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To cite this article: Zohari Akob *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **512** 012037

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IOP Conf. Series: Materials Science and Engineering **512** (2019) 012037 doi:10.1088/1757-899X/512/1/012037

Deployment of GIS + BIM in the construction of Pan Borneo Highway Sarawak, Malaysia

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Abstract. Construction of the Pan Borneo Highway across 786km of the Malaysian state of Sarawak is leveraging on technology to achieve greater efficiency and productivity throughout the project's life-cycle. With a tight construction delivery timeline and budget to keep in check, the ability to design and plan efficiently, minimize errors and discrepancies during construction, manage risks, visually monitor and track progress at the site, and finally to establish accurate 3D as-built models for future asset management are among the challenges faced. To address such challenges of a linear construction, Project Delivery Partner, Lebuhraya Borneo Utara (LBU), has deployed the use of Malaysia's first-ever Highway Information Modelling (HIM) as an integral part of its Integrated Project Management System. HIM is a combination of Geographical Information Systems (GIS) and Building Information Modelling (BIM) which incorporates three dimensional (3D) parametric highway models and optimal utilization of accurate and precise Geospatial Datasets. This paper discusses the application of GIS in development of the Pan Borneo Highway Sarawak project and its role as a foundation for design, planning, monitoring of construction and operation and maintenance of the future highway asset by providing precise data in a timely and cost-efficient manner.

1. Introduction

The long-awaited Pan Borneo Highway in the Malaysian state of Sarawak on the island of Borneo will span an estimated 1,060km. Works is on-going to develop and upgrade the current 2-lane single carriageway which connects the entire state into a 4-lane dual carriageway. The project is being undertaken by the Government of Malaysia and State Government of Sarawak through a Project Delivery Partner (PDP). A special purpose vehicle private entity, Lebuhraya Borneo Utara (LBU), has been appointed as the PDP.

Costing RM16.5 billion, Pan Borneo Highway Sarawak is deemed to be the single largest infrastructure project ever awarded by the Government in Sarawak. Implementation of the project involves construction of 786km of a new 4-lane highway in 11 works packages. Works began in January 2016, with the Highway targeted for completion in 2021. Operations and maintenance of the highway will follow upon completion of construction.

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As PDP, LBU is in charge of the entire project lifecycle - from planning to design and construction, to operations and maintenance of the completed highway. LBU is committed to deliver the project on time and within budget.

There are numerous challenges in a linear construction project, particularly in highway construction, from challenges at project commencement, to engineering design stage, construction and also asset management. This paper highlights efforts to address issues that arise during construction stage and also anticipated obstacles post-construction by leveraging on technology, specifically with the use of Geographical Information System (GIS) and Building Information Modelling (BIM).

Project visibility is crucial for the project management team to monitor progress according to schedule and cost agreed. Visibility facilitates executive decision-making by providing accurate information and a realistic perspective of the project being executed, especially in construction stage. In the case of the Pan Borneo Highway Sarawak, it is burdensome to manually monitor progress of thousands of activities and tasks for the whole stretch of the highway. Physical progress monitoring through site visits is time consuming and employs many resources.

Post-construction, it is imperative for the asset owner to have an adequate geodatabase for maintenance of the asset. A complete geodatabase is important to develop a systematic plan for linear asset management and maintenance. Many road issues can be resolved faster with the availability of geo-information in a maintenance database.

This paper discusses the integration of GIS and BIM as a platform to support project management, construction management and asset management. In the case of the Pan Borneo Highway Sarawak, a dedicated task force was formed to manage the integration process of GIS and BIM to ensure the project is delivered on time and with minimal errors.

A foundation of the GIS and BIM project is geodesign which combines geography with design by providing designers with robust tools that support rapid evaluation of design alternatives against the impacts of those designs. Geodesign infuses design with a blend of science and value-based information to help designers, planners and stakeholders make better-informed decisions [6].

GIS plays a crucial role in linear projects, especially in infrastructure such as highway construction, pipeline and railroads. Meanwhile, BIM plays a major role in modern construction. By integrating GIS with BIM in one complete system, Malaysia's first-ever Highway Information Modelling (HIM) was developed for the Pan Borneo Highway Sarawak. GIS data provides the geolocation using real world coordinates, while BIM represents the physical and functional characteristics of the facility.

With technology, implementation of the Pan Borneo Highway Sarawak has been able to achieve increased efficiency of construction and project management with the aid of precise data provided in a timely and cost-efficient manner throughout the lifecycle of the project.

2. Methodology Overview

2.1. Design Stage

LiDAR enabled preliminary engineering design (PED) and detailed engineering design (DED) for the entire alignment to be completed according to the project implementation schedule as stipulated in the Project Delivery Partner Agreement with the Government.

In developing HIM for the Pan Borneo Highway Sarawak, all required data was captured using several methods and technologies. This included satellite imagery, ground survey data, LiDAR data, Unmanned Aerial Vehicle (UAV) imagery and Underground Detection Mapping (UDM). From there, all gathered data was processed to produce GIS layers to be used as base data for the designer to produce design drawings.

The integration of GIS and BIM has enabled better decision-making and improved communication. By using GIS and BIM together with time information, project teams now have a better view on the impacts of decisions made before, during and after construction of the project.

2.2. Construction Stage

Monthly UAV imagery at various locations along the 786km construction site are captured to assist in progress monitoring, towards ensuring the project is completed on time. Concurrently, GIS data together with UAV imagery is merged in a web-based monitoring platform designed for this project, namely HIM WebGIS. From WebGIS, key stakeholders, management, site personnel, contractors and consultants, have access to data to monitor progress of the project from anywhere in the world.

LiDAR will again be conducted upon completion of the highway to support the BIM/HIM requirements.

3. Geographical Information System (GIS)

Geographical Information System (GIS) is a framework for gathering, managing, and analysing data [7]. Rooted in the science of geography, GIS integrates many types of data. It analyses spatial location and organizes layers of information into visualizations using maps and 3D scenes. With this unique capability, GIS reveals deeper insight into data such as patterns, relationships and situations, where this would help the users to make the right decision [1].

In producing an effective solution for the Pan Borneo Highway Sarawak, certain methodologies have been conducted, such as topographical survey, LiDAR data feature extraction, Underground Detection Mapping (UDM), Unmanned Aerial System (UAS) and Web GIS as a common data environment to manage data.

- Ground Control Marker Survey Program: Prior to beginning the survey collection, a reconnaissance was done of existing controls in the project and surrounding areas. From the findings, controls to be included in the network were selected based on their location, horizontal and vertical orders, and accessibility. This program was introduced to establish the control network for the entire project area, towards ensuring a fixed common reference and an accurate and reliable survey control.
- Polygonal Control Network – Primary**:** A primary network of Global Positioning System (GPS) network control stations was established at certain intervals along the highway alignment. These polygonal networks (or closed traverse survey) allowed for the identification and correction of any 'erroneous' local datums or measurements, without compromising the accuracy of the total survey control network. A primary network of 75 GPS network control stations was established at approximately 15km intervals along the Pan Borneo Highway Sarawak alignment.
- Polygonal Control Network – Secondary: Temporary Bench Marks (TBM) support local site survey and investigation works (such as crossings and bridges), underground utility detection, as-built and hydrography / bathymetry surveys (as connections when these come on-shore) to ensure they match with the primary survey network. A secondary network of over 324 TBM was established, at around 2km spacing, interspersed between the primary Ground Control Marker (GCM) stations along the Pan Borneo Highway Sarawak alignment [3].

As part of the linear Pan Borneo Highway project, a complete geospatial engineering solution was implemented to manage and enhance the infrastructure lifecycle - from road design, construction, and maintenance. Throughout the infrastructure lifecycle, key processes were improved as the geospatial engineering solutions were deployed across the project team for data management, analysis, and coordination. As illustrated in Figure 1, this included data collection and as-built surveying, route planning and optimisation, pre-design analysis, infrastructure design, construction management, and operations and maintenance.



Figure 1. Geospatial Engineering approach for the infrastructure development lifecycle of the Pan-Borneo Highway Sarawak project

3.1. Data Acquisition

3.1.1. Satellite Imagery. Imagery is a type of data useful for many GIS applications and is defined as any type of photograph. Photographs used for GIS projects consist of images gathered from a satellite or aircraft. Printed topographic maps that are scanned as digital images also constitute imagery. In terms of the specific GIS data type, imagery is considered as raster data.

3.1.2. Light Ranging and Detection (LiDAR). LIDAR systems are varied and flexible. It should be specified to match the intended target area and user requirements. The GIS teams deployed leading-edge imaging systems, and applied the latest best-practice techniques and knowledge. This is to ensure a truly useful multi-disciplinary dataset is acquired to meet both the immediate and long-term requirements of this project.

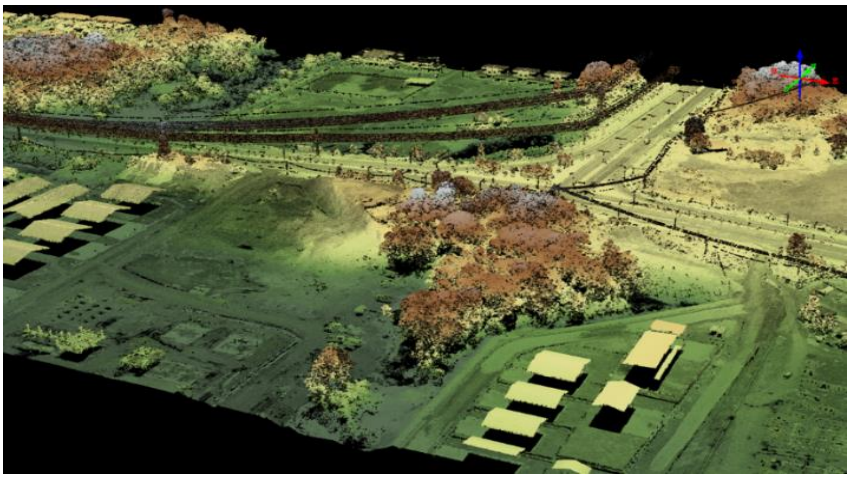


Figure 2. LiDAR data from Pan Borneo Highway Sarawak Project

By utilizing LiDAR technology, multiple output could be generated in shorter time in comparison to ground survey data. A single flight LiDAR data acquisition was able to produce multiple resolution options to result in various outputs to meet both mapping and modelling needs. LiDAR data products

include Raw LiDAR geolocated data, processed point cloud data, Digital Surface Model (DSM), and Digital Terrain Model (DTM).

For Pan Borneo Highway Sarawak, the derived vector contour line mapping was acquired and utilized from this method as shown in Figure 2 above. In addition, GIS- and CAD-compatible digital surface models were generated to produce basemap layers for engineering, planning, and long-term monitoring.

In short, LiDAR data provided the Pan Borneo Highway Sarawak team with a broad coverage of high resolution data applications, such as high accuracy terrain/topography, road geometry, utilities, lane mapping, slope, structures, and many others. Figure 2 illustrates processed LiDAR data comprising approximately 23.6 billion LiDAR points captured throughout the 786km stretch of the Highway.

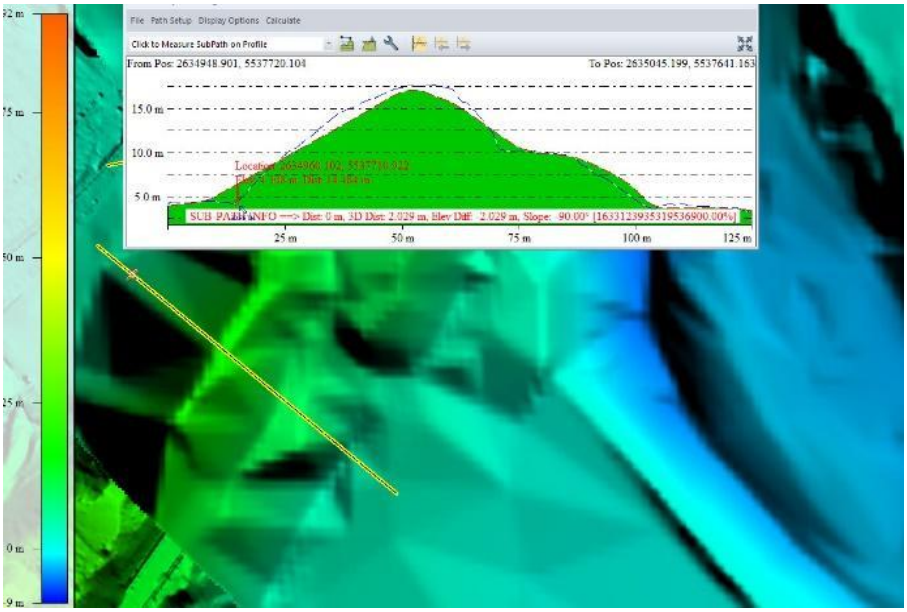


Figure 3. Ground Survey Data vs. LiDAR Survey Data

Reliability and accuracy of captured data (see Figure 3) is important. In comparing the precision of ground survey data versus LiDAR survey data, it was found that the LiDAR points were able to provide more information, thus reducing design errors and ensuring smooth progress during construction. With accurate elevation data and well defined DTM and DSM, such data can also be used as input into other powerful Alignment Optimisation Systems, such as Quantm System.

For the Pan Borneo Highway Sarawak, the LiDAR points density captured within one square meter range is between 20 to 30 points as shown in Figure 4.

LiDAR of the 786km highway alignment took 6 months to complete, as compared to 18 months if solely ground surveys were used. The LiDAR data thus enabled the preliminary engineering design (PED) and detailed engineering design (DED) for the entire alignment to be completed according to the project implementation schedule as stipulated the Project Delivery Partner Agreement (PDPA).

The final product of LiDAR is GIS. Among its applications was for land acquisition. In addition, GIS enabled the team to identify land usage and encumbrances, as well as resolve design conflicts which were not captured by conventional drawings.

Going further, as per the BIM/HIM requirement of the PDPA, LiDAR is proposed to be carried out upon completion of construction of the Highway replacing the normal conventional method for As-Built survey. In addition, around 28,000 aerial images were captured during the data acquisition flight. The resolution of images captured is 5cm, which is considered as very high quality and reliable aerial imagery for engineering usage.

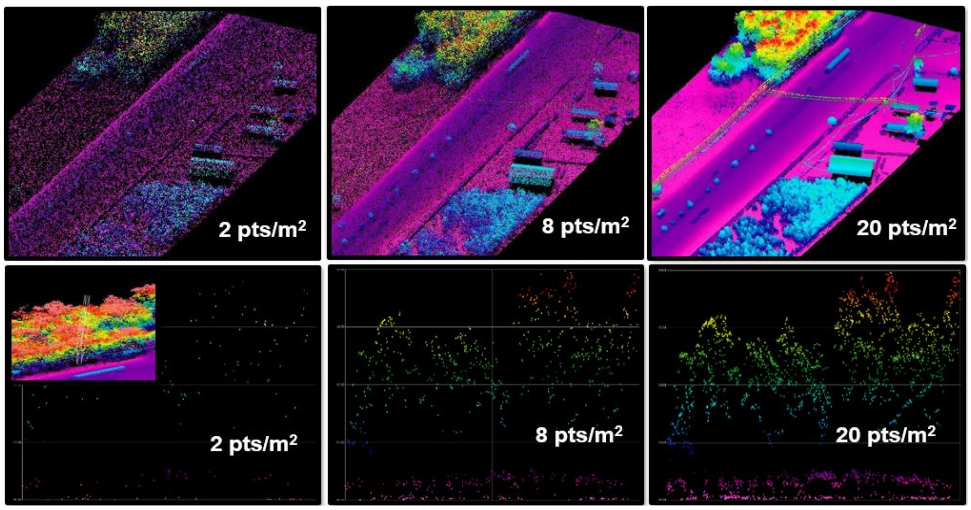


Figure 4. LiDAR points density captured in a square metre area

3.1.3. Underground Detection Mapping (UDM). The state of Sarawak is currently implementing major infrastructure developments. While doing so, the challenge lies in accurately detecting what lies underground - thousands of kilometres of water pipes, gas pipelines, electric cables and telecommunication cables. These underground utility cables, pipes and sewerage networking have to be detected using correct and proper devices to ensure accuracy, in order to avoid or minimise accidents by utility contractors doing excavation works.

Data collected from detection works were then surveyed and incorporated into the surveyor's overall reports and drawings. All such information has been studied, designed and consulted prior to excavation works.

Underground Utility Detection and Mapping is an important element at the planning level as shown in Figure 5. The application of Underground Utility Detection helps improve decision-making for relocating utilities, designing new proposed routes, quality survey, costing for project execution and data inventory enhancement [2]**.**



Figure 5. Underground Utility Detection & Mapping in a high density area

3.1.4. Unmanned Aerial Vehicle (UAV). Unmanned aerial vehicle (UAV) is a type of aircraft that operates without a human pilot on-board. Recent technologies enable UAV to be used for mapping and site monitoring purposes [8].

For the Pan Borneo Highway Sarawak project, UAV are used to facilitate monitoring of progress. Monthly aerial imagery is captured using UAVs to see and track changes of progress made at the various construction sites. The data will then be processed into meshed imagery which is uploaded in the WebGIS (see Figure 6).

Data from the UAV can be compared monthly through time-slider feature in the WebGIS. The time-slider allows management and construction personnel to see the development and changes made in construction site on a single screen. Such technology has made project management more efficient and accountable.

Images captured through UAV are also meshed to generate 3D reality models for certain areas that require more detailed monitoring and amplification [5].



Figure 6. 3D Model from UAV photo mesh

3.2. Data Processing & Management

The GIS designer supports road designer to perform engineering related analysis by providing relevant geospatial data. For Pan Borneo Highway Sarawak, analysis is done by combining information from multiple independent layers and applying spatial operations to address a wide range of problems. This will allow users to visualize the results and gain deeper insights to make important decisions.

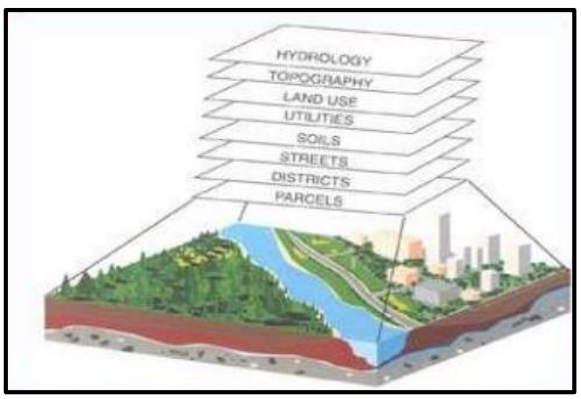


Figure 7: Geographic Data for Geoprocessing

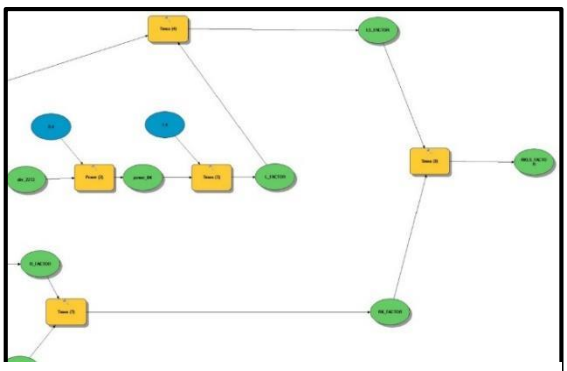


Figure 8. Example of Automation Analysis using ModelBuilder

Geoprocessing is a framework and set of tools for processing geographic and related data as illustrated in Figure 7 [6]. Various geoprocessing tools can be used to perform spatial analysis or to manage GIS data in an automated way. Geoprocessing is an integral part of the GIS analysis that creates new data from existing GIS data. Users are able to create a model to automate and keep track of the workflow.

Geoprocessing tools in ArcMap perform an operation on an input dataset and usually create a new output dataset. Geoprocessing tools perform analysis, data management, editing and other operations. ModelBuilder (Figure 8) is a graphical interface for making GIS models. It is one of the best environments for exploring ArcGIS tools, learning how inputs and outputs tools are used, and visually understanding how GIS modelling works. Figure 9 shows an example of output from geoprocessing.

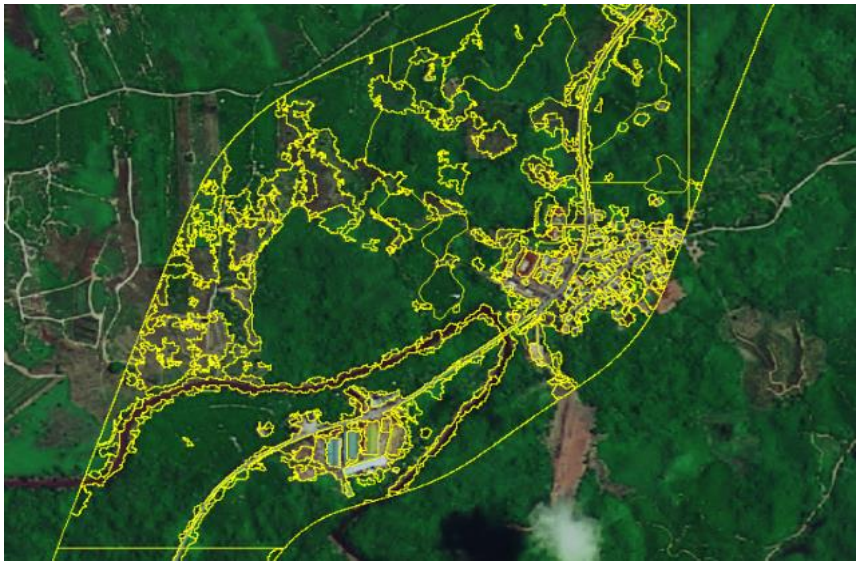


Figure 9. Example of Geoprocessing Output: Landcover Data

3.3. Data Visualization

3.3.1. WebGIS. Rapid deployment and implementation of a WebGIS-based Project Tracking and Monitoring System has helped Pan Borneo Highway Sarawak Project Management Team increase project delivery efficiency with access to tracking and monitoring functions on the computer and mobile devices.

Key datasets are integrated into the WebGIS server, and accessed by the Project management team and contractors as and when required. Database development is fast-tracked and real-time, as shown in Figure 10 whilst maintaining rigorous database design protocols to ensure compatibility for later conversion into a working Road Maintenance and Management System (RMMS), as illustrated in Figure 11, if required [4].



Figure 10. Time Slider feature in WebGIS

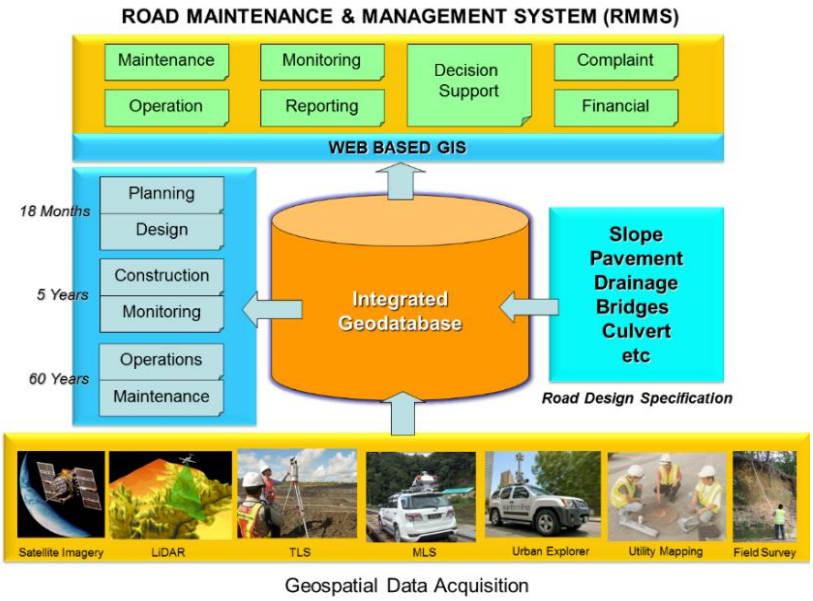


Figure 11. Geospatial Data Acquisition for RMMS

3.3.2. ArcGIS. ArcGIS 3D Analyst extension and ArcMap were used to provide a variety of ways to symbolize and display different types of GIS surface formats, such as rasters, Triangulated Irregular Networks (TIN), terrain and LAS datasets (point cloud format). Rasters, TINs and LAS datasets can be easily displayed inside ArcScene using different symbology options. Figure 12 and Figure 13 show different sets of LiDAR data displayed in ArcGIS.

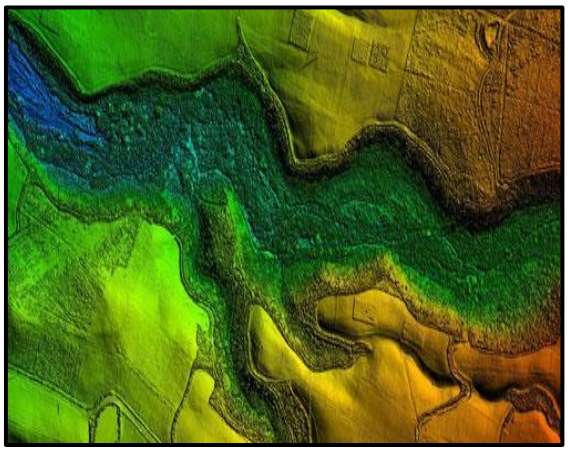


Figure 12. Example of LiDAR and Terrain

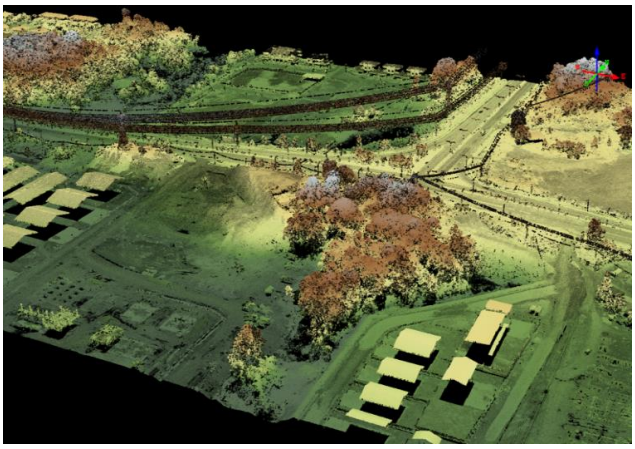


Figure 13. LiDAR point cloud of Pan Borneo Highway Sarawak

4. GIS + BIM Integration

GIS amplifies the value of Building Information Modelling (BIM) design data (2D drawings and 2D Models) through visualization and analysis of structures in the context of the natural and built environment.

The integration of GIS and BIM in the Pan Borneo Highway Sarawak to generate the first-ever Highway Information Modelling (HIM) has enabled better decision-making and communication. By using GIS and BIM together with time information, project teams now have a better view on the impacts of decisions before, during and after the construction of a project.

The process of integration was not without its challenges. The biggest obstacle to achieving GIS and BIM integration is the process of integrating BIM data, in the form of an assortment of proprietary files, web and database information stores, with GIS.

Engineers utilized information from BIM in GIS analytical and visualization tools. Converting CAD and BIM data into ArcGIS is the first step towards integration. This included converting individual BIM elements to GIS features, using a BIM file as a single complex GIS feature, or using BIM-derived data as a complex point marker symbol. The results of the integration can be viewed in WebGIS or any 3D model viewer as illustrated in Figure 14.



Figure 14. Integration of LiDAR 3D Point Clouds Data and BIM 3D Model for Batang Rajang Bridge, Pan Borneo Highway Sarawak

5. GIS in Linear Asset Management and Maintenance

Maintenance of roads is undertaken to ensure the safety of traffic and to sustain the serviceability and appearance of the road. Road maintenance involves both corrective maintenance and preventative maintenance. GIS and BIM elements, through HIM, will add greater value in the future Road Maintenance Management System employed by the Government by enhancing the system with a complete geodatabase and updated asset inventory.

6. Conclusion

As at October 2018, development and implementation of 786km of the Pan Borneo Highway Sarawak is nearly half-way in its construction timeline. Works on site is progressing satisfactorily at 11 works packages which is further broken down into 25 sections. With a tight timeline to meet and budget to keep towards delivery of the Project, efficient project management that leverages on technology is key.

An example is the efficient usage of LiDAR, completed in record time, thus enabled preliminary engineering design (PED) and detailed engineering design (DED) to be implemented according to schedule of the PDPA with the Government.

For Pan Borneo Highway Sarawak, an Integrated Project Management System (IPMS) is used to communicate with multiple stakeholders and manage risks across the project lifecycle on issues regarding planning, design, construction and later to prepare for asset management.

A key pillar of the IPMS is the Highway Information Modelling (HIM), which is a combination of GIS and BIM and WebGIS. Used daily by project teams at site across Sarawak, consultants, contractors, head office teams and Government stakeholders, the integration of GIS and BIM has successfully increased the efficiency of construction and project management by providing precise data in a timely and cost-efficient manner through geolocation which is coupled with the physical representation and functional characteristics of facility from BIM.

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