driven Model
LiDAR	Light Detection and Ranging
LOD	Level of Detail
MLS	Mobile Laser Scanning
NDVI	Normalized Difference Vegetation Index
DEM	Digital elevation Model
nDSM	normalised Digtial surface model
INS	Inertial Navigation System
CNN	Convolutional neural network
GPS	Global positioning system
3D	Three-dimensional
CNN	Convolutional neural network

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Identifying urban areas' geographical distribution and expansion is critical for planning, resource administration, and mapping. The built-up regions are among the most fundamental actions necessary to map the built-up areas. When conducted using traditional methods such as ground surveying and aerial photography, any mapping operation necessitates many resources**.** The issue of rapid and reliable mapping of urban built-up environments is made more challenging by the sometimes fast urbanization process (Bhatti & Tripathi, 2014; Q. Y. Zhou & Neumann, 2013). A proficient probe of the built environment is suitable for the future world where human functionalities might be replaced by automation and machines. The urban environment is exceedingly complex and diversified. This is chiefly because the vast majority of the human population lives in urban areas. With over half of the earth's population presently residing in urban centres, the well-being of societies is heavily reliant on the efficiency of the city area (Ali et al., 2017; Ok, 2016)

According to the UN report, urbanization has become an unavoidable phenomenon with the global population's sustained growth. Presently more people live in urban areas than in rural areas. The urban spread intensifies and is expected to exceed 6 billion by 2050 in 30 years. Cities in emerging nations will account for 95% of the expansion. This drift to the city areas will rise to 2.5 billion inhabitants, primarily in Asia, Africa, and Latin America, comparable to 66% of the world's population. These urban areas are often faced with the challenge of maintaining their infrastructure and offering timely deliveries to safeguard the well-being of their residents (UNDESA,2019). It is anticipated that 40% of the world's population would need sufficient buildings for their housing, which equates to nine years of construction of ninety-six thousand new apartments per day. These numbers suggest that the expansion of informal settlements will unavoidably constitute global urbanization. The accelerated pace of urban expansion challenges city planners in ensuring effective urban infrastructure administration and, at the same time, reducing environmental damage and proactively responding to the increasing demand of cities. The present-day urban planners need to have technical awareness of the complex challenges that modern cities are faced with; one of the key urban features is looking for a home with access to housing delivery(Barney cohen, 2006; Lojanica et al., 2018)

In addition, efficient urban information is a crucial precondition for strategic development for city planning. We need to respond aggressively to the expanding demand of our cities by consistently mapping, monitoring, updating, and having accurate, detailed plans(Kadhim et al., 2016). The importance of the urban planning unit in overseeing the physical evolution of towns/cities by building a framework and settings to serve varied requirements, such as social, cultural, financial, and leisure, and to create a better for both affluent and poor people, is often noted above. Hence, the work of urban planners is a time-consuming and challenging task involving the designing and building of cities (Judyta, 2016). There are numerous types of house property available right now. Property costs vary depending on their category, size, and location. Semi-D, terrace houses, and bungalows, amongst many others, are residences with the land.

Condominiums and apartments in the realm of housing: we have two broad categories of housing, namely residential and commercial properties (Aurand, 2010). These can be further categorized into:- Residential properties consisting of condominiums, residential houses, serviced apartments, and apartments all fall under the residential property. It is only utilized for domestic uses, not for commercial or official reasons. Let us look at the many types of residential properties available. Residential houses include single-family detached houses, terrace houses, and semi-detached houses (Lu et al., 2014). Numerous families frequently live in the same building in terrace houses and semi-detached houses. It is connected but is divided by fences or walls. This type of property is available on various levels, including one, two, and three stories. Most people, particularly families, choose residential houses over other dwellings because they provide more living space.

A condominium includes recreational amenities and 24-hour security with swimming pools, tennis courts, gyms, convenience stores, and other standard amenities. On the other hand, apartments are usually living units in high-rise or low-rise buildings. Moreover, most service apartments are found in commercial districts at the many business properties available (Aurand, 2010). Consequently, it becomes imperative to gather information about how urban houses or building objects are distributed and used.

The current technology advancement supports new home solutions (Kadhim et al., 2016). This information offers city planners awareness, assisting them in managing existing urban infrastructure, and planning for imminent cities is critical for reporting on advancements in Sustainable Development Goals (SDGs (Srivastava et al., 2019)). The extraction of buildings acquired via remote sensing technology, a competitive technology, is reliable, large-scale, and affordable (Lai et al., 2019a). Therefore, Urban remote sensing is one vital aspect of geospatial technology used to acquire information to understand and forecast the diverse urban dynamics that support a sustainable decision system (Ngo et al., 2017). It has become increasingly essential for balancing competing goals and solving complex challenges like maximizing new building locations or identifying the viability of a dumping area. Nevertheless, field surveys, imagery, drone, and radar can perform the task of feature mapping, and it is often time-consuming, costly, and conventional in practice (Han et al., 2014; Torok et al., 2013).

1.2 Statement of the Problem

The information about building location and types is a prerequisite for planning. The cost of embanking on traditional field Surveying for the automatic extraction of the position of different building forms in urban areas has various challenges: Buildings come in multiple forms, shapes, designs, densities, data collection methods, registration blunders, and locations, among others. These complexities pose an issue for urban planning authorities in the precision mapping of buildings features. It is especially challenging to acquire complete, accurate, detailed building geometric and volumetric details about the buildings from the ground over a broad area with complex building forms (Awrangjeb et al., 2010; Yu et al., 2010). The cost of traditional field Surveying methods for this purpose is time-consuming labour-intensive, and expensive; although highly precise, on the other hand, aerial photographs are updated more often for provincial mapping purposes in numerous nations (Acar et al., 2018; Song et al., 2019) Classification algorithms relying on examining a single pixel are not always effective in extracting features of interest from high-resolution orthophotos (Ok, 2016). The spectral complexity of urban land-covered topographies would weaken by employing per-pixel analysis to distinguish natural and artificial elements. Also, aerial photogrammetric surveys generate massive data quantities that necessitate parallel processing and, as a result, a significant investment in hardware and software (Chen et al., 2020a; Yu et al., 2010). Lastly, the loss of information: buildings are 3D objects, but the third dimension is lost in 2D images. There is no perfect approach for automation extraction from images for building extraction. Hence, the image extraction process is slow, requires highly trained personnel, and is error-prone. Some key reasons why only images do not provide adequate output occlusion: in urban areas, building facades can obscure the view of other objects in addition to shadows (Fang et al., 2019; Varol et al., 2019). One of the most remarkable innovative technologies in the 21st century is the emergence of Airborne LIDAR sensors. These technologies are all-weather independent, have fast data acquisition time, and penetrate canopies. Its point cloud is dense and provides highly accurate vertical coordinate information to extract 3D objects on the earth's Surface (D. Li et al., 2020a; Tarsha Kurdi & Awrangjeb, 2020a). A thick point cloud of LIDAR data reflects the city area's complicated morphology, allowing vertical information to be extracted. LiDAR point clouds can be utilized for automated modelling workflows and visualizing urban areas. The proliferation of the LiDAR can be a cost-effective method for automated mapping and can be employed in urban management (Awrangjeb et al., 2010; Tarsha Kurdi & Awrangjeb, 2020b).

Urban buildings are essential in many facets of life in Malaysia and worldwide; applications could span from economics, safety, planning, taxation, and many other areas. LiDAR is widely used for urban mapping, detection, monitoring and maintenance. Its high spatial resolution and mapping accuracy make it an interesting catch (Raber & Cannistra, 1935). The sensor has also gained popularity in the geospatial world due to its low cost and high reliability (Trinder & Salah, 2011). Compared to airborne laser scanning, aerial photographs are often updated for provincial mapping purposes in numerous Nations (M. Li et al., 2018; Xie et al., 2018). As a result, aerial photography with detailed building boundaries can be integrated with LiDAR data to improve building extraction accuracy. The difficulty of quickly creating Digital Elevation Models (DEM) from spectral imagery data as passive sensors on the one hand, and the lack of textural details in LIDAR data on the other (Chen et al., 2020; Nguyen et al., 2020). Several methods have been developed and set up to address these issues extraction (Li et al., 2020b; Ullo et al., 2020). The combination of Airborne LiDAR and very high-resolution aerial photography tends to compensate for the weakness of the other and hence could improve buildings detection and extractions. The goal of this study is to develop a method for detecting and extracting urban building models using LIDAR and high resolution aerial image-based sensors: The findings will serve as a foundation for future data management, knowledge management, and strategic planning and could serve as a support to policy-making by the government agencies, planning offices, and even managers connected with planning, research, engineering, and construction make meaningful decisions that would be efficient and beneficial to the public and their immediate communities.

1.3 Motivation

Awareness of the wealth of information derived from the mapping accuracy of Airborne LiDAR has the capacity for detection, and 3D reconstruction can produce an inclusive understanding of broad city research. The LiDAR sensor is affordable and dependable. It is now a primary focus for a variety of applications, such as urban planning, Surveying and mapping, virtual information systems for tourists, and the generation of 3D city models with other city applications (Kabolizade et al., 2012; T. Lu et al., 2018a). The Airborne LiDAR technology delivers the unusual ability in gathering exceedingly accurate and densely sampled surface elevation capacities over urban areas. Consequently, it is necessary for city managers and urban planning agencies to grasp the mountainous opportunities of this emerging technology and its equivalent applications. This study proposes a practical strategy for building extraction in a city with a wide range of structures on a large scale. There is an urgent need for accurate, precise, and consistent updates of building footprints for proper planning and management. The ability to sustain productivity when extending from a small area to a wide area is essential because of the study size scale. The nature of urban environments can be very challenging, where buildings of varied geometry such as shapes, colours, and sizes can be found and cannot be generalized across urban areas with varying vegetation and density distribution (Nguyen, Daniel, et al., 2020b)(Nguyen, Daniel, et al., 2020). This complexity could pose a challenge for developing building extraction solutions for large-scale building extraction (Awrangjeb et al., 2020). A great deal of research with relatively significant results has been documented over the years, assuming building shapes implemented geometrical assumptions(Syed Ali Naqi Gilani et al., 2016; Yan et al., 2015; K. Zhang et al., 2006).

The building features are one of its major vital objects and play a significant part in the economic and daily life of the residents(Feng et al., 2020). Nevertheless, such premises and restrictions restrain the building extraction process's scalability, particularly across vast areas consisting of scene complexity and diverse building forms: sensor dependency and incomplete cue data extraction. Therefore based on this premise, it is appropriate to have a solution that will be a highly accurate, intelligent, and accessible approach. Over large areas with comparative computational ease, Robust is suitable for various urbanized areas without depending on predefined conditions, restrictions, or past knowledge of the scenes and buildings features. Airborne Laser scanners and high-resolution aerial imagery sensors are the most suitable for urban feature detection, extraction and reconstruction (Elias, 2002; Tomljenovic et al., 2016). The resultant model output can enable city planners, real estate agents, and the government to decide about urban features.

1.4 Objectives

The main aim of this study is to develop a framework to improve building extraction in an urban area.

The following are the specific objectives of the study:

- ❖ To delineate based on LiDAR alone and orthophoto to create a 2D building model.
- ❖ To develop an Automate building extraction by the fusion of LiDAR with orthophoto
- ❖ To validate the developed process for building type classification.

1.5 Research Questions

To fulfil the overall research objectives, the following research questions are addressed in this research:

- ❖ What modelling technique provides an automated building extraction assignment for the Urban modelling
- ❖ How does Airborne Laser Scanning data serve as an information source for Urban feature extraction?
- ❖ How does the integration of LiDAR with orthophoto improve modelling results using an image and object processing approach provides for the 3D city for city planners and designers?

1.6 Scope and Limitations

There are several approaches for urban feature operation; however, specific attention is given to buildings, not foliage or trees, power lines or roads. Minimal to no user intervention is employed to automate the process as much as possible, and the final output expected is a 3D block model. This study explores the Airborne Laser scanning survey mission, also referred to as LiDAR techniques, in combination with aerial imagery for urban building extraction. This synergy is preferred to conventional field Surveys, which are costly, time-consuming, and laborious. However, the coverage is equally broad, which takes time to gather such precise information. Apart from that, some areas are not accessible on foot, but it is easier to access such places with an airborne laser scanner. Specific interest is given to building objects and automating the process as much as possible with minimal user intervention in the extraction. The final output is expected to be a 3D polygon model.

Nevertheless, the details at disposal are expensive and huge. The research is entirely a data-driven concept used for many applications. The urban building types considered here are the residential, apartment, high rise buildings, mixed building apartments, also referred to as complex building types and single detached low apartments. All those mentioned above are significant considerations for smart cities and urban planning. The method developed for detecting urban building objects was applied to various building forms to test its applicability within study areas with various landforms and roof types.

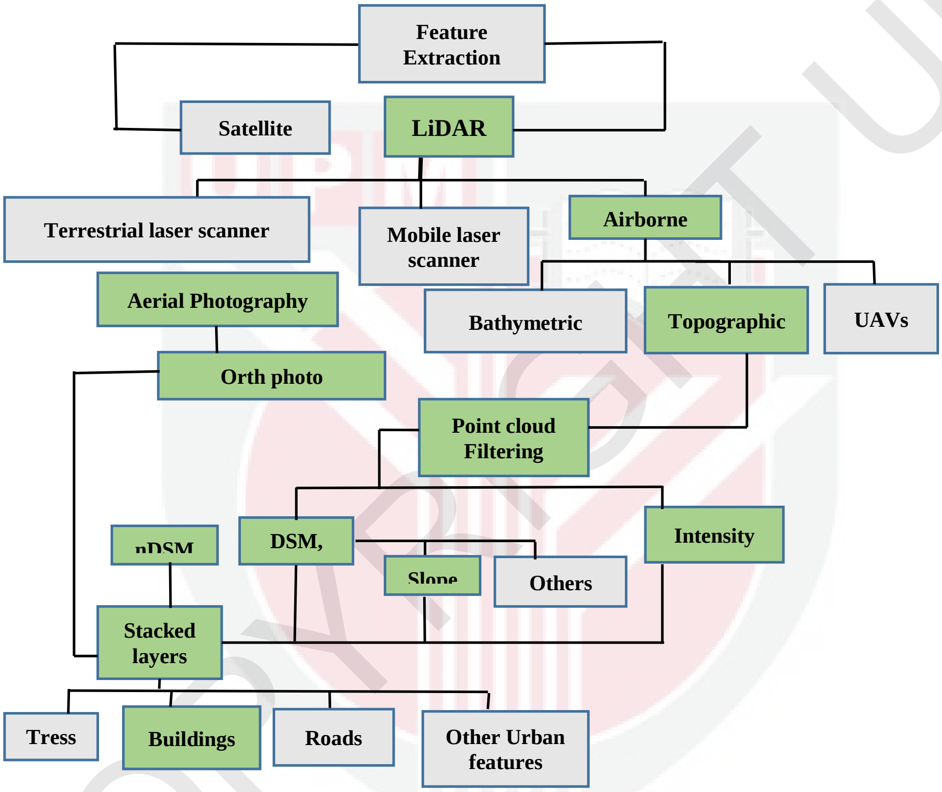

Figure 1.1 : Scope of the study shows specific methods employed in the green colouration study

1.7 Thesis Outline

This thesis is structured into five chapters: Chapter one entails the research background and the study's problem statement, objectives, and significance in addition to the research questions, scope, and, lastly, the overall structure of the thesis. The chapter concentrates on instrumentation, scanning procedures, and raw point cloud processing. Chapter Two describes the literature review of building detection, extraction, and modelling with Airborne laser scanning. Additionally, several applications of laser scanning products advance in sensor growth and feature extraction using the machine learning method. Chapter Three presents in the general methodology slightly the description of the study areas. First, the laser scanning survey of the UPM and its surroundings in Serdang with raw point cloud processing from DSM, DTM, Curvature, laser intensity images, and 3D point datasets were produced. This was advanced with specific methods employed to reach each objective,

Chapter Four concentrates on the results and discussion. The detection, extraction, classification and 3D modelling approach, detection accuracy, reliability, and transferability are described with supplementary tables and figures. Also presented in the chapter is the potential of a 3D model for building identification and documentation. Lastly, Chapter Five provides the study's general conclusion, recommendations, and future study.

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