Integration of Building Information Modelling with Geographic Information System for Underground Utility Mapping

Nurul Izzati Abd Karim*, Nur Shafika Alia Abu Bakar

Geoinformation, Faculty Built of Environment and Survey, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

Abstract. The accurate positioning of underground utilities plays a crucial role in managing urban infrastructure, especially in densely populated areas. Traditional 2D CAD drawings often fall short in representing both the depth and precise location of these utilities, which increases the risk of damage during construction and maintenance works. To address this challenge, this study explores the integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) to improve the mapping of underground utilities and enhance both accuracy and efficiency. The research was conducted at Kuala Terengganu, where data were collected using Unmanned Aerial Vehicles (UAV), Terrestrial Laser Scanning (TLS), Pipe and Cable Locators (PCL), and Ground Penetrating Radar (GPR). These datasets were processed in Autodesk Revit and ArcGIS Pro to generate a georeferenced 3D model of the underground network. The findings demonstrate a significant improvement in the accuracy and interoperability of utility data, enabling more effective analysis and visualization of networks. This approach minimizes manual effort, supports safer excavation, and assists urban planners and managers in making well-informed decisions. Overall, the integration of BIM and GIS strengthens the reliability, efficiency, and sustainability of underground utility mapping, contributing to safer urban development and improved infrastructure management

1 Introduction

Underground utilities comprising water mains, sanitary sewers, electrical conduits, and telecommunication networks constitute the foundational infrastructure of modern urban systems. Yet, their accurate representation remains a critical challenge. Traditional methods, including two-dimensional (2D) CAD drawings, as-built documentation, and disparate record systems, are inherently deficient in capturing the three-dimensional spatial configuration, material condition, and dynamic interactions of subsurface assets. These limitations precipitate utility conflicts, excavation-induced damages, project delays, and life-threatening incidents during construction and maintenance [1].

To mitigate such risks, Building Information Modeling (BIM) and Geographic Information Systems (GIS) integration offers a transformative paradigm. BIM provides semantically rich 3D models with attribute data (diameter, material, installation year, condition index) [2], while GIS enables geospatial contextualization, topological analysis, and real-time environmental integration [3,4]. When fused, they generate georeferenced, interoperable 3D utility models capable of supporting clash detection, risk forecasting, and lifecycle management. Integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) enables precise 3D asset modeling within a spatial framework [3,4]. Advanced sensing, Ground Penetrating Radar (GPR), Terrestrial Laser Scanning (TLS), and Unmanned Aerial Vehicles (UAVs) supports real-time data acquisition and model validation [5,6]. Despite potential, subsurface applications remain immature, with most studies focused on aboveground infrastructure [7]. Key barriers include data fragmentation, software interoperability, and lack of real-time updates, compounded by outdated records [4]. This study addresses these gaps by developing an integrated BIM-GIS framework for underground utilities in Kuala Terengganu, with direct relevance to high-risk areas like Masjid India and Putra Heights. By fusing GPR, TLS, and UAV data into a cohesive, georeferenced 3D model, it overcomes integration challenges data volume, format compatibility, and spatial accuracy [3,5]. The research delivers a scalable solution for enhanced safety, efficiency, and long-term sustainability in urban subsurface management [4,8].

2 Research Methodology

This study integrates Building Information Modeling (BIM) and Geographic Information Systems (GIS) with advanced data collection technologies Unmanned Aerial Vehicles (UAVs), Terrestrial Laser Scanning (TLS), Point Cloud Laser (PCL), and Ground Penetrating Radar (GPR) to develop a georeferenced 3D model of underground utilities in Kuala Terengganu. The workflow comprises four structured phases: (i) Data Acquisition, (ii) Data Processing, (iii) 3D Modeling, and (iv) BIM-GIS Integration and Validation. Each phase follows rigorous,

* Nurul Izzati Abd Karim: nizzati.ak@utm.my, nurshafikaalia@graduate.utm.my

reproducible protocols to ensure spatial precision, semantic integrity, and system interoperability.

2.1 Data Acquisition

This study was conducted in Jalan Sultan Muhammad in Kuala Terengganu because of the high density of the urban infrastructure and the diversity of underground utilities. There was a combination of advanced technologies that were applied to obtain precise spatial data of both surface and subsurface utilities. These were the methods used:

2.1.1 Establish Ground Control Points

Real-Time Kinematic (RTK) GPS technology was used to create as well as georeferenced all collected data by using Ground Control Points (GCPs) as can be seen from Fig.3. Five GCPs were used carefully placed in the study area to co-relate data generated by UAV, TLS, PCL and GPR technologies through a common coordinate system.

2.1.2 Unmanned Aerial Vehicles (UAV)

To record aerial photos of the study field, Unmanned Aerial Vehicles (UAVs) which are fitted with high resolution cameras (4000 x 3000 pixels) were used. The UAVs were able to achieve a height of about 80 meters which gave a balance in both picture clarity and the area that had been covered. The flight plans had overlapped sections (approximately 80 percent) so that there was no gap in coverage. The length of each UAV flight was approximately 15 minutes of which 12 minutes were solely used to capture the image and 3 minutes used in take-off and landing. A total of 40 high- resolution images (in grid fashion) were captured during the flight and then the images were processed with the help of Pix4D software which produced the georeferenced orthomosaics and Digital Surface Models (DSMs) and further modeled and analysed in the GIS system.

2.1.3 TLS Data Collection (for above-ground infrastructures)

High precision 3D point cloud Terrestrial Laser Scanning (TLS) was employed to scan the outside of the building, roads, manholes and above-ground utilities. Faro Laser Scanner was used to capture detailed points of surface characteristics with 1.5mm being the point density per scan. 22 scan positions were used to scan the whole study area. The scan was done at 8 minutes per scan where 7 minutes were spent to scan and 1-minute captured reference images. The acquired point cloud data has been processed and registered with the help of Faro Scene software and then imported into the Autodesk Revit and used to model the surface infrastructure in 3D, which gives a precise and detailed representation of the study area.

2.2 Pipe Cable Locator and Ground Penetrating Radar Scanning

To determine the location of utilities under the surface, Pipe and Cable Locators (PCL) and Ground Penetrating Radar (GPR) have been used. The RD 8100 Pipe and Cable Locator (PCL) was adopted in tracing metallic underground utilities like water pipes, electricity and communication cables. PCL transmits electromagnetic pulses that react with metallic utilities and accurate location, and depth of utilities can be detected. The scans would dedicate around 1 to 2 minutes per utility segment regarding the network intricacy. In non-metallic utilities (plastic pipes, and so on) the Mala GPR system was used. The GPR operates by directing care with electromagnetic waves of high frequency in the ground and reflects the buried objects that permit treasuring their location. The GPR scans were done 15 minutes per section which depended on the size and area conditions. The PCL data was also checked against the GPR data to ensure complete data when it came to the detection of underground utilities, especially where the plans of the underground utilities were poor or they were lacking.

2.3 Topographic Data Collection

GPS data was instrumental in collecting topographic information in the entire study area. The main target of this activity was to get accurate terrain point intensities of Jalan Sultan Muhammad of Kuala Terengganu to develop correct 2D site plans. RTK GPS technology with a high level of precision was used to obtain centimeter accuracy of horizontal and vertical measurements. The elevation and other topographic characteristics were also noted by the GPS device, and they were imperative in making quality 2D drawings. The drawings were taken as a starting point where the other data of other survey tools, e.g. UAV images and TLS scans could be incorporated. The GPS measurements were converted and plotted accurately in form of 2D maps which clearly reflected the topography so that the other instruments data would fit perfectly well in the modeling phase and that there would be an accurate fixing of the data in the modeling process.

3 Data Processing

After the data was obtained through the different technologies (UAV, TLS, PCL, GPR, and GPS) it was processed through several stages to make the raw data ready to be incorporated into the final BIM-GIS model. Data cleaning, alignment and processing were done as follows:

3.1 UAV Data Processing

Pix4D, a photogrammetry software, was employed to process the UAV data. Firstly, in the processing workflow is the alignment of the images, in which the tie points of the overlapping images were detected by Pix4D to align the images in 3D space. Images thus aligned were subsequently georeferenced based on the GPS data that the RTK system integrated on the UAV. This is to ensure that the obtained models were properly aligned in real-world coordinates. The stitching of images and production of 3D model of the study area onto a seamless product was then performed by the photogrammetry software. Pix4D automatically generated point cloud during processing and subsequently generated orthomosaics and DSM which were then ready to be analysed and incorporated into the BIM-GIS system.

3.2 TLS Data Processing

The data acquired by the Terrestrial Laser Scanning (TLS) were worked on using Faro Scene software. It started with the registration of point clouds using the available scan positions and aligning into a single model in 3D. The scan matching and scan registration was done using the Cloud-to-Cloud option of Faro Scene to make sure that all point clouds of different stations were properly aligned in space. After registration, the point clouds were cleaned after any unwanted data had been removed leaving only the required surface features. The surface infrastructure was modelled in 3 dimensions in Autodesk Revit after exporting and importing the point cloud data after cleaning it. It was also possible to optimize points density and determine proper pointing of data which was transferred to Revit to be further modelled and analysed with the help of Faro Scene.

3.3 Topographic Data Processing

The RTK GPS technology was used to gather GPS data to determine the accurate Ground Control Points (GCPs) of the study area. These were critical to georeferencing the data that was obtained using UAV, TLS, PCL, and GPR. GPS information was used to map the underground utility locations and the PCL and GPR were used to give the precise location of the metallic and non-metallic utilities respectively. The correction process entailed the correction of the coordinates of any possible discrepancy or error in the raw data so that all the readings were correct and matched the real-world coordinates. Topographic drawings were then created using the final corrected GPS data which incorporated all the positions of the utilities so that the final BIM-GIS model could be able to represent the underground utilities accurately.

4 BIM Modelling

Once the data was processed, the following step was to incorporate it into a (BIM) system with the help of Autodesk Revit. The main aim was to develop a 3D BIM model of surface and underground utilities where all the elements were represented and georeferenced correctly. First, the 2D utility drawings, georeferenced with the help of GPS data, were imported to Revit as reference layers. These drawings gave the initial layout of the underground utilities that was subsequently completed with the 3D data of the UAV, TLS, PCL and GPR technologies as shown in Fig.1.

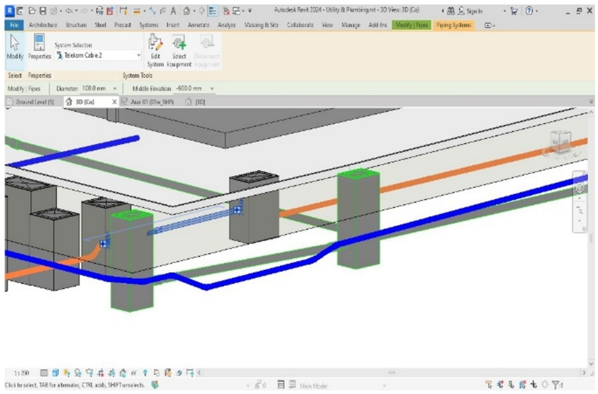

Fig 1. The utility model in the BIM environment

MEP (Mechanical, Electrical, and Plumbing) tools in Revit were used to model the underground piping and cable systems such as domestic water, sanitary and stormwater systems. The information on each pipe and cable such as the diameters and specifications was directly obtained using the 2D utility drawings and matched against the project specifications. These specifications gave accurate details of the kind of pipes, cables and their sizes that were required to make sure that all systems were designed. Revit view range settings were customized to make sure that underground systems can be seen and it also has automatic routing functions that make it easier to place the pipes and cables. The elevation and slopes of sanitary and stormwater pipes were altered to ensure that they have proper drainage. The coordinated visualization of the whole utility network was made possible by the integration of this 3D BIM model, which aided in the identification and elimination of possible clashes before they happened, therefore, increasing the efficiency of the construction process and decreasing conflicts in the implementation.

4.1 Data Integration

The BIM model generated in the Autodesk Revit was exported as Industry Foundation Classes (IFC) and imported into ArcGIS Pro to be spatially integrated into a 3D GIS environment. The Revit model was projected in a real-world coordinate system and survey points, so there was no need to perform any extra georeferencing manipulation. To further improve visualization, a high-resolution orthophoto of the study area was imported to ArcGIS Pro to have control of the visual alignment of the surface features in the model. This process of integration confirmed the spatial accuracy of the BIM model and proper alignment with other geospatial data of UAV, GPR, EML, and TLS surveys. A special geodatabase was created to hold BIM elements, utility layers, topographic data and survey control points, which enabled high-end 3D visualization, spatial analysis and the development of a risk-free infrastructure design.

5 Result and analysis

5.1 UAV Data and Orthomosaic

To analyse the study area, Fig. 2 display the orthomosaics and digital surface models (DSMs) that were developed with the data collected by UAV and processed in Pix4D. The mean Ground Sampling Distance (GSD) was 0.0263 meters that corresponds to high-resolution mapping. Mean Reprojection was minimized to 0.325 pixels, which indicated enhanced post block adjustments in terms of image alignment and accuracy of the model. Moreover, RMSE values of the X, Y, and Z coordinates calculated by the GPS were 0.026 m, 0.018 m and 0.025 m respectively, which proves that the georeferencing process was very reliable. Making use of 63,368 solution points and 188,349 tie points in the construction of the model confirmed that the UAV-generated data were accurate.

Fig 2. Final Orthomosaic of the Study Area Generated from UAV Data

The decrease in Mean Reprojection Error, 1.004 pixels to 0.325 pixels, shows that there was a substantial change in alignment of the images which means that the process of photogrammetry was successfully done. The small RMSEs also support the quality of the georeferencing, which makes the model developed using the UAV consistent with the real-world coordinates. These findings indicate that the UAV data quality is very good, and it can be reliably incorporated into the BIM and the GIS systems. Other research, [3] evidenced the success of UAVs in city mapping to obtain all the intricate details with high precision. There could have been some minor errors when image overlapping or georeferencing was being done, but this was insignificant and did not affect the overall accuracy of the model. These small errors can be reduced through future UAV surveys that will have better image overlap to ensure accuracy.

5.2 Point Cloud Data and Processing

Faro Scene software was used to process TLS data to generate a 3D point cloud, with a point error maximum of 14.9 mm that is well below the acceptable point error of 20 mm. Mean Point Error was 4.6 mm which is far from the acceptable limit of 8 mm. Nevertheless, the least scan overlap was registered as 13.5%, as opposed to the recommended 25%. The low point errors indicate that the TLS scanning procedure provided data of high accuracy that is crucial in proper modeling. The scan overlap is below the recommended level, which does not have a considerable effect on the model, but shows that there is a way to improve scanning in the future.

Adding more scan stations or relocating the ones that are already in place might increase the overlap and the overall accuracy of the model. This finding proves that TLS is effective in surface data collection as observed by Liang et al. (2024). Although the 13.5 percent overlap is below the optimal level, other comparable studies by [3] indicate that the presence of small overlaps does not compromise the creation of usable models if the errors in the points are within the acceptable range. In the future, surveys might be improved by having more scan stations or scan stations in better locations to increase the coverage of the data and the accuracy of the overall model.

5.3 Integration between BIM and GIS

As soon as a BIM model was prepared in Autodesk Revit, it was incorporated into other geospatial data that include orthophotos and GPS control points produced by UAVs in ArcGIS Pro. This integration developed a georeferenced 3D GIS environment that integrated surface and underground infrastructures. The integration between the technologies of BIM and GIS provided superior spatial analysis and mapping of the underground utilities with better visualization of urban infrastructure and led to better control of the urban infrastructure. The BIM elements, the utility layers, topographic data, and survey control points were stored in a ArcGIS Pro geodatabase that made utility mapping to be considerably efficient since it made it possible to perform queries, updates, and data visualization efficiently.

This makes it possible to be able to position the BIM model accurately in the real-world coordinate system and so the underground utilities could be placed appropriately with regards to the feature appearing on the surface as shown in Fig. 3. The integration aligns with [9], because he pointed out that BIM and GIS should be combined when it comes to managing utilities in highly urban places. The spatial accuracy of BIM-GIS integrated model was confirmed by overlaying the Revit model produced in ArcGIS Pro with the orthophoto produced using UAV. This overlay process made a visual confirmation of the correlation of surface marks and utilities underground possible. The underground structures were properly aligned with the features on the surface, and that established that the model was correct.

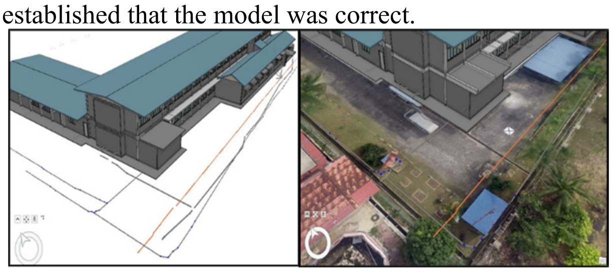

Fig 3. The utility model in the GIS environment

5.4 Geodatabase Creation in ArcGIS Pro

To hold and administer all the spatial data connected to the investigation, a special geodatabase was produced in ArcGIS Pro. The geodatabase contained BIM objects, utility maps and layers, topographic information and survey control marks so that all the information could be looked at and controlled effectively and at a single point. This geodatabase was to help organize and manage the data in a better way, availing one central place with all the geospatial information. It helped in the overlaying of different levels of data to produce a single combination and this is critical in advanced spatial analysis and display. Moreover, the geodatabase simplified querying on the information, updating the information, and analysis of the information leading to an improved decision-making process of underground utility management and urban planning. The table 1 below shows the kind of information that will usually be regarded by a geodatabase to manage and represent a utility with high efficiency and with visual execution in GIS as part of incorporating BIM models to map infrastructures.

Table 1. Geodatabase Table for Electric Cable

Object	Shape Length	Pipe ID	Material	Voltage (V)	Depth Start (m)	Depth End (m)	Length (m)
1	Polyline	LV001	Copper	11kV	0.6	0.7	99.543
2	Polyline	LV002	Copper	11kV	0.7	1.1	66.543

5.4 Georeferencing & Visualization in GIS

After importing the BIM model into ArcGIS Pro, the process of georeferencing was used, to guarantee proper alignment of all the layers of the data, on the real-world coordinate. This georeferencing activity was important in ensuring that the surface and the underground utilities were well located in relation to one another. An orthophoto of the UAV data was generated at the high-resolution and was consequently used as a validation of the alignments of the BIM model in the GIS system. Fig.4 shows that the spatial accurateness of the combined BIM-GIS model was also justified through the overlaying of the BIM model on the orthophoto. Such a visual verification method has been useful in confirming the alignment of the underground utilities regarding the features on the surface. The correct georeferencing and visualization of the integrated BIM-GIS model greatly contributed to utility mapping which boosted the efficiency and precision of the urban planning methods and decision making.

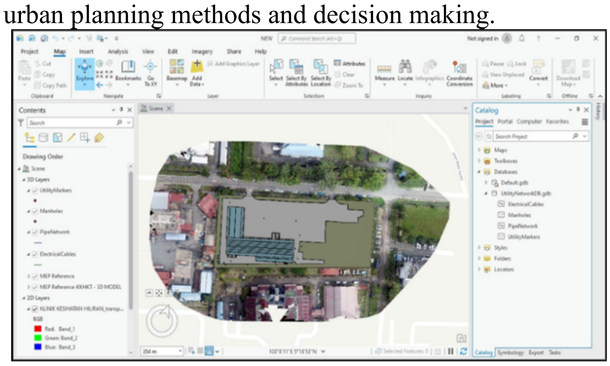

Fig. 4 Overlay BIM model with orthophoto in ArcGIS Pro

6 Conclusions

This paper concentrated on the Building Information Modeling (BIM) and Geographic Information Systems (GIS) to map and control underground utilities at urban settings. Work was carried out by means of the use of the latest technologies of data collection, including UAVs, Terrestrial Laser Scanning (TLS), Pipe and Cable Locators (PCL), and Ground Penetrating Radar (GPR), which was then processed and further incorporated into a georeferenced 3D GIS model.

These outcomes proved that integration of BIM and GIS, as well as high precision of data collection techniques, led to excellent results of the underground utilities mapping in terms of accuracy and efficiency. The developed geodatabase allowed integration of different data layers easily and detailed spatial analysis and visualization that helped to improve better decision-making in the management of urban infrastructure. The accuracy of the model in space was confirmed by overlaying the BIM model with high dispersion orthophotos and making sure that the utilities were properly aligned at the surface and below that surface.

Results of this creatively constructed study can be applied to enhance the enhancement of urban design and utility control because it provides a more accurate and effective approach to mapping and supporting underground utilities. In the future, it would be possible to continue optimizing the data integration methods further, perhaps automating some of the data processing processes, and extending the methodology to other urban regions that have intricate infrastructure networks.

Acknowledgement

This research is fully supported by Government Agency Grant, R.J130000.7352.1R073. The authors fully acknowledge Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia (UTM) for the approve fund which makes this important research viable and effective.

References

1. Wang, M., Deng, Y., Won, J., & Cheng, J. C. P. (2019). Automation in Construction An integrated underground utility management and decision support based on BIM and GIS. Automation in Construction, 107(November 2018),102931.
2. Li, P., Zheng, S., Si, H., & Xu, K. (2019). Critical Challenges for BIM Adoption in Small and Medium-Sized Enterprises: Evidence from China. Advances in Civil Engineering, 2019.
3. Chapman, D., Providakis, S., & Rogers, C. (2020). ScienceDirect BIM for the Underground – An enabler of trenchless construction. Underground Space, 5(4), 354–361.
4. Sharafat, A., Khan, M. S., Latif, K., Tanoli, W. A., Park, W., & Seo, J. (2021). applied sciences BIM-GIS-Based Integrated Framework for Underground

https://doi.org/10.1051/e3sconf/202668301023

Utility Management System for Earthwork Operations.

5. Liang, R., Zhang, C., Li, B., Saydam, S., Canbulat, I., & Munsamy, L. (2024). Data-driven visual model development and 3D visual analytics framework for underground mining. Tunnelling and Underground Space Technology, 153(March), 106054.
6. Ali, H., Razak, M. A. A. A. A., Amran, T. S. T., Zaidi, A. F. A., Haron, A. H., & Yusof, M. A. M. (2025). Evaluation and analysis of underground mild steel pipe using pipe cab le locator and ground penetrating radar. Journal of Physics: Conference Series, 2998(1).
7. Jeong, D. W., Yu, S. C., & Ahn, J. W. (2022). Design of 3D Data Model of Underground Utilities in Korea Using CityGML Application Domain Extension. Sensors and Materials, 34(1), 319–336.
8. Oguntoye, K. S., Laflamme, S., Sturgill, R., & Eisenmann, D. J. (2023). Review of Artificial Intelligence Applications for Virtual Sensing of Underground Utilities. Sensors, 23(9).
9. Nie, S. (2019). 3D BIM-GIS for underground network management 3D BIM-GIS for underground network management.